Supporting Situation Awareness and Workspace Awareness in Co-located Collaborative Systems Involving Dynamic Data

by

Yu-Ling Chang

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AUTHOR'S DECLARATION

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

STATEMENT OF CONTRIBUTIONS

This dissertation contained contents that were collaborative efforts with several others. In this dissertation, “we” will be used when referring to the work that was a joint effort with my collaborators. While it is impossible to state each collaborator’s exact contribution to this work, the following notes describe the approximate amount and type of their contribution to various parts of this dissertation.

The first study introduced in Chapter 3 and Chapter 4 was designed and developed in collaboration with several others.

- While I implemented the majority of the Pandemic digital tabletop board game, my supervisors, Stacey Scott and Mark Hancock, provided overall guidance in the design and development of the software. They also provided insights to guide the user study design and data analysis.
- Mylène Mengual implemented most of the animations in the software and created most of the textures used.
- Mylène Mengual and Brian Parfett acted as the additional raters to help create the situation awareness questionnaire.
- Bridjet Lee and I collaborated on the video coding analysis for the study. We together iterated on the coding scheme to reach an acceptable inter-rater reliability, and she coded about half of the study videos.

The second study introduced in Chapter 5 was designed and developed in collaboration with several others.

- This project was in collaboration with SMART Technologies in Calgary, Alberta, Canada. Edward Tse, Stacey Scott, and Mark Hancock provided overall guidance to the iterative design of the awareness feature, user study design, and data analysis.
- The study software, SMART amp™, was an existing product. I collaborated with the development team at SMART Technologies, specifically Min Xin, to implement the various versions of the awareness cue tested.
- I collaborated with Cresencia Fong and Min Xin to iteratively design of the awareness feature, conduct user testing sessions, and design study surveys.

- Cresencia Fong and I collaborated on the text coding analysis of teacher and student responses. We worked together to reach full agreement on the coding results.
- Erica Arnoldin and Colin Dere recruited and coordinated the participants for testing sessions with teachers and students.

ABSTRACT

Co-located technologies can provide digital functionality to support collaborative work for multiple users in the same physical space. For example, digital tabletop computers — large interactive tables that allow users to directly interact with the content — can provide the most up-to-date map information while users can work together face-to-face. Combinations of interactive devices, large and small, can also be used together in a multi-device environment to support collaborative work of large groups. This environment allows individuals to utilize different networked devices. In some co-located group work, integrating automation into the available technologies can provide benefits such as automatically switching between different data views or updating map information based on underlying changes in deployed field agents' locations. However, dynamic changes in the system state can create confusion for users and lead to low situation awareness. Furthermore, with the large size of a tabletop system or with multiple devices being used in the workspace, users may not be able to observe collaborators' actions due to physical separations between users. Consequently, workspace awareness — knowledge of collaborators' up-to-the-moment actions — can be difficult to maintain. As a result, users may be frustrated, and the collaboration may become inefficient or ineffective.

The current tabletop applications involving dynamic data focus on interaction and information sharing techniques for collaboration rather than providing situation awareness support. Moreover, the situation awareness literature focuses primarily on single-user applications, whereas, the literature in workspace awareness primarily focuses on remote collaborative work. The aim of this dissertation was in supporting situation awareness of system-automated dynamic changes and workspace awareness of collaborators' actions. The first study (Timeline Study) presented in this dissertation used tabletop systems to investigate supporting situation awareness of automated changes and workspace awareness, and the second study (Callout Bubble Study) followed up to further investigate workspace awareness support in the context of multi-device classrooms.

Digital tabletop computers are increasingly being used for complex domains involving dynamic data, such as coastal surveillance and emergency response. Maintaining situation awareness of these changes driven by the system is crucial for quick and appropriate response when problems arise. However, distractors in the environment can make users miss the changes and negatively impact their situation awareness, e.g., the large size of the table and conversations with team members. As interactive event timelines have been shown to improve response time and decision accuracy after

interruptions, in this dissertation they were adapted to the context of collaborative tabletop applications to address the lack of situation awareness due to dynamic changes. A user study was conducted to understand design factors related to the adaption and their impacts on situation awareness and workspace awareness.

The Callout Bubble Study investigated workspace awareness support for multi-device classrooms, where students were co-located with their personal devices and were connected through a large shared virtual canvas. This context was chosen due to the environment's ability to support work in large groups and the increasing prevalence of individual devices in co-located collaborative workspaces. By studying another co-located context, this research also sought to combine the lessons learned and provide a set of more generalized design recommendations for co-located technologies. Existing work on workspace awareness focuses on remote collaboration; however, the co-located users may not need all the information beneficial for remote work. This study aimed to balance awareness and distraction to improve students' workspace awareness maintenance while minimizing distraction to their learning. A *Callout Bubble* was designed to augment students' interactions in the shared online workspace, and a field study was conducted to understand how it impacted the students' collaboration behaviour.

Overall, the research presented in this dissertation aimed to investigate information visualizations for supporting situation awareness and workspace awareness in co-located collaborative environments. The contributions included the design of an interactive event timeline and an investigation of how the *control placement* (how many timelines and where they should be located) and *feedback location* (whether to display feedback to the group or to individuals when users interact with timelines) factors affected situation awareness. The empirical results revealed that individual timelines were more effective in facilitating situation awareness maintenance and the timelines were used mainly for perceiving new changes. Furthermore, this dissertation contributed in the design of a workspace awareness cue, Callout Bubble. The field study revealed that Callout Bubbles were effective in improving students' coordination and self-monitoring behaviours, which in turn reduced teachers' workloads. The dissertation provided overall design lessons learned for supporting awareness in co-located collaborative environments.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank God for His abundant providence during my PhD journey. In addition to the mental strength and financial resources, He supplied me with amazing people that guided every single step of my journey. I cannot possibly list every single person who has contributed to my dissertation in this section, yet I thank a few people that made significant impacts in the completion of this dissertation.

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I thank all my collaborators for their effort and insights into all the research work that became parts of this dissertation. I also thank SMART Technologies and the Mitacs accelerate program for the opportunity to conduct research in a real-world setting. I am deeply grateful for the guidance of Edward Tse on the Callout Bubble project. I also thank Cresencia Fong for her mentorship in both my personal and professional life. To Min Xin, I cherish all the long meetings we had together with Cresencia. The challenges we have overcame together provided tremendous satisfaction for me. I thank the research, UX, project management, and SMART amp development teams for all their insights and hard work into the Callout Bubble project.

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Finally, I thank God for David Lee whose patience and love have sustained me through this PhD journey. Your confidence in me and your support have enabled me to keep fighting the obstacles and exploring the unknown. Thank you for accompanying me along the journey. I am grateful to have you as my partner for life.

DEDICATION

To God, who is my source of strength, wisdom, and joy.

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Chapter 1

Introduction

In our daily lives, we collaborate while *co-located* in many different contexts such as working on a large design project, conducting a design critique, responding to an emergency, preparing a Thanksgiving dinner, or playing a cooperative board game. Even when people are co-located, they have to keep track of their collaborators' actions and changes in the situation to maintain high levels of awareness to support communication and coordination during group activities. Imagine Alice and Bob are cooking a Chinese New Year dinner together. While Bob is preparing an appetizer, he is also monitoring Alice's progress on the dumplings she is making and the roasted pig in the oven. Maintaining awareness in this context can be difficult due to several factors such as limited attentional resources, occlusion in the kitchen, and distraction from children. As technologies are being introduced to co-located collaborative environments, they are also competing for attention and creating distraction. For example, a tablet showing recipes and an oven beeping can draw Alice and Bob's attention away from the food. Careful considerations are needed to support awareness maintenance while minimizing distractions for co-located technologies. The research presented in this dissertation investigated the design of interaction techniques and interfaces for supporting users' awareness of dynamic changes and collaborators' actions in co-located collaborative environments.

The following sections first provide background on the specific types of awareness information and collaboration technologies investigated in this research. To contextualize this research, the scope and related research topics are discussed. The next section then presents the research problem and goals. An overview of the research methodology is presented next to provide information on how the awareness support was designed and evaluated. The next section concludes this chapter with the contributions of this dissertation and provides an overview of the rest of this dissertation.

1.1 Background

Observations of co-located workspaces conducted in this dissertation revealed that users experienced frustration and confusion due to lack of awareness while collaborating in the same physical space. Although users are co-located, their awareness of collaborators and environment do not come for "free". As Heath and Luff (1991a) and Schmidt (2002) have noted, collaborators need to maintain awareness of each other through active observation. Simply being present in the environment is not sufficient since people need to pay attention to collaborators' activities to maintain awareness. The design of co-located technologies should carefully consider how to support users' awareness of collaborators and the environment to avoid distracting the users. Specifically, this dissertation presents an investigation of two types of awareness: *workspace awareness* and *situation awareness*.

Workspace awareness refers to the understanding of collaborators' current interactions in the environment (Gutwin & Greenberg, 2002). People can gain awareness of collaborators by observing each other and the shared artefacts in co-located workspaces (Pinelle et al., 2003). Consider, for example, a group of police officers who are standing around a table with a map in front of them, discussing how to direct emergency response teams. While engaging in conversations, they can make eye contact and observe subtle changes in each other's facial expression and posture (Short et al., 1976). Moreover, they can be aware of each other's actions and interactions with shared artefacts in the shared workspace (Pinelle et al., 2003). When they notice that one person is writing on a logbook, they can assume that the logbook is being updated and the person is busy with this task. The person who is updating the logbook can overhear colleagues' discussion and the sound of drawing on the map, and can infer that new information is being added to the map. These cues are essential to the success of the collaboration and help people coordinate their work. However, when these cues are stripped away or hard to obtain, for instance, due to other distractions or barriers in the environment, users can become frustrated with the group work (Gutwin & Greenberg, 2000). One of the goals of this research is to balance workspace awareness support and potential distractions of the system for co-located environments.

Situation awareness refers to a person's perception, comprehension, and prediction of the environment (Endsley, 1995). The concept has been studied in-depth in the field of aviation (Endsley, 1993; Jones & Endsley, 1996). As a pilot observes a cockpit display, they gain knowledge of changes. They have to then piece together the meaning of multiple changes and understand their significance to

Figure 1-1: A group of people playing a collaborative game on a digital tabletop. Digital tabletops supplement the familiar face-to-face collaboration with digital capabilities.

the overall flight status. Finally, they need to forecast future states of the flight to allow for adjustments if potential problems are detected. However, as a system is redesigned to incorporate automation, it may present users with unfamiliar forms of feedback (e.g., sensing aircraft speed through vibration of the control stick may be replaced with a digital display) or simply present no feedback of certain changes to the users. This leaves the user with lower situation awareness by excluding them from receiving appropriate feedback (Norman, 1990). Consequently, users may be slower to respond or make suboptimal decisions (Kaber & Endsley, 1997). Digital devices can provide dynamic information such as changing data views based on the current tasks or updating information based on sensor data. As co-located technologies leverage their digital capabilities, situation awareness should be an important requirement for the design.

Two types of co-located environments were selected as the study contexts for this research: digital tabletop computers and multi-device environments. Co-located collaborative work can be enhanced via a *digital tabletop computer*: a large, horizontal interactive display that enables input directly on its surface (see Figure 1-1). This technology combines the advantages of traditional tables and of digital media. It has the potential to preserve the rich interactions and awareness cues in a co-located environment since it does not block the collaborators' view of each other and the shared workspace. At the same time, it provides functionality enabled by digital computation. For example, people can bring digital documents with them to the table and then distribute modified documents electronically to their collaborators after a tabletop session. Users can also gain access to up-to-date documents at any time. Furthermore, digital tabletops provide an opportunity to automate some complex tasks during co-located collaborative activities. For example, in the emergency response scenario discussed above, the system could aggregate updates from the field and present an overview of the situation to the commanders for strategizing. The first study (Chapter 3 and Chapter 4) examined an interactive timeline visualization to support situation awareness and workspace awareness in the context of tabletop systems. The results showed that further investigation of workspace awareness was needed.

The second study (Chapter 5) explored workspace awareness support in the context of a *multi-device environment* where multiple networked computational devices such as tablets, laptops, and digital whiteboards were used in conjunction (see Figure 1-2). This study focused on a collaborative context where multiple users utilized different, individual devices in the same room and were working together to achieve a shared goal. The various devices were connected through a web-based virtual shared workspace.

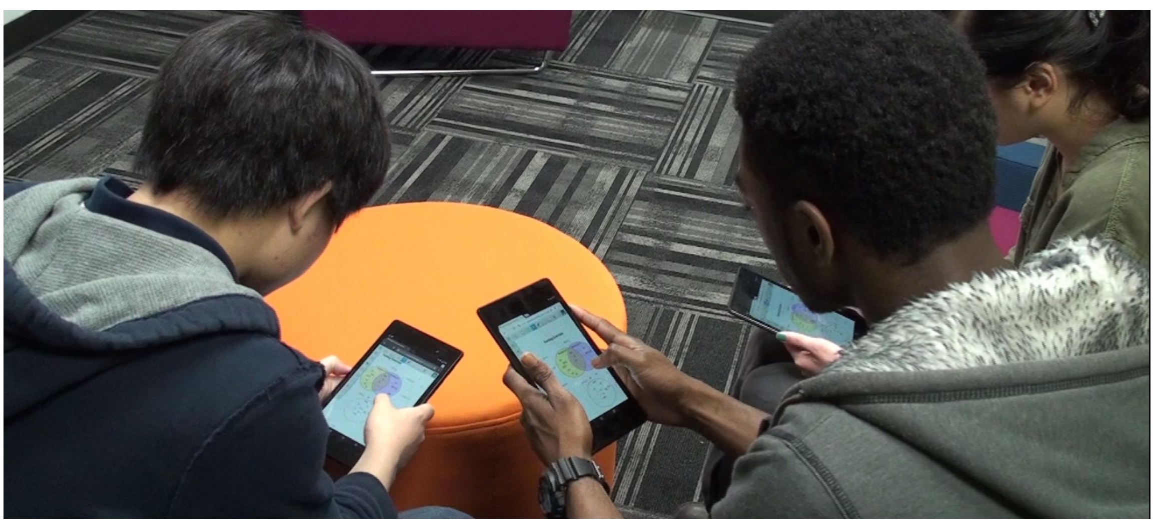

Figure 1-2: A group of students is working on a math problem together using their tablets. Additional devices, such as whiteboards, can be added to provide an overview of the work progress. Multi-device environments can leverage the benefits of different interactive displays to allow for collaborative work of large groups and for people to work in parallel.

The multi-device environment was chosen to study workspace awareness for several reasons. First, multi-device environments allow for subgroup work happening in parallel to the larger group's work. Digital tabletops support small group work, but scaling to support large group work is difficult due to the limited physical space around tabletops. Conducting subgroup and individual work can be challenging and distracting due to the limited screen real estate and physical space. Thus, multi-device environments provide the benefits of supporting large groups and parallel work. Furthermore, by studying tabletop systems and multi-device environments, this research sought to provide a set of general design recommendation for supporting awareness in co-located environments. Finally, multi-device environments share similar challenges in workspace awareness deficiency as tabletop systems do. A person may have difficulties seeing who changed which part of the work due to physical distance between users or occlusion of the device screen(s) by collaborators' bodies. This technology setting also has its own unique challenges. For example, as the size of the group grows, the physical or virtual workspace may become chaotic as too many changes may be happening at the same time, and keeping track of them is difficult without awareness information being provided to each individual. At the same time, providing too much information of other users' actions may distract and overwhelm them. Thus, multi-device environments were selected to further investigate workspace awareness support and to allow for generating more general insights on awareness support in co-located environments.

The research presented in this dissertation investigated visualization and interaction techniques to support situation awareness and workspace awareness maintenance in two co-located collaborative environments, namely digital tabletop and multi-device environments. This research was built on prior work in various fields. The next section presents relevant research areas to put this research in context.

1.2 Scope

The research presented in this dissertation aimed to investigate awareness support for co-located technologies by incorporating information visualization principles. This research was built upon three main research areas: information visualization, computer-supported cooperative work (CSCW), and human factors. They all intersect with the field of human-computer interaction (HCI). See Figure 1-3 for an illustration of this dissertation's scope.

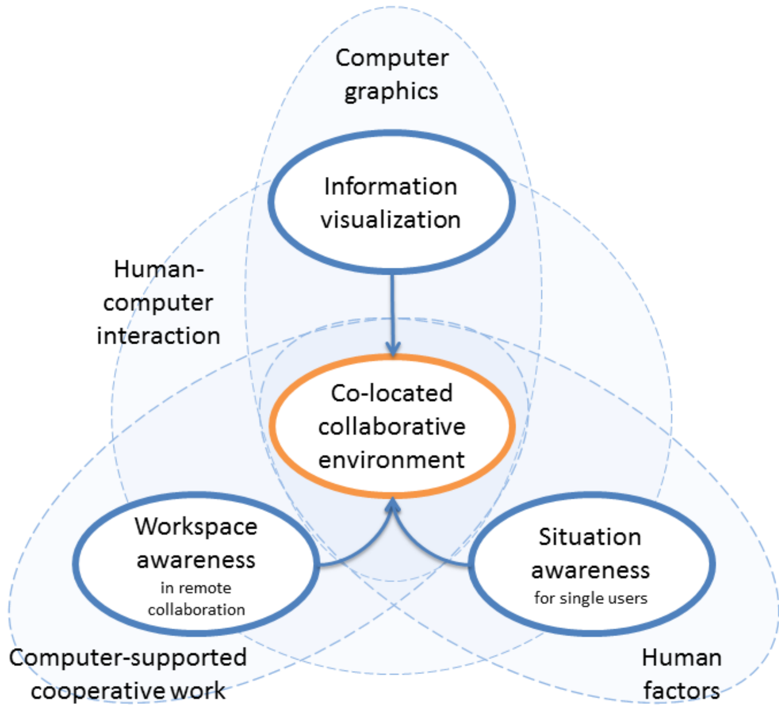

Figure 1-3: Scope of this dissertation. This dissertation contributed to the design of awareness support for co-located technologies by incorporating information visualization, workspace awareness, and situation awareness research. This research was situated in four research areas: human-computer interaction, computer graphics, human factors, and computer-supported cooperative work.

The field of HCI focuses on the design and evaluation of computer machinery for human users (ACM, 1992). Intersecting with HCI, the field of CSCW examines the design of computer systems to enhance human collaborative activities including both remote and co-located contexts. The workspace awareness literature has traditionally focused on remote collaborative contexts (Gutwin & Greenberg, 2000; Tuddenham & Robinson, 2010). Where there has been some research on workspace awareness support for co-located contexts on tabletop systems (Isenberg et al., 2012; Morris et al., 2010), there still lacks an understanding of techniques for balancing workspace awareness and distractions in co-located contexts. In this research, the workspace awareness literature from both co-located and remote collaboration was applied to guide the design of awareness support in tabletop systems and multi-device environments.

Moreover, this research aimed to support situation awareness of dynamic changes driven by computer systems in the co-located collaborative context. Situation awareness has been widely studied within the field of human factors, which studies humans' abilities and limitations for the design of equipment, systems, jobs, and environments to ensure the safety and performance of the work (Chapanis, 1991). However, the literature on situation awareness mainly focuses on the knowledge of the environment of a single user within a complex system of devices, human entities, and organizations. The situation awareness literature was applied to designing awareness support of dynamic changes for multi-user co-located applications.

To provide awareness information, this research also made use of information visualization principles. Information visualization refers to "[the] use of computer-supported, interactive, visual representations of abstract data to amplify cognition" (Card et al., 1999, p. 7). Information visualization originated from traditional data visualizations on physical media. With the advances in computer graphics, visualizations can now be presented digitally for the purpose of enhancing users' cognitive abilities in understanding abstract data. The research presented in this dissertation investigated the design of awareness displays to provide feedback of dynamic changes and collaborators' actions in co-located collaborative environments by employing information visualization principles.

1.3 Research Problems and Goals

Overall, this research was concerned with the lack of situation awareness and workspace awareness support in co-located collaborative environments. This section describes the research problems and goals, as summarized in Figure 1-4.

1.3.1 Problem 1: Lack of Situation Awareness in Collaborative Tabletop Applications

There is growing interest in using digital tabletops to support co-located group activities that involve complex, often dynamically changing data. Tabletop interfaces have been proposed for crisis and disaster management (Döweling et al., 2013; Paelke et al., 2012), military simulation (Bortolaso et al., 2013), and military and commercial maritime operations (Domova et al., 2013; Scott et al., 2010). In these cases, situation awareness is crucial to the success of the mission.

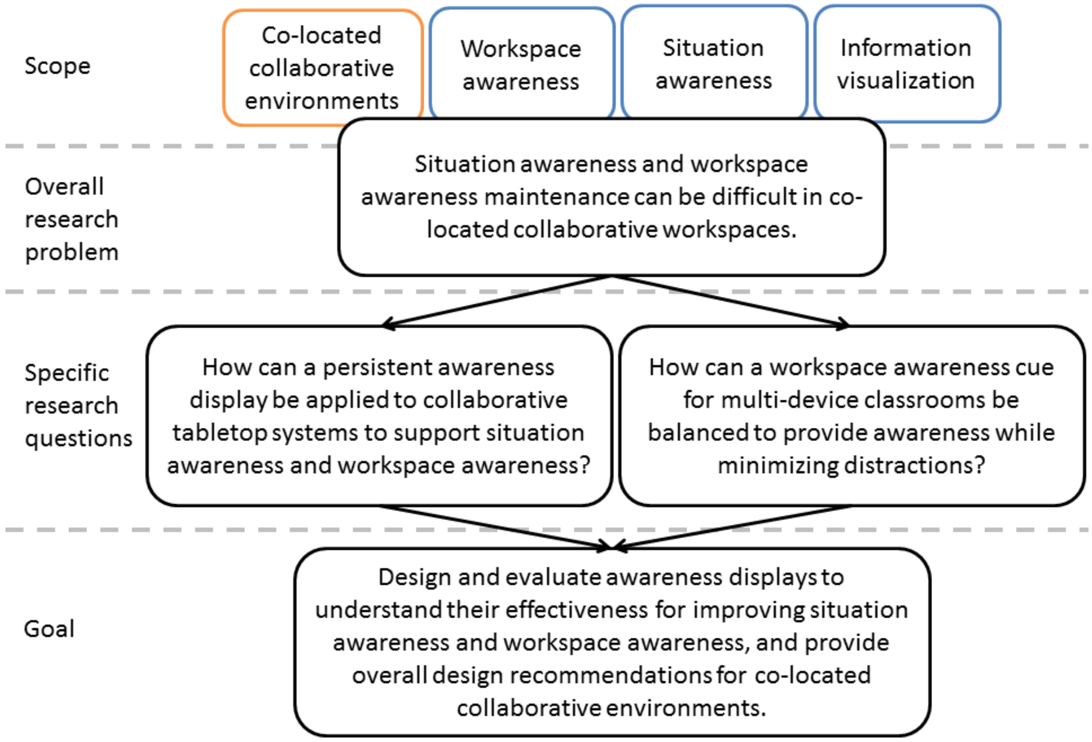

Figure 1-4: An overview of the research problems and goals. The overall research was concerned with the application of information visualization principles to provide situation and workspace awareness support. The research question was broken down into two problems: how to adapt interactive event timelines to collaborative tabletop systems and how to balance workspace awareness and distractions for multi-device classrooms. This research sought to design and evaluate awareness displays for co-located collaborative systems and provide design recommendations for such systems.

Computer automation may lead to lower situation awareness (Kaber & Endsley, 1997). Thus, enabling users to maintain high levels of situation awareness is important as tabletop systems begin to leverage automation to manage complex data for real-world application domains. Due to a variety of potential distractors, tabletop applications cannot assume that users will attend to and notice all system changes. For example, conversing with collaborators at or near the tabletop, or attending to other devices being used in conjunction with the tabletop (e.g., a smart phone or tablet) can distract users. Moreover, a user may be called away from the tabletop temporarily. Consequently, a change occurring on the tabletop (automated, or made by another user) can be easily missed. However, existing tabletop applications that incorporate dynamic data provide little to no provisions for situation awareness maintenance and focus on supporting collaboration of the current, real-time view of the system state (Bortolaso et al., 2013; Conversy et al., 2011). Existing literature on situation awareness focuses on single-user applications (John et al., 2005; Sasangohar et al., 2014; Scott et al., 2006). The research presented in this dissertation sought to address the lack of situation awareness problem due to automation in the context of collaborative tabletop systems.

This research aimed to design, develop, and evaluate a persistent information display in the form of an interactive event timeline for the purpose of supporting situation awareness maintenance. This research also sought to explore various design alternatives to understand their effectiveness in improving situation awareness for collaborative tasks that involve computer automated actions.

1.3.2 Problem 2: Balance Workspace Awareness and Distractions in Multi-Device Environments

The first study revealed that maintaining workspace awareness on a large tabletop system can be difficult due to several factors, and further iteration was needed to improve the original design. For both the tabletop technology and multi-device environment contexts, observing user actions in their personal workspace can be difficult due to the physical separations between users. In tabletop systems, users also do not constantly pay attention to collaborators' personal workspace (Scott & Carpendale, 2010). In multi-device environments, users may be sitting in various arrangements, not limited to face-to-face, and the devices can be occluded by users' bodies in the physical space. Thus, users may not be able to perceive collaborators' interaction with artefacts. This can result in confusion when changes suddenly appear on the tabletop or on individual devices without first knowing who made the changes. Without this awareness information, users need to spend extra effort to consciously resolve the confusion. This problem leads to more effort spent on the coordination rather than the task.

Prior work on multi-device environments for co-located collaboration have viewed the individual devices as users' private devices (Döweling et al., 2013; Scott et al., 2014), and there has been little work on supporting workspace awareness of individual's actions on their devices. This research sought to support workspace awareness while minimizing distractions for individuals in multi-device environments.

This research aimed to design, develop, and evaluate a workspace awareness cue in the form of a transient identity tag called a Callout Bubble, to provide information for collaborators to maintain awareness of each other's actions. Based on the overall findings in the two types of collaborative workspaces, this research sought to provide design recommendations for supporting situation awareness of automated actions and workspace awareness of collaborators in co-located workspaces.

1.4 Method

This research took an iterative design approach, where the design-implement-evaluate cycle was used to create and refine the prototypes (Nielsen, 1993). In the design phase, design recommendations were drawn from the existing literature and from the initial observations of system usage. In the implementation phase, the design was prototyped at appropriate fidelity levels such as drawn on paper, mocked-up on PowerPoint[1] or Illustrator[2], or fully programmed. For evaluations, a variety of techniques were used, ranging from informal to formal evaluations and varying degrees of precision and realism (McGrath, 1984). The techniques were selected based on the goals of the evaluations (e.g., a quick interview with early prototypes, a formal laboratory experiment for testing design alternatives, and a field study for realistic behaviours). A mixed-methods methodology (Creswell & Plano Clark, 2007) was used by collecting and analyzing both quantitative and qualitative data. This approach allowed for validating the improvements of the design and gaining insights into the how and why of the observed behaviours. The results of the evaluation were then fed into the design phase again to improve it. The rest of this section overviews the methods used in the two studies presented in this dissertation.

1.4.1 Overview of the Timeline Study

For the first study on digital tabletop systems, a popular collaborative tabletop board game, Pandemic[3] (Figure 1-5), was used as the study context to rapidly prototype design concepts, and to enable lab-based studies with a complex task for which "experts" could be easily recruited. The Pandemic board game required a group of three to four players to collaboratively engage in intense strategy discussions, resource management, and advance planning to prevent the world from epidemic outbreaks. Moreover, Wallace et al. (2012) found that their digital version of the Pandemic game

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[1] https://office.live.com/start/PowerPoint.aspx
[2] http://www.adobe.com/ca/products/illustrator.html
[3] The Pandemic game was published by Z-Man Games, used with permission.

elicited the out-of-the-loop automation problem due to the amount and complexity of changes and the fact that players were not constantly paying full attention to the system.

Figure 1-5: The Pandemic physical board game. It was used as the study context for the digital tabletop environment.

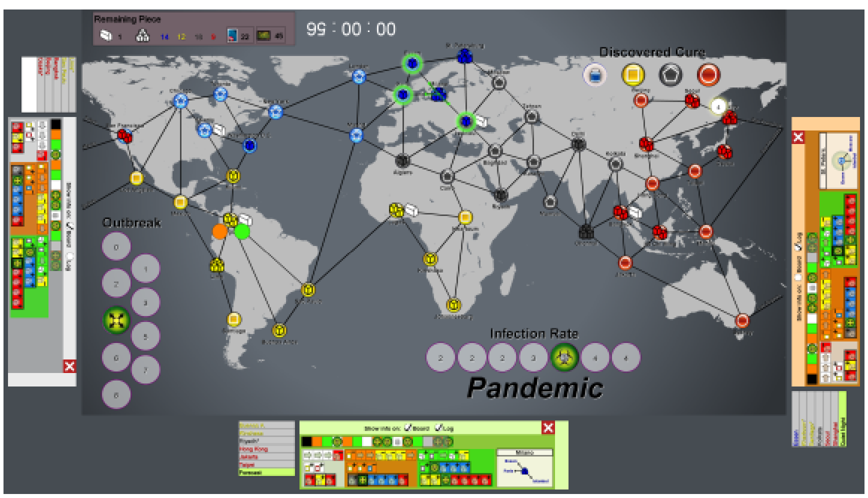

Figure 1-6: The interface of the digital Pandemic tabletop game. It was used to study situation awareness and workspace awareness support.

In the digital tabletop conversion of the Pandemic game implemented in this research (Figure 1-6), the system automated the game mechanics typically carried out by the players. Interactive event logs

Figure 1-7: Students using SMART amp™. SMART amp™ was a web application that connected individual devices to an online shared canvas. The photos show students using SMART amp™ on Left) laptops and Right) tablets. Photo credit: SMART Technologies. See Appendix C.1 for the permission statement to use these photos.

and timelines have been previously shown to reduce response time and improve decision accuracy for single-user applications involving automated system changes (John et al., 2005; Sasangohar et al., 2014). Thus, similar interactive timelines were adapted to the tabletop system investigated in this dissertation. These timelines allowed users to interactively investigate the historical system game events and previous collaborator actions at any time. The study investigated two design factors: *control placement* (how many timelines were provided to a group of users and where these were placed) and *feedback location* (where to display feedback upon interacting with a timeline). This study sought to understand how these two design factors impact collaborative work and situation awareness of dynamic changes in collaborative tabletop applications. In the rest of this dissertation, this study is referred to as the *Timeline Study*.

There were two phases in the Timeline Study. Phase 1 involved a controlled experimental design that tested the two design factors by asking participants to play three short partial games in which they used three different timeline alternatives. Participants' situation awareness and gaming experience were measured, and Repeated Measures Analysis of Variance (RM-ANOVA) tests were conducted to analyze the situation awareness performance. In Phase 2, participants completed a full Pandemic game from start to finish using a configurable version of the timeline that allowed them to utilize any combination of the *control placement* and *feedback location* at any time. Phase 2 provided more realistic data, and an in-depth video analysis was conducted to understand participants' usage of the timelines for situation awareness maintenance and how the different locations of the interaction feedback affected users' workspace awareness.

1.4.2 Overview of the Callout Bubble Study

The second study on multi-device environments used a commercial web application called SMART amp™ [4], created by SMART Technologies[5] (see Figure 1-7). It was a collaborative learning environment designed for bring-your-own-device (BYOD) classrooms, targeting students aged six to seventeen. Each student had a laptop or tablet, and SMART amp™ connected them to an online shared canvas. The canvas allowed students to add and manipulate text, drawings, shapes, and pictures in a free-form manner, and students could freely zoom and pan using gestures. It was primarily used for co-located students in a single classroom setting.

Teachers and students using early versions of the SMART amp™ system reported high levels of frustration and confusion while students were working in the virtual canvas. There was a problem in students' lack of workspace awareness of other students' actions. To address this problem, an iterative design approach was taken. The process included consultations with teachers, a test with selected students, and a field study in four classes. The design emerging from this process was the Callout Bubble, which consisted of two parts: a circle containing a student's first name and last name initial, and a directional triangle pointing toward the object being manipulated. Survey data was collected from students and teachers in the final classroom evaluation. A correlation analysis conducted on the Likert-scale survey questions and coding of the free-form answers revealed the effectiveness of the Callout Bubble design in supporting workspace awareness. Hereafter, this study is referred to as the *Callout Bubble Study*.

1.5 Contributions

The investigations conducted in this dissertation contributed to the design of awareness displays for co-located collaborative activities in the following ways:

- An awareness display, in the form of interactive event timelines, was designed, developed, and evaluated to support situation awareness of automated computer actions in co-located collaborative tabletop systems

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[4] https://www.smartamp.com/about
[5] http://home.smarttech.com/

- The Timeline Study provided empirical data which showed that providing individual, replicated timelines resulted in higher levels of situation awareness, and that timelines were primarily used to support perception level of the situation awareness maintenance process
- An awareness cue, in the form of Callout Bubbles, was designed, developed, and evaluated to provide workspace awareness of collaborators' actions in a co-located multi-device classroom setting
- The Callout Bubble Study provided empirical data which showed that the Callout Bubbles balanced workspace awareness information and distractions, and they enabled coordinating space usage and self-monitoring behaviours among students, which in turn reduced teachers' workloads
- A set of design recommendations for providing situation awareness and workspace awareness in co-located collaborative environments based on results from the Timeline Study and the Callout Bubble Study

Overall, this research sought to provide empirical data and design recommendations on supporting situation awareness and workspace awareness to allow for more efficient and effective collaborative work in the context of co-located technologies. Situation awareness is essential to decision making in complex environments (Endsley, 1995), and workspace awareness is beneficial for coordination and faster task completion (Gutwin & Greenberg, 2000; Sarma et al., 2008). The lack of situation awareness and workspace awareness can lead to users' confusion and frustration during work (Endsley & Kiris, 1995; Gutwin & Greenberg, 2000). By providing awareness support in co-located collaborative systems, users can focus on the primary tasks rather than trying to maintain awareness, which is their secondary task. This research identified situation awareness and workspaces challenges in co-located collaborative environments, and careful attention in supporting them is needed to ensure an efficient and effective workflow. As tabletop systems are being introduced to complex domains and individual devices are becoming ubiquitous in co-located meetings and classrooms, this research provided a timely and impactful contribution to the design of co-located collaborative technologies.

1.6 Dissertation Overview

Figure 1-8 depicts the progression of this research and the structure of this dissertation, which is organized as follows: Chapter 2 provides the relevant background and work in the areas of situation awareness and workspace awareness. It also presents the co-located systems studied in the context of other co-located technologies, and discusses related awareness literature for the co-located systems investigated in this dissertation. Chapter 3 and Chapter 4 present the Timeline Study. Chapter 3 first presents an overview of the study method used and the design of the Pandemic digital board game. Next, the design of the interactive event timelines and the user study design are presented. Chapter 4 presents the findings of the Timeline Study, and discusses the design implications for situation awareness displays for collaborative tabletop systems. The results showed how the timelines impacted users' situation awareness and workspace awareness, and also showed that the workspace awareness techniques used needed further improvements. This workspace awareness need inspired the Callout Bubble Study presented in Chapter 5. Chapter 5 first presents the design requirements of a workspace awareness cue for co-located multi-device classrooms. Next, this chapter presents the iterations and evaluations conducted to refine the Callout Bubble cue, and it discusses the findings from the field study conducted and the implications on designing a practical workspace awareness cue. Chapter 6 discusses the overall design lessons on co-located collaborative systems, learned through the Timeline Study and the Callout Bubble Study. Chapter 9 concludes this dissertation with a summary of the contributions, limitations, and future research directions.

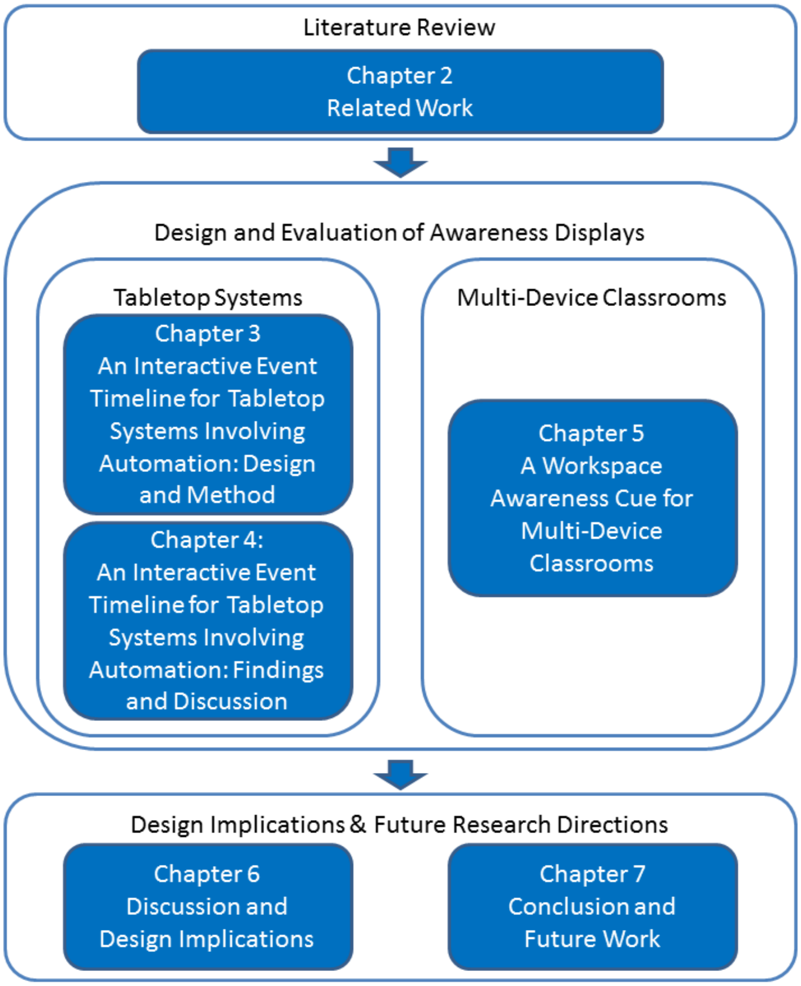

Figure 1-8: The progression of this research and the structure of this dissertation. The literature review contextualized this research for the next two investigations: the design and evaluation of awareness displays for tabletop systems and multi-device classrooms. The study results revealed overall design recommendations for co-located collaborative systems and suggested future research directions.

Chapter 2

Related Work

Through observations, interviews, and literature reviews conducted in this dissertation, lack of awareness was indicated as one of the main contributing factors to confusion and frustration in tabletop systems and multi-device classrooms. Thus, this research focused on awareness support for co-located technologies.

Many different types of awareness have been studied to support various forms of collaborative work (see review by Rittenbruch & McEwan, 2009). The research presented in this dissertation focused on two specific types of awareness concepts: situation awareness (Endsley, 1995) and workspace awareness (Gutwin & Greenberg, 2002). Situation awareness focuses on a user's understanding of the changes in the environment while workspace awareness focuses on users' awareness of collaborators' actions. Moreover, this research focused primarily on co-located synchronous work (Johansen, 1991), meaning that users were working in the same physical location at the same time. Furthermore, this research investigated workspaces that involved multiple users and dynamic changes driven by system automation or by other users.

The following sections first define the concept of situation awareness (SA) and discuss the impact of system automation on situation awareness. Next, workspace awareness (WA) is defined and previous work in this area is discussed. The next section contextualizes this thesis research by presenting the types of co-located technologies studied: tabletop systems and multi-device classrooms. The situation awareness and workspace awareness literature in these two contexts are discussed next to further motivate this dissertation work.

2.1 Automation and Situation Awareness

Situation awareness describes a person's awareness of the environment that they are in. It has been applied to many domains including air traffic control (Smith & Hancock, 1995), aircraft cockpit design (Andre et al., 1991), and nuclear plant operation (Carvalho et al., 2006). Endsley (1988) defined situation awareness (SA) as the following:

> *"Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (p. 792)*

In other words, there are three steps to achieve SA: the perception of changes in the system state (level 1), the comprehension of changes (level 2), and the prediction of future states (level 3). The second level of situation awareness requires the users to connect multiple pieces of knowledge (gathered on level 1 and previously known) to infer their meaning and form an understanding of the perceived changes. The third level then describes the ability to predict the future state of the system.

As Endsley noted, maintaining SA is an important job for users in an environment with dynamic changes since "tasks are dependent on an ongoing, up-to-date analysis of the environment" (Endsley, 1995, p. 33). In the Timeline Study (Chapter 3 and Chapter 4), supporting SA was essential to the users' decision making quality since the Pandemic digital tabletop game used involves dynamic changes driven by automation.

The word "automation" has carried different meanings over time. Traditionally, automation refers to the replacement of physical labour with machines in the traditional manufacturing setting. With computer systems, automation can also refer to ways of reducing mental workload, a meaning that is relevant to the current research in automation design (Parasuraman et al., 2000). In this dissertation, automation refers to the process of fully or partially replacing both physical and mental work previously done by humans (Parasuraman et al., 2000). In addition to viewing automation as a replacement of human work, it can also be seen as the process of changing the state of the environment using technology. For example, automated car assembly lines can be seen as the partial replacement of human work in car assembly, as well as a change of state from having car parts to having an assembled car. In this dissertation, automation will denote both the function of replacing human work and the process of changing states.

While automation can improve efficiency and reduce costs (Spath et al., 2009), automation can also have a negative impact on situation awareness due to three main reasons (Endsley & Kiris, 1995). First, while monitoring automation, users may become overly reliant on the system and lose their vigilance in detecting system state changes. They may fail to detect problems early on. Second, when users become passive observers of the system states, they are not actively reorienting themselves to the new system states nor deciding whether a manual intervention is needed. Third, the lack of familiar forms of feedback or any feedback at all can make the users unable to stay up-to-date with the current system state. For example, when switching from manually controlling an airplane to the automated control, the pilot may receive the flight information through a visual display that is unfamiliar. The flight speed is displayed visually rather than through haptic feedback—the vibration from the flight stick (Kuipers et al., 1990). The change in feedback forms may affect how well the pilot understands the system state (Endsley, 1996). Furthermore, the lack of or inappropriate feedback for users involved in controlling and monitoring an automated system has been identified as one of the main problems of automation (Endsley, 1996; Lee & Seppelt, 2009).

While the automation literature noted that overreliance of automation and unfamiliar system feedback can result in lower situation awareness, the psychology literature can help elucidate the challenges in human perceptions. The phenomenon of c*hange blindness* (Rensink, 2005) has been well studied in psychology, and it refers to people's inability to detect changes due to a shift in attention. It has also been identified as one of the key causes of low situation awareness (Durlach, 2009). The phenomenon happens when the timing of changes taking place and divergence of attention coincide such as during eye blinks and interruptions from the environment. While the attention shifts from the original scene to a new scene, a new change takes place. As a person shifts their attention back to the original scene, they cannot detect the change (see an illustration of this problem in Figure 3-1 from Section 3.1). This challenge of change blindness is one of the major problems for collaborative tabletop applications involving automation. As users shift their attentions from the display to collaborators to engage in conversations, they miss changes that take place during the conversation. After their attentions return to the application, they may not be able to recognize the new changes. Furthermore, given the large size of tabletop systems, users can only see a limited part of the system at a time. While users are focusing on one part of the system interface, other parts of the system may have new changes. However, as users shift their attentions to the changed areas in the interface, they may not be able to detect the changes due to the change blindness phenomenon.

While change blindness explains the failure to detect changes when distracted, a special form of change blindness, *inattentional blindness* (Simons & Chabris, 1999), explains why people may still miss changes while attending to an interface. Inattentional blindness refers to the case when people are focusing on a visual scene, but they still miss the changes to the scene. In the classic gorillas study, Simons and Chabris (1999) instructed the participants to count the number of times a basketball was passed between the members of the white team. During the video, a gorilla was walking through the scene among the white and black teams of basketball players. However, people failed to notice the gorilla. As people were cued to pay attention to the basketball, they could not detect the new stimulus. The phenomenon of inattentional blindness helps to explain why people fail to detect changes when they are passively observing the system states. When people are overly relying on the automation in the system and focusing on specific elements of the interface, new and unexpected events that are not in their focus of attention may be overlooked.

The phenomenon of change blindness can be mitigated by deploying animations to guide users' attention to the new changes (Chang & Ungar, 1993) and to help users understand these changes (Baudisch et al., 2006). However, as mentioned previously, users may not be looking at the tabletop interface at all or may be looking at other parts of the interface. They can miss the animation completely. To address this challenge on a large whiteboard, Bezerianos et al. (2006) animated changes that happened at unattended areas when users pay attention to them. Although this approach can address change blindness, how such a technique can be applied to a multi-user application is unclear since there will be different unattended areas for each user.

Alternatively, persistent interactive information displays have been explored by the interruption recovery literature as a way to mitigate change blindness and to rapidly improve situation awareness after an interruption. These displays can provide a centralized location for users to check new changes. Interactive history logs have been found to help mitigate change blindness after interruptions. John et al. (2005) and Smallman and John (2003) investigated the effectiveness of interactive text-based history logs, in a table format, for airplane speed and location in a single-user supervisory task on desktop computers. The results showed that the interactive log helped reduce response time, misses, and errors in identifying abnormal changes. Moreover, by allowing participants to click on items to highlight corresponding airplanes, the interactivity helped reduce clutter in the interface.

Interactive graphical event timelines were also shown to be effective by Sasangohar et al. (2014). In a supervisory task involving unmanned aerial vehicles, a geospatial map of the area of interest was shown on an interactive TV, and a graphical event timeline was shown on the users' handheld device (a tablet, see Figure 2-1). Interaction with the bookmarked events invoked highlights of historical events on the map. Their results showed that the timelines reduced interruption recovery time and improved decision accuracy. Moreover, they argued that the interactive timelines provided a "simplified representation of important events [that] facilitated the quick encoding of perceptual information and minimized the visual search" (Sasangohar et al., 2014, p. 1115). For designing situation awareness support on large tabletop displays with multiple users, minimizing visual searches across the interface would be ideal. Thus, the concept of interactive graphical historical event timelines was applied to the tabletop application in this dissertation to facilitate situation awareness maintenance.

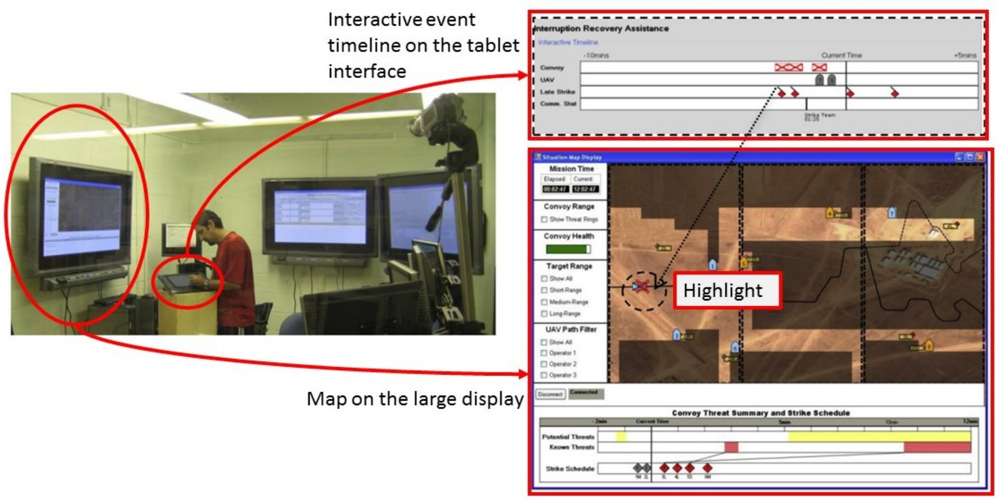

Figure 2-1: Study setup and application interfaces from Sasangohar et al. (2014). In a supervisory of unmanned aerial vehicles task, Sasangohar et al. (2014) designed an interactive timeline for individuals and studied its effectiveness in facilitating interruption recovery. Left) The setup of the control room, including large displays and a tablet interface. Right) Interacting with the interactive timeline on the tablet (top) invoked highlights on the large display (bottom). (The left and right two images are used with permission from Sasangohar et al. (2014) with additional annotations in red. See Appendix E for the permission statement).

Much research effort has investigated the designs of awareness displays to support situation awareness for individual users (John, 2008; John et al., 2005; Sasangohar et al., 2014; Scott et al., 2006). The Timeline Study built upon the situation awareness research for individual users and adapted interactive event timelines for collaborative tabletop applications.

2.1.1 Team Situation Awareness

As this thesis research aimed to support team environments where users had a shared goal, examining individual SA of the system was not sufficient to understand the collaborative process of gathering situation awareness and strategizing as a group. The literature in team situation awareness (TSA) is presented next.

TSA is the team members' overlapping knowledge of the situation as well as the full situation awareness required for individuals to successfully coordinate actions and complete the shared goal (Endsley, 1995; Salas et al., 1995; A. R. Wellens, 1993). A team member needs to be aware of both the *task*- and *team*-oriented knowledge. Task-oriented knowledge refers to the awareness of system and tools state while team-oriented knowledge refers to the awareness of team members' state (Parush et al., 2011). As both these types of knowledge are needed to maintain TSA, users need to maintain awareness of the system state and the collaborators. This distinction is similar to the *taskwork* and *teamwork* differences from the Computer-Supported Cooperative Work literature. In a collaborative system, taskwork refers to actions needed for completing the task. Teamwork refers to actions needed to help the team complete the task, e.g., coordination (Pinelle & Gutwin, 2008). Maintaining team-oriented knowledge would be essential for teamwork. In the Timeline Study, the design of the interactive event timeline and overall tabletop application sought to support both users' task and team-oriented awareness needs.

There has been much work on theoretical models of team situation awareness (Endsley & Jones, 2001; Salas et al., 1992, 1995; A. R. Wellens, 1993). However, they focused on high level processes. For example, Endsley and Jones (2001) presented a conceptual model with four components to achieve team situation awareness including 1) the SA requirements dictated by teams' goals; 2) shared artifacts and communication within the team for gathering and transmitting awareness information; 3) the shared mental model of the work and system (Mohammed & Dumville, 2001); and 4) the teamwork, norm, and members' soft skills in collaboration. Salas et al. (1995) presented a model that incorporated the team members' background and expectations. While these conceptual frameworks provided insights into high level TSA processes, they lacked specific recommendations for designing awareness support for collaborative systems.

The existing work generally agrees on the notion that TSA requires high levels of individual SA related to the specific task and communication among team members (Endsley & Jones, 2001; Gorman et al., 2006; Stanton, 2016; Stanton et al., 2006; A. R. Wellens, 1993). Thus, much of the research in TSA has focused on individual tool design (i.e. to facilitate individual SA, discussed in the previous section) and analysis of communication and coordination behaviours (Gorman et al., 2005; Parush et al., 2011) to provide design implications and advanced measurements (Endsley & Jones, 2001; Gorman et al., 2006; Kaber & Endsley, 1998; Salas et al., 1995; Sulistyawati et al., 2008). The research presented in this dissertation sought to investigate the design of awareness displays for the interfaces of co-located collaborative systems to complement the existing work. Thus, the qualitative analysis of the Timeline Study presented in Chapter 3 and Chapter 4 focused on how SA devices (timelines and other system features) were used to facilitate individual users and the group's SA maintenance. The Timeline Study also sought to provide design recommendations for supporting SA.

2.2 Workspace Awareness

In co-located synchronous workspaces, users' awareness of collaborators may still be deficient due to the distance between collaborators such as in tabletop systems and multi-device environments. Thus, there is a need to understand the awareness maintenance of human collaborators in addition to the automated changes in the system. This section presents the literature in workspace awareness.

While situation awareness focuses on a person's knowledge of the state of their environment, workspace awareness (Gutwin & Greenberg, 2002) focuses on a person's knowledge of their collaborators' actions within a shared workspace (both virtual and physical). Workspace awareness is defined as people's "up-to-the-moment understanding of another person's interaction with the shared workspace" (Gutwin & Greenberg, 2002, p. 417). In co-located settings, extensive research has shown the richness of awareness information provided by the people, artefacts, and environment, and the research has also shown the value of workspace awareness to collaborative activities (Gutwin & Greenberg, 2002; Heath & Luff, 1992; Hutchins, 1990; Pinelle et al., 2003). For example, a study of the London subway system found that people monitored their colleagues' actions and intentionally overheard their phone conversations (Heath & Luff, 1991b). People also intentionally make utterances so that their colleagues stay aware of their current status.

In the mechanics of collaboration work by Pinelle et al. (2003), workspace awareness information can be gathered in many different ways such as observing collaborators, overhearing activities in the workspace, and paying attention to the state of shared artifacts. Two of the concepts in the mechanics of collaboration (Pinelle et al., 2003) are difficult to achieve in digital tabletop systems and multi-device environments without system support: *feedthrough* and *consequential communication*. Feedthrough refers to the observation of the shared artefacts' states in the workspace to understand collaborators' activities. The observation can be made through various senses in additional to the visual channel such as auditory and even olfactory channel. In the example of two people preparing a feast together, by looking at the amount of chopped vegetables, hearing the sounds of opening the fridge, or smelling the burnt food, a person can get a sense of another person's progress or what another person is currently doing. Consequential communication refers to observing collaborators' body to infer their actions and states. For example, during a meeting, when a person is facing a whiteboard and their hand moves up and down, they are most likely erasing content on the whiteboard even if the exact details of the action cannot be observed afar. While a person's body movement can consequently give information about their actions and states, other cues, such as orientation and posture, can also provide consequential communication. For example, when a person is looking and holding a phone on their hand, their posture indicates that they are paying attention to information on their phone. By observing where a person's gaze is, collaborators can infer their focus of attention, whether they are focusing on the list of new ideas on the whiteboard or previous sketches of designs. In the tabletop systems and multi-device environments, due to the distance between collaborators and occlusion, collaborators may not be able to gather these pieces of information easily. In multi-device classrooms, a student cannot see what objects another student is currently interacting with, nor can they observe the type of interaction being performed, e.g., enlarge an object, rotate an object, vs. zoom in the view.

In Gutwin and Greenberg's workspace awareness framework (Gutwin & Greenberg, 2002), they defined elements of workspace awareness, which consisted of information related to the present and past in the workspace. Present elements consisted of detailed information related to who, what, and where such as presence of collaborators, their actions, intentions, artifacts manipulated, location, and gaze. Past information was related to the historical information of who, what, where, and when. In a remote workspace, much work for awareness information is stripped away for distributed collaborators since they are not physically present in the same space to observe each other. The co-located contexts studied in this dissertation shared similarities with a remote workspace in the sense that some of the awareness information was difficult to obtain without system support due to physical separations and occlusion. However, since users were co-located, some information could be gained by observing the workspace such as presence, location, and gaze. It is unclear yet how to apply the elements of workspace awareness to co-located collaboration, and whether they are all applicable, given the potential distractions and clutter of providing all elements.

In a workspace where collaborators have difficulty maintaining awareness or where the awareness information is stripped out, group work can become frustrating (Gutwin & Greenberg, 2000). Moreover, previous research has shown many benefits of supporting workspace awareness in remote collaboration, such as improving coordination and rate of conflict resolution (Sarma et al., 2008), as well as task completion times, communication, and user preference (Gutwin & Greenberg, 2000). Thus, augmenting co-located workspaces with awareness information of collaborators to enable workspace awareness maintenance was one of the important design requirements for the investigations conducted in this dissertation.

2.3 Awareness and Co-located Technologies

This section first provides an overview of co-located technologies to contextualize this thesis research, and then tabletop systems and multi-device environments are introduced to further specify the types of systems studied. Next, the related situation awareness and workspace awareness work in these technologies are presented to reveal the gap in the current literature.

2.3.1 Co-located Technology Overview

Many technologies have been designed and developed to facilitate collaboration, and several factors affect the design of the awareness support. Table 2-1 shows some examples of collaborative systems, ordered by the degree of separation between the collaborators from top to bottom. As the technologies move from co-located to remote, the system can potentially support more collaborators at once at the cost of increased physical separation among users. Due to the physical separation, more sophisticated workspace awareness support is needed due to the difficulties in maintaining awareness of collaborators' actions. In the co-located scenarios, there are physical limits to the size of the shared displays and the room. Although these physical constraints are loosened as bigger interactive displays and intelligent spaces are being built, they are not as flexible as the remote collaboration scenarios such as video conferencing rooms and online collaboration spaces. However, since users are in the same physical space, there are more awareness cues that can be observed.

	Collaborative technologies	Examples	Degree of Separation	Amount of Collaborators
Co-located	Laptop / Workstations	(Amershi & Morris, 2008; Pawar et al., 2006)	Increasing physical separations among collaborators	More collaborators in the workspace
	Large interactive displays	(Morris et al., 2006; Seifried et al., 2012)		
	Multi-device environment	(Beaudouin-Lafon et al., 2012; Fong et al., 2015; Kharrufa et al., 2013)		
Mixed-presence	Remote large displays	(Robinson & Tuddenham, 2007; Tang, Neustaedter, et al., 2006)		
Remote	Remote video conferencing / online collaboration spaces	(Domova et al., 2014; Gutwin & Greenberg, 2002; Schafer et al., 2005)		

Table 2-1: Examples of different collaborative technologies. As the physical separations between users increase, the system needs to provide more awareness support.

The research presented in this dissertation focused on co-located collaborative work, and there are varying degrees of physical separation even within this setting. Users may be seated in front of a computer for collaborative tasks such as learning in a classroom (Pawar et al., 2006) and searching on the web (Amershi & Morris, 2008). As the display becomes bigger, the physical separations between users increase such as in the case of tabletop systems. Although the tabletop system can generally support two to five users, observing collaborators' actions becomes more difficult due to the increased distance. With multi-device environments, even more people can work together by using individual devices to access the shared data. As people can be distributed in the same physical space, some awareness cues are difficult to observe. Co-located systems also need to provide awareness support for users to maintain awareness information. Furthermore, as some co-located environments start to scale up and support more users, providing too much awareness information can become overwhelming and create too much distractions. While Gutwin and Greenberg (2002) noted that co-located technologies do not need to support all workspace awareness elements, the co-located technologies studied in this dissertation involved a large degree of physical separation compared to the traditional single display groupware. Even though users were co-located, awareness support was necessary. The research presented in this dissertation sought to provide workspace awareness support for such co-located environments to help understand how to balance awareness and distractions. The following two subsections introduce tabletop systems and multi-device environments.

Tabletop Systems

Digital tabletop systems are large, horizontal, interactive surfaces that people can interact with using direct inputs. The virtual objects in the systems can be manipulated directly using finger touches or pen inputs. These systems can enhance work and play with digital functionalities such as showing up-to-date data, changing data visualizations based on underlying sources and tasks, and sharing digital documents. The utilities of these systems have allowed them to be applied to diverse domains such as education (Kharrufa et al., 2013; Piper & Hollan, 2009; Shaer et al., 2011; Valdes et al., 2012), games (Dionísio et al., 2015; Tse et al., 2007; Zimmerer et al., 2014), disaster and crisis management (Döweling et al., 2013; Paelke et al., 2012), maritime operation (Domova et al., 2013; Scott et al., 2010), and military training (Bortolaso et al., 2013). The research presented in this dissertation uses a digital tabletop system for its ability to support face-to-face discussions while providing digital benefits.

Many different hardware designs have been developed to enable interaction on tabletop systems, (e.g., Han, 2005; Strickon & Paradiso, 1998; P. Wellens, 1993; Wilson, 2005). In terms of awareness support, user tracking is one of the most notable features. Much research has investigated ways to allow for identifying and distinguishing between users such as finger orientations (Zhang et al., 2012), Kinect sensors (Genest et al., 2013), and electric fields (Dietz & Leigh, 2001). With the ability to determine who is performing what action, more advanced awareness support can be implemented. For example, in a cross-device information transfer scenario, Scott et al. (2014) showed people's hand and arm shadows over the tabletop while they were transferring information between their personal tablets and the shared tabletop workspace. A more fluid interaction can also be provided by eliminating the need for assigned colours and widgets. As players in the physical Pandemic game typically sit in the same seat throughout the game, the digital conversation of the tabletop game did not need to track users. The Callout Bubbles provided identity information based on users' logins in the application. While the contexts studied in this dissertation did not need to track users' movements in the physical space, this dissertation research also sought to provide designs that allow for distinguishing users.

Interaction techniques for manipulating virtual objects on digital tabletops have been one of the major digital tabletop research areas. Examples include object manipulations (Buchanan et al., 2013; Hancock et al., 2007; Kruger et al., 2004; Mendes et al., 2011), control widgets (Morris et al., 2006), and techniques for menu invocation (Seto et al., 2012; Yoshikawa et al., 2012). While some work in this area investigate issues related to collaboration, such as coordination, communication, and awareness (Kruger et al., 2004; Nacenta et al., 2007), the majority of the work tends to focus on novel interaction techniques. Section 2.3.2 further discusses related work which investigates awareness support for tabletop systems.

For collaborative scenarios, much research has investigated the use of tabletop systems for visual analytics (Isenberg, Fisher, et al., 2010) and sensemaking (Wallace et al., 2013). While many collaborative information visualization applications focused on static data exploration (see a review by Isenberg, Hinrichs, et al., 2010), a few studies have used dynamic data (Bortolaso et al., 2013; Conversy et al., 2011; Scott et al., 2010). Section 2.3.2 further discusses the support for situation awareness of dynamic data and workspace awareness on tabletop systems.

Significant work has been done to investigate how people collaborate, in order to inform the design of digital tabletop interfaces. Scott & Carpendale (2010) found that during collaboration around a table, people exhibited territorial behaviour, and three kinds of territories were identified: personal, group, and storage. Personal territories were the table area immediately in front of each person, and the group territory covered the rest of the table space. Storage territories were mobile and distributed in the peripherals of personal and group territories rather than being another partition of the table space. With this view of the workspace, the design of the interactive event timelines in this dissertation sought to also provide awareness of users' actions in their personal territory since it was harder for collaborators to maintain awareness of other users' personal territory.

Prior research has found the importance of allowing for flexible transitions between individual and group work as well as between different activities (Isenberg et al., 2008; Scott et al., 2003; Tang, Tory, et al., 2006). Thus, the interactive event timeline presented in Section 3.5.3 allowed for user interactions at any time and did not impose temporal modes. Overall, this dissertation seeks to support awareness maintenance, rather than enforcing a particular sequence of behaviour, to allow for flexible collaboration styles.

Multi-Device Environments

Multi-device environments are becoming common given the prevalence of personal devices and large interactive surfaces, and they refer to a set of devices inter-connected through networks (e.g., interactive whiteboards, tabletops, and tablets), see reviews by Elmqvist (2011) and Terrenghi et al. (2009). The Callout Bubble Study (Chapter 5) focused on the multi-user co-located context.

Many co-located multi-device setups have been explored, and they typically consist of both shared and personal devices. Large interactive displays, such as whiteboards and tabletops, can be used as a shared workspace (Beaudouin-Lafon et al., 2012; Johanson et al., 2002) or simply as a display to show the overall situation (Chokshi et al., 2014; Seyed et al., 2013). While shared workspaces can be physically displayed in the space, they can also be virtual and not displayed. For example, while a group of users are playing games on their mobile devices, they are situated in a virtual world, irrespective of whether the virtual world is physically displayed or not (Szentgyorgyi et al., 2008). The Callout Bubble Study presented in Chapter 5 used a similar setup for multi-device classrooms. Students' individual devices were connected through a large virtual canvas, with an optional large interactive whiteboard showing the virtual workspace. The students' personal devices acted as an input device for manipulating the virtual workspace as well as an output device to view the workspace. Such a multi-device environment uses individual devices and poses different awareness needs than other setups that make heavy use of large shared displays. The rest of this subsection gives an overview of multi-device environment research.

Multi-device environments have been utilized in various domains such as education (Fong et al., 2015), retail stores (Masuko et al., 2015), data analytics (Beaudouin-Lafon et al., 2012), and emergency response (Chokshi et al., 2014). However, in most of these cases, the personal devices act only as a source of data for information sharing with collaborators (Beaudouin-Lafon et al., 2012; Scott et al., 2014; Shen et al., 2003), or as an interaction medium for browsing information on large displays (Masuko et al., 2015; Seyed et al., 2013). In these use cases, the awareness needs are relatively low since little to none of the underlying data are being modified, unlike in the case of multi-device classrooms where students are actively modifying the states of the shared workspace.

For research in multi-device environments, much work has focused on the infrastructure and interaction techniques for intelligent meeting spaces, e.g., Colab at Xerox PARC (Stefik et al., 1987) and iRoom at Stanford University (Fox et al., 2000; Johanson et al., 2002). There has also been prior research into the underlying software engineering to enable and speed up the development of multi-device applications (Badam & Elmqvist, 2014; Gjerlufsen et al., 2011; Klokmose et al., 2009; Nebeling, Mintsi, et al., 2014; Nebeling, Teunissen, et al., 2014; Seyed et al., 2015). Another major research effort has been in investigating interaction techniques for data transfer across devices (Dachselt & Buchholz, 2009; Everitt et al., 2006; Marquardt et al., 2012; Rekimoto, 1997; D. Schmidt et al., 2012). Despite the intense research into the infrastructure, development, and interaction techniques of multi-device environments, awareness is rarely an area of focus of this prior work. Section 2.3.3 discusses some exceptions specific to the research in workspace awareness for multi-device environments.

2.3.2 Awareness Support on Digital Tabletop Systems

As tabletop systems start to incorporate dynamically changing data, there is a need to support situation awareness. Furthermore, since this research investigated collaborative applications, workspace awareness support was essential to allow for collaborators to keep track of each other's actions and work progress. This section presents related research on awareness support in tabletop systems.

Situation Awareness Support on Tabletop Systems

As more sophisticated tabletop applications are developed to support complex task domains, (Bortolaso et al., 2013; Chokshi et al., 2014; Domova et al., 2013; Döweling et al., 2013), application tools that allow maintenance of awareness of dynamic changes will become essential. However, much of the work in the area of information visualization on tabletop displays has focused on static data exploration. For example, Sultanum et al. (2010) proposed an interactive 3D information visualization tool for reservoir engineering. The system allowed users to manipulate the view through gestures such as panning, zooming, rotating, and choosing a cross-section. Users could also use tangible cards to select the properties of a reservoir to view, and the system would update the simulated model appropriately. Even though the tabletop systems provided enhanced digital abilities for data exploration, the data was relatively static.

While many information visualization techniques addressed challenges in static data exploration, (see a review by Isenberg, Hinrichs, et al., 2010), little existing work has studied dynamic data with historical event support. Existing tabletop applications that incorporate dynamically changing data have focused on novel interfaces and interaction techniques for sharing or collaborating with the current, real-time system state with little to no support of historical data (Bortolaso et al., 2013; Conversy et al., 2011; Domova et al., 2013; Döweling et al., 2013; Micire et al., 2009; Scott et al., 2010). Scott et al. (Scott et al., 2010) investigated the use of a digital tabletop to improve collaborative decision-making in the context of maritime operation, which originally used paper maps. Although the system displayed dynamic, up-to-date, map and vessel information, the project focused on addressing the interaction issues such as orientation and role-based access. OrMiS (Bortolaso et al., 2013) was a tabletop application for military training, and the project explored design issues in providing command and control interfaces for a small group of officers to work together. Although OrMiS automatically updated the current situation by animating the troops' changing states on the map, it focused on providing the current, real-time view of the situation, and did not provide a way for understanding and exploring historical events. As current tabletop research has provided limited investigations of situation awareness support for dynamic data in a collaborative context, this dissertation is the first step towards addressing the gap.

Workspace Awareness Support on Tabletop Systems

Most of the workspace awareness literature has focused on addressing remote collaboration, with a few exceptions that have examined the awareness of collaborators in a co-located contexts (Conversy et al., 2011; Ha et al., 2006; Nacenta et al., 2007). A few prior work has compared direct touch and mouse pointers as user inputs for tabletop systems (Ha et al., 2006; Hornecker et al., 2008). They both found that the direct-touch condition allowed for higher levels of workspace awareness. In a competitive game, this resulted in quicker responses to opponents' moves (Ha et al., 2006). In a collaborative office seating planning scenario, this resulted in more fluid interactions between collaborators, more unrequested help behaviour, and more non-verbalized object handovers (Hornecker et al., 2008). Furthermore, Nacenta et al. (2007) studied five different interaction techniques for selecting, moving, and rotating images for two collaborative tasks. They similarly found that the interaction technique requiring explicit input in the shared space (i.e., drag-and-drop) allowed for easier tracking of collaborators' actions and helped avoid conflicting actions.

These prior investigations of tabletop systems revealed the benefits of providing workspace awareness, and Hornecker et al. (2008) suggested providing more resources in the environment for users to coordinate and maintain awareness as a way to support the fluid frequent interactions rather than enforcing sequential work patterns and predefined working areas. The research conducted in this dissertation also took this approach of providing information to enable coordination and awareness maintenance.

Some existing work has specifically examined techniques for supporting workspace awareness on tabletop systems. Cambiera (Isenberg, Fisher, et al., 2010) was a visual analytics tool for collaborative textual document analysis on digital tabletops. Each user could independently search and view documents, and the system provided features that allow users to keep track of collaborators' searches and viewed documents. It provided indicators on users' search widgets to show other collaborators who had also searched for the same term and who had viewed or were viewing the same documents. As this information was attached to the search results widget, the awareness information was close to the users. Although the overall Cambiera application was beneficial for the information exploration task, the workspace awareness feature was not fully utilized by the participants. The authors noted that the cues might have been too subtle. The WeSearch system (Morris et al., 2010) was a tabletop application that supported collaborative web searching and sensemaking, and the authors observed groups, who already knew each other, worked on topics that they would normally research together in their real-lives. A marquee feature was provided to help users maintain awareness of each other's searches. It was a stream of searched terms flowing within a fixed-size container, and the marquee was placed on users' individual search widgets. The results showed that the feature sparked interest and awareness, and users sometimes discussed the terms searched by others. However, participants reported issues with clutter as the search terms built up. Both of these approaches showed the workspace awareness feedback at users' personal workspace. In this dissertation, as users' interactions with timelines are transient and they may explore a lot of events in a short amount of time, it is unclear if displaying awareness in users' personal space will create too much distraction. Furthermore, since the interactive event timeline seeks to provide geographical information, the usefulness of textual information and potential distractions created by multiple users' explorations is also unclear. Users may also spend too much time isolated in their personal territory. Thus, the tabletop system in the Timeline Study showed feedback of the collaborators' actions on the shared workspace. Further research may explore showing information in the personal area on tabletops as a way to share information.

The research in workspace awareness for co-located settings has provided important insights in the design of interactive timelines investigated in this dissertation. However, due to the unique nature of the timeline as both a visualization and control widget for invoking feedback, the prior research could not provide comprehensive guidance on how to best adapt timelines to tabletop systems. This gap is further discussed in Section 3.1 and Section 3.3.

2.3.3 Workspace Awareness Support for Multi-Device Environments

The Callout Bubble Study on multi-device classrooms sought to investigate a workspace awareness cue for co-located environments. This section presents related work that guided and inspired the workspace awareness cue design.

Workspace awareness has been researched in depth in work on remote collaboration. Thus, commercial online collaboration tools that support group brainstorming and creative processes such as Google Docs[6], Mural.ly[7], and Padlet[8], were examined. The review showed that only a few of them provided awareness of collaborators' actions. In most cases, collaborators only see the updated workspace state after a user makes a change without the information of who did what.

Google Docs showed collaborators' full names next to their insertion cursors in the document (at the time the tool was surveyed). While an insertion cursor is a popular approach, considering an online free-form canvas used on tablets, students cannot always be associated with an insertion location on the canvas, since there is no fixed structure to the canvas, and there can be media types other than text. Next, the research in remote collaboration is presented to provide insights into designing workspace awareness cues for individual devices.

Telepointers (Roseman & Greenberg, 1996) showed collaborators' mouse pointers on each other's workspaces, and they can allow the collaborators to coordinate based on each other's location. Mural.ly showed the collaborators' mouse cursors with the users' full names. By showing other users'

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[6] https://www.google.ca/docs/about/
[7] https://mural.ly/
[8] https://padlet.com/

mouse cursors, their attention and intended interactions could sometimes be inferred, which made this approach very beneficial. Moreover, Tuddenham and Robinson (2010) as well as Tang et al. (2006) both investigated arm shadows as another form of embodiment for remote tabletop collaboration and mixed-presence collaboration with one remote user and three co-located users, respectively. Since most touch-enabled devices do not support hover, especially the ones typically purchased by schools, the design of a practical workspace awareness cue could not leverage the telepointers. Showing shadows would also require an advanced level of user tracking, making this idea infeasible for this thesis research. However, providing cues to collaborators' potential attention and interaction can be valuable, so the awareness cue design presented in Chapter 5 sought to incorporate this aspect.

Mini-maps and radar views are frequently used in many work and gaming contexts (Cheung et al., 2012; Greenberg et al., 1996; McClelland et al., 2011). Many multi-player games provide a mini-map with all or part of the game world while marking the game players' locations or a radar view that is centred on the player while showing the surrounding area. In the Callout Bubble Study, students could view their workspace at a zoomed out level, inferring students' location may be difficult or inaccurate.

The research in multi-device environments has explored ways to share information and manage information across devices (Dachselt & Buchholz, 2009; Houben et al., 2014; Marquardt et al., 2012; Rekimoto, 1997). However, most work has provided very limited information of other collaborators' actions on individual devices. For example, Scott et al. (2014) investigated the use of shadow feedback on tabletops during information transfer between tabletop and tablets. The technique provided feedback for users who have information in transit as well as for collaborators to know about this transfer. The awareness information was presented on the shared tabletop, and provided limited suggestions for feedback on personal devices. Marquardt et al. (2012) investigated the use of proxemics as a way to gradually engage users in cross-device transfers. The awareness of a device's presence was reflected on the large displays and personal tablets in the environment. However, there was limited support of awareness for collaborators' actions.

A few projects have used colours to provide awareness of user identity and action in a shared wall display (Cheung et al., 2014; Masuko et al., 2015). The WallSHOP allowed people to explore items in a public signage through their individual devices, and they could view detailed information of the products on their personal devices. Coloured dots were used as virtual embodiments for users to keep track of their own interaction and for people to gain a sense of popular items. However, given the collaborative nature of multi-device classrooms, students need to know the identity of each other, and colours may not be salient enough and may require much cognitive power to process. The Timeline Study also found that the colour coding did not provide quick enough recognition for collaborators. Few work has investigated ways to provide awareness of collaborators' actions on their personal devices. In many cases, the personal devices are used as a source of private data (Beaudouin-Lafon et al., 2012; Scott et al., 2014), and showing awareness information of other users' activities on their devices could violate their privacy and conflict with the rationale of using personal devices.

Users of large interactive tabletops and multi-device environments have similar workspace awareness needs due to the distance between users and occlusion of user actions. However, few tabletop systems have explicitly provided cues to support workspace awareness (Conversy et al., 2011; Isenberg, Fisher, et al., 2010). The previously mentioned Cambiera system (Isenberg, Fisher, et al., 2010) and WeSpace system (Wigdor et al., 2009) showed feedback of collaborators' actions in users' personal workspaces. The workspace awareness cue in the Callout Bubble Study took a similar approach in the sense that users could see the awareness cue on their personal device. However, the cue was displayed near the objects being manipulated in the shared virtual workspace. Users would only see them if the manipulated objects were within their viewports.

The interactive event timelines presented in the Timeline Study provided a historical view of commands taken by other collaborators, and could be redesigned to support the in-the-moment awareness of user interactions. Similarly, some online collaboration tools, such as Google Docs, provide a revision history where users can see who made what edits at what time. However, browsing a historical log requires students to spend time navigating, which takes their time away from learning activities. Students also have a limited amount of time for the collaborative activities portion of the lesson, and they may not have time to use the timeline. Given this consideration, an awareness cue that requires no or minimal interaction would be more appropriate for the multi-device classroom setting.

Conversy et al. (2011) investigated the use of a digital air traffic control system to replace the traditional paper-based workflow, and a high degree of collaborative effort was required for the safety of the air traffic. The system was designed for two controllers with different roles and responsibilities to work together at the same time. It consisted of two components: a vertical display that shows two radar views, potentially at different zoom levels; and a tabletop as the main collaborative workspace with the flight status information and functionality to annotate and issue commands. To improve consequential communication, the system required users to directly manipulate flight information on the tabletop. Previous work has shown that direct touch on digital tabletops allows collaborators to more easily observe others' actions than with mouse pointers (Ha et al., 2006). To support feedthrough, the system developed by Conversy et al. (2011) displayed highlights on the radar view for flights that were being controlled on the tabletop so that the controller could stay aware of their colleague's actions no matter where they were looking. For multi-device classrooms, observing each other's touch interactions on their tablets can be challenging, but could be improved by augmenting these interactions with visual cues to support workspace awareness maintenance. While providing feedthrough can be beneficial, one important design consideration is to ensure that the cues are distinguishable for group work with large numbers of users.

Wallace et al. (2009) compared single-display groupware (with multiple mice) with multiple-display groupware. The participants were collaborating over a scheduling task. One of the project's goals was to understand the impact of display configuration on communication and awareness. While users in the multi-display groupware condition had more coordination problems, they made fewer errors. The individual devices might have provided a less distracting environment since it was a personalized view without other users' mouse cursors. The study results showed the benefits of using individual devices at the cost of awareness of collaborators. For the Callout Bubble Study, balancing the potential distractions and awareness was an important investigation area.

While the prior research on workspace awareness has provided insights to inspire and direct the design of the Callout Bubble, they focus on remote contexts. The workspace awareness work on tabletops provides insights into the design for workspace awareness cues for co-located settings. However, prior workspace awareness cues for multi-device environments has mainly investigated information sharing techniques. Further investigation into workspace awareness cues in multi-device environments is still warranted.

Awareness in Student Learning

Since the Callout Bubble Study was in the multi-device classroom context, related work in the domain of computer-supported collaborative learning (CSCL) was examined. Research on supporting workspace awareness has recently gained popularity within CSCL. In Janssen and Bodemar's (2013) review of awareness tools in the computer-supported collaborative learning domain, they considered the collaborative spaces as consisting of two overlapping spaces: *content space* (e.g., cognitive activities, the subject-matter content) and *relational space* (e.g., collaborator social interaction). However, the research on these two spaces usually aims to evaluate students' learning progress and performance, which can be difficult to observe and detect, as opposed to students' interaction with objects in a workspace.

One of the main approaches was to provide students with feedback on their learning progress. Present students with their group mates' self-created concept maps was shown to be effective for students to share and compare their learning (Engelmann et al., 2009; Molinari et al., 2008). These sharing activities increased discussions and co-manipulation of the concepts in the maps. Another approach was to provide students with results of peer assessments and group members' participation levels. This was shown to increase students' level of active contribution (Kimmerle et al., 2007), group performance (Jongsawat & Premchaiswadi, 2009), and group satisfaction (Phielix et al., 2010).

While the CSCL literature provides insights into encouraging students' collaborative activities in class and motivating learning activities, improving student learning is not the goal of this research. The research presented in this dissertation seeks to provide for students' workspace awareness to reduce their confusion and frustration while working together in the shared virtual workspace.

2.4 Summary

This chapter introduced the concepts of situation awareness and workspace awareness, which are the primarily types of awareness investigated in this research. Furthermore, this research focused on co-located environments that presented the following challenge: the physical separations between users and occlusions in the environment increased the difficulty in maintaining awareness of the automated changes and collaborators' actions without system support. Specifically, tabletop systems and multi-device classrooms were chosen as the study contexts, and the related literature on awareness and these technologies was discussed in this chapter.

In this chapter, the literature review revealed a gap in supporting situation awareness of dynamic changes on tabletop systems. There also lacks in-depth understanding of how to adapt interactive event timelines to tabletop systems for workspace awareness maintenance. The Timeline Study was a first step to address these gaps. While the Timeline Study revealed the benefits of the timeline designed in this research for situation awareness maintenance, further work was needed to understand how to improve workspace awareness support for co-located collaborative work. The Callout Bubble Study in a multi-device classroom context had a similar workspace awareness deficient problem, and this context was chosen specifically for its benefits in supporting large group collaboration and individual work. The literature review revealed a gap in practical design recommendations for supporting workspace awareness in a co-located environment since most of the related work focused on remote collaboration. The Callout Bubble Study sought to investigate a practical workspace awareness cue to balance awareness support and potential distractions. The following chapters present the Timeline Study (Chapter 3 and Chapter 4) and the Callout Bubble Study (Chapter 5). Based on the results from these two investigations, overall design implications for awareness support in co-located environments are presented in Chapter 6.

Chapter 3

An Interactive Event Timeline for Tabletop Systems Involving Automation: Design and Method

The literature review (Chapter 2) revealed a gap in supporting situation awareness in complex tabletop applications involving dynamic automated changes[9]. Interactive event timelines have been shown to improve interruption recovery time and decision accuracy for single-user applications (Sasangohar et al., 2014; Scott et al., 2006). However, there is a lack of understanding in how to adapt timelines to a collaborative tabletop context to support situation awareness. Thus, we designed, developed, and evaluated two design factors impacting the effectiveness of interactive event timelines for collaborative tabletop applications.

We chose a cooperative turn-based board game, Pandemic, as our study context to simulate a complex collaborative scenario, and designed an interactive event timeline within this context. Our goal was to evaluate the usefulness and effectiveness of two design factors: *control placement* (number of timelines for a group of users and timeline placements) and *feedback location* (where to display interaction feedback of timelines). Thus, several alternative event timeline designs were implemented within our Pandemic game. A revised version of the Pandemic game was implemented

[9] Material ideas, figures, and tables from this chapter have previously appeared in Chang et al. (2014, 2016). Appropriate permissions have been obtained for the re-use of these materials, and can be found in Appendix D. This chapter presents collaborative work done with the collaborators mentioned in the Statement of Contribution on page vi.

to give us full controls of the code base for prototyping various timeline designs, see the previous version of the Pandemic digital game in Pape (2012).

The timeline allowed players to explore historical game events at any time during the gameplay. After automated events occurred, users could interact with the timelines to regain situation awareness. For workspace awareness support, we designed the timelines to present two types of collaborators' actions. First, collaborators' previous commands, which had permanent impacts to the system state, were logged in the timelines. Second, some version of the timelines provided real-time feedback of collaborators' interactions with the timeline, which had no permanent effects to the system state.

A user study was designed to understand how an interactive event timeline can be adapted to a tabletop collaborative environment. The study consisted of two phases, all conducted in one single session. In Phase 1, we conducted a mixed-design experiment with *control placement* (between-participants factor) and *feedback location* (within-subjects factor) to understand their impacts on situation awareness. Participants only played partial games for each condition. In Phase 2, participants played a full game uninterrupted with the timelines that can be freely reconfigured to any combinations of the *control placement* and *feedback location*. Phase 2 provided more realistic data to understand participants' usage of the interactive event timelines.

The rest of this chapter first describes the problem of lack of situation awareness on tabletop systems and the exploration of the design space. Through an iterative design process, we decided to investigate the use of interactive event timelines for providing situation awareness and workspace awareness on tabletop system. The next section presents the conceptual design of our event timeline and the design factors for adapting timelines to tabletop systems. The research questions are presented next. The Pandemic physical game is then presented to provide the context of our study. The interface of the digital Pandemic game and the design of the interactive event timelines are described next, followed by our user study method. The situation awareness questionnaire and the quantitative and qualitative data analysis are also explained in the study design section. Related user study materials can be found in Appendix B. The analysis results are presented in Chapter 4.

3.1 Problems

As mentioned in Section 2.1, automation is used to refer to the change in states and the replacement of manual work. Automation can reduce physical work and cost (Spath et al., 2009). However, it may negatively impact situation awareness due to change blindness (Rensink, 2005) and inappropriate feedback for users (Endsley, 1996). On digital tabletop systems, the problem of situation awareness deficient due to automation was also observed (Wallace et al., 2012). As illustrated in Figure 3-1A, people at a digital tabletop could be unaware of a change occurring in the system interface due to the large size of the display or other competing demands for their attention such as conversing with a teammate. Moreover, even when a change occurred within a person's field of view, they might still miss the change due to limited attentional capacity. Or they might be searching for the changes, but unable to find it via visual scanning for differences. Furthermore, users might not always be around the tabletop system. For example, they could be away from the tabletop due to other duties, so they might miss their collaborators' actions. The next section describes our exploration of various design concepts to iteratively design and prototype an awareness display to address the lack of situation awareness.

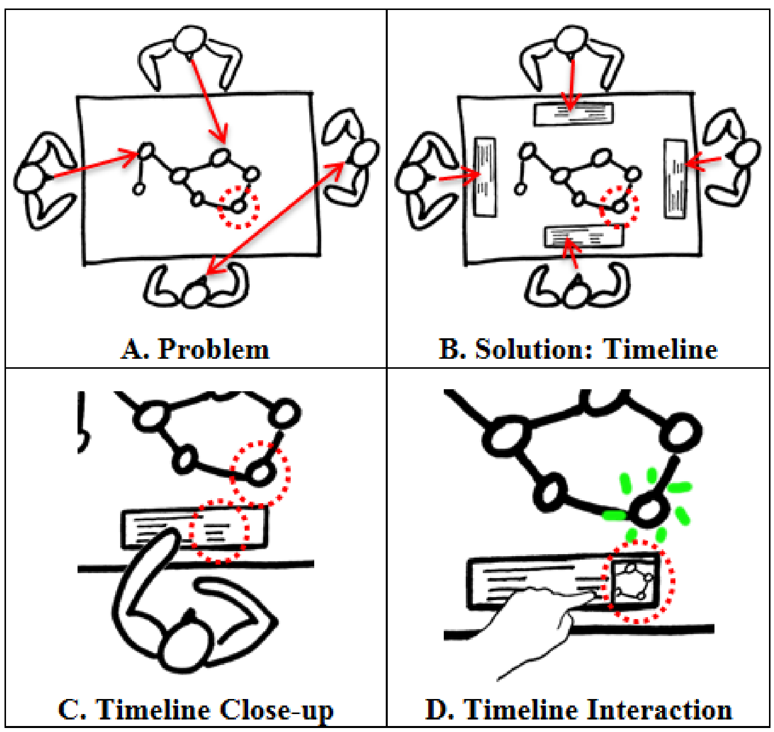

Figure 3-1: Conceptual design of the interactive event timeline. A) Problem: users could miss automated changes if they were engaging in conversations or focusing on other parts of the tabletop display (red arrows show attentional focus). B) Solution: timelines could provide a way for users to view and explore changes. C) As new automated changes appeared in the system, they were logged by the timelines, and D) Users could interact with the timelines to locate the changes on the group workspace (highlighted in green) and on the timeline (graph cut-out on the right of the timeline).

3.2 Exploration and Iteration of Design Alternatives

To address the lack of situation awareness due to automation, we first explored the design space by examining relevant literature and decided to focus on providing persistent information displays to mitigate distractions in the environment. Next, we created design sketches to explore potential ideas for persistent information displays, and then moved on to create medium- and high-fidelity prototypes. This section presents the exploration of the various design alternatives for awareness support and the iterative design process.

3.2.1 Exploration of Design Alternatives Through Literature Reviews

The literature in automation, situation awareness, and animated visualizations provided potential solutions for supporting awareness of automated actions. To address the negative impacts of automation, one of the approaches is to "optimize the assignment of control between the human and automated system" (Endsley, 1996, p. 173). By adjusting the level of automation, we can automate tasks that are well-suited to the machine, and provide manual control for tasks well-suited to humans. This approach allows us to take advantage of automation while mitigating the negative impacts of a lack of situation awareness. However, for many contexts, such as emergency response and maritime surveillance, the users have no control over when dynamic changes occur. If users are distracted when automated changes take place, they can still miss them. Furthermore, the situation awareness literature has pointed out that inappropriate or no feedback to automated actions as one of the key causes of low situation awareness. Thus, we decided to focus on providing more awareness feedback to address the lack of situation awareness.

We next examined the animation, motion, and human perception literature. Animation may be used to guide users through potential changes. Cartoon-style and ”afterglow” animations have been shown to be beneficial for facilitating the understanding of system changes (Baudisch et al., 2006; Chang & Ungar, 1993). In terms of human perception, certain stimuli such as blinking lights and motion are highly effective in immediately drawing users' attention (Bodenhausen & Hugenberg, 2009), and the literature on motion has shown that it is effective in highlighting information (Bartram & Ware, 2002; Ware & Bobrow, 2004). However, given the challenge that users may not be paying attention to the tabletop interface and its much larger size than displays tested in previous research, users may completely miss the animated changes, as observed by Wallace et al. (2012). As animated graphics disappear after certain amount of time, users may not have enough time to gain the information needed once they pay attention to the system again. Considering the potential distractions in the environment, we decided to further explore persistent information displays that would allow for exploration of information at any time.

3.2.2 Design Iterations on Persistent Information Displays

We next deployed an iterative design process to explore ideas and refine our design. We used a turn-based collaborative board game, Pandemic, as our case study. Players need to collaborate to control the spread of diseases while collecting cards to win. The game mimics many complex domains, as it requires intense strategizing and resource management to prioritize actions. The full details of the Pandemic game are described in Section 3.5.1.

Throughout the design iteration, we leveraged fundamental information visualization principles (Bodenhausen & Hugenberg, 2009; Carpendale, 2003; Ware, 2004) and examined human factors issues to consider for large displays (Robertson et al., 2009; Yost et al., 2007). Specifically, we also considered the perception and orientation issues on tabletop systems (Kruger et al., 2004; Wigdor et al., 2007). We decided to support rotation for all widgets with textual information. Furthermore, the data we sought to visualize was discrete, focusing on the types of automated events and relationship between them, and they required minimal interpretation of length, angle, and slope of the data. We also sought to minimize the potential clutter and distractions the awareness displays may add to the interface and the workflow.

We conducted three phases of iteration: low-, medium-, and high-fidelity, see Appendix A for the details of the design iterations. During the low-fidelity sketching phase, we considered both group and personal territories (Scott & Carpendale, 2010) on the tabletop system as candidates for persistent information displays. A wide range of design factors were considered, such as the interactivity of the displays, different types of historical information, different levels of details, chronological vs. spatial representations, and use of individual devices. For the group workspace, we decided to focus on designs that provided feedback of automated and player actions to enhance situation awareness and workspace awareness. For the personal workspaces, we decided to provide detailed historical event logs to mitigate the distractions in the environment, as they were found to be beneficial for reducing response time and error rate by (John et al., 2005; Smallman & John, 2003).

In the medium-fidelity phase, we created digital mock-ups of the sketches. We considered a wide variety of design alternatives such as textual vs. graphical event logs, various interaction mechanisms with the timelines, different levels of details, and showing detailed information on demand. Furthermore, we considered different encodings of the detailed information such as colour, size, text, symbols, and a spatial map. For the group workspace, we decided to provide historical information in-place, on a node when players interacted with it, so that the information is placed at the centre of players' attention to reduce searching time. For the personal workspace, we decided to use a graphical event timeline for its benefits in improved interruption recover time, decision accuracy, and quick recognition of crucial information (Sasangohar et al., 2014). Furthermore, it provided a space-efficient way to provide additional information on demand, and it fitted into a users' field of view to allow for quick perception of changes.

In the high-fidelity phase, the chosen designs were implemented. Feedback in the group workspace introduced a substantial amount of clutter and was removed from the interface. For the personal workspace, the timeline design was iterated to refine the layout, colour palette, icons, and input interactions. Through the iterations of our design, we discovered open questions for adapting the timelines to a collaborative tabletop environments, these questions have primarily been studied for single-user applications. We next discuss the conceptual design of the interactive event timeline, and the design factors chosen to study the timeline's adaptation to collaborative tabletop environments. Section 3.5.3 presents the detailed design of the final interactive event timeline.

3.3 Conceptual Design of Interactive Event Timeline

To address the issues introduced by the use of automation in digital tabletop systems, we explored using interactive event timelines to provide persistent information of historical system events. Such timelines also provide the information in a visual form that could fit within a person's field of view, despite the large size of the table. To gain awareness of the current system state, a person could examine and explore the timeline, which provides an overview of historical events (Figure 3-1B and Figure 3-1C). To get more in-depth information, they could invoke further feedback on the shared display or on their personal areas (Figure 3-1D).

Based on the existing literature, we considered two key factors in adapting these timelines: *control placement* and *feedback location*. The control placement factor was primarily to investigate situation awareness. As we adapted the concept of timelines that was successful for single-user applications to multi-user applications, the immediate questions were how many timelines there should be to facilitate situation awareness, who should now own the timeline, and whether a shared timeline or individual timeline would better facilitate situation awareness. Furthermore, the detailed information that was shown on demand could be displayed in both the group and personal workspaces, impacting players' situation awareness and workspace awareness. While showing the feedback in the group space would allow for in-context feedback and workspace awareness maintenance of collaborators' interactions, showing feedback in the personal space would minimize the amount of visual search time. Thus, for the feedback location factor, we were interested in where to display the feedback of timeline interactions and whether feedback in the group or personal workspaces would better facilitate situation awareness and workspace awareness. Based on these questions, we investigated the control placement and feedback location factors. The following subsections describe the two factors and potential trade-offs in the design. The details of the existing work mentioned below were previously discussed in Section 2.3.

3.3.1 Control Placement

The event timeline is a visualization of historical events as well as a control for invoking detailed information of the automated changes. It was unclear how to distribute and place the timelines to best support situation awareness and workspace awareness in a group setting.

Morris et al. (2006) compared providing individual replicated system controls around the border of a tabletop system with a single, shared control in the centre for a collaborative photo tagging application. They found that while individual controls were preferred, the groups were more collaborative (i.e., more labels per image) when using the shared controls. This result suggests that a shared timeline may contribute to more collaborative work and improved team situation awareness (e.g., joint investigation for all team members). However, it is unclear how well shared timelines support individual situation awareness since users need to coordinate their use of the timelines.

Ha et al. (2006) compared direct touch and mouse pointers for a two-player competitive image search game on digital tabletops, and their results show that the direct touch condition allowed for higher levels of workspace awareness and resulted in quicker response to opponents' moves. Nacenta et al. (2007) studied five different interaction techniques for selecting, moving, and rotating images for two collaborative tasks: an image sorting game and a storyboarding activity. They similarly found that the interaction technique requiring explicit input in the shared space (i.e., drag-and-drop) allowed for easier tracking of collaborators' actions and helped avoid conflicting actions. While participants may have higher workspace awareness using the shared control, it was unclear how individual versus shared timelines would impact participants' situation awareness. Providing replicated timelines allows each user to view and manipulate the timeline for the purpose of maintaining situation awareness. As the current research still lacks understanding in how the placement of timelines impacts users' situation awareness, we examined the control placement factor.

3.3.2 Feedback Location

Another design consideration is where to provide the visual feedback related to a user's exploration of historic system events. Information about the event can be displayed locally (on the timeline) or on the shared area of the tabletop. These design alternatives may better facilitate either individual control or group function, respectively (Gutwin & Greenberg, 1998). Displaying feedback on the timeline provides a consistent location to look for the information, and it fits into a person's field of view. On the other hand, feedback in the shared area provides more contextual information of the overall situation to the individual. This feedback location also better facilitates feedthrough—the observation of shared artifacts in the workspace to gain awareness of collaborators' actions and work progress (Pinelle et al., 2003)—by making collaborators' actions more visible to the whole team. However, the size of the display may still necessitate searching for the feedback in the shared workspace, making situation awareness maintenance more difficult for individuals. Moreover, other users' feedback on the shared area may make searching more difficult and distract users.

Existing work that explored the impact of specific input methods and interaction techniques on workspace awareness (Ha et al., 2006; Nacenta et al., 2007) provides insights that helped us hypothesize how the different feedback locations may impact workspace awareness. However, our timelines were designed for situation awareness maintenance, which is a different goal from the previous work. Thus, the Timeline Study presented in this chapter and Chapter 4 investigated the timeline's impacts on situation awareness and the trade-off between providing awareness and reducing distractions.

3.4 Research Questions

We sought to understand the utility of different design factors for adapting interactive event timelines to collaborative tabletop applications. Specifically, we were interested in the following research questions:

- How do *control placement* and *feedback location* affect situation awareness and workspace awareness?
- How would the timelines be used in a collaborative tabletop application? What are the usage patterns for different design factors?
- Given that users may gain their situation awareness from multiple sources in a collaborative environment, what roles do users' communication with each other and the different system features, including the timelines, play to facilitate situation awareness maintenance?

3.5 Pandemic Digital Tabletop Game

We digitized the cooperative board game, Pandemic, onto a digital tabletop system (see Figure 3-2). See the permission to use the Pandemic board game in Appendix B.1. The Pandemic game is a popular commercial board game for three to four players. Players work together as a team of specialists, with distinct roles and abilities, to save the world from epidemic outbreaks. A typical game is about forty-five minutes. The Pandemic game requires intense collaborative activities such as forecasting of game states, planning for actions in advance, and managing resources. By using games, we can have a more rapid, human-centred prototyping process, since recruiting experts of popular games is easier in our community than recruiting experts in other complex domains. Moreover, we have more control in manipulating parameters in a game, e.g., degree of difficulty. In our previous project (Wallace et al., 2012), we used the Pandemic game as a case study, and found that the version of the digital Pandemic game elicited a lack of situation awareness, due to the automation of game mechanics. The study participants were often confused about what specific automated actions took place, and thus, had difficulties strategizing. Considering both the practical concerns and the potential contributions in providing awareness support in such a context, the Pandemic game was used as the study context for the first study.

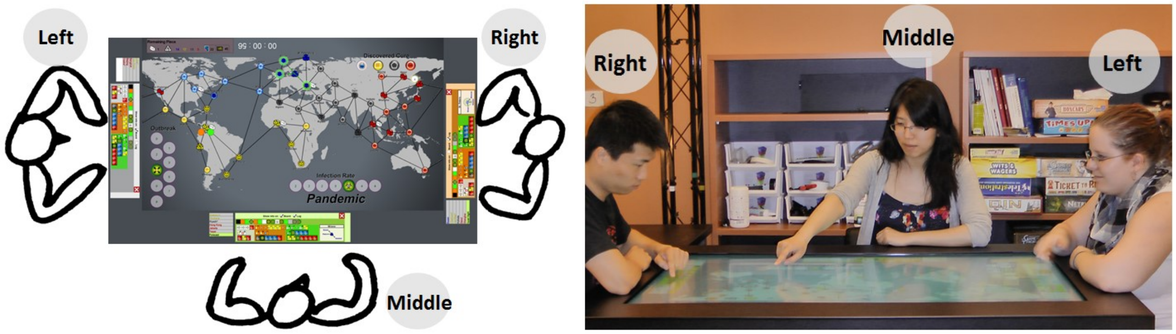

Figure 3-2: The *Pandemic* board game was used to study awareness support in tabletop systems. (Left) A screenshot of the game interface, labeled with participants' seating locations, based on the orientation of the game map. (Right) A group was playing the game.

3.5.1 Pandemic Game Rules

In the Pandemic game, players win by curing all the diseases, and lose if they run out of time (not having enough cards to draw from) or if the game state is out of control (too many outbreaks or diseases). A player turn consists of three phases: act, draw, and infect. Players first carry out their four actions through careful planning and strategizing, and some of the actions include moving to a city, treating a disease at a city, exchanging player cards, and building a research station for more efficient travels. They will need to balance between keeping the game state under control (i.e., not to lose the game) and spending actions for cure discovery (i.e., to win the game). Next, they draw player cards, which they collect to trade for the cure. At the end of a player turn, they act as the game board (opponent) and draw infection cards that determine which cities are to be infected with new diseases (in reality, players place wooden cubes (diseases) onto the game map based on the cards drawn). These three phases repeat for every player's turn. Thus, the next player goes through the same set of phases to act, draw, and infect.

Players periodically are faced with special events, Outbreaks and Epidemics, which increase the difficulty of the game as they happen. A city can contain a maximum of three disease cubes. When players need to add a fourth cube, an Outbreak event is triggered. All the neighbouring cities (connected cities on the game map) will be infected with one additional cube. Epidemic events appear periodically throughout the game, and our digital game has six Epidemic events in a game[10]. When an Epidemic event is drawn (in the draw phase), players need to take several steps to resolve it including drawing cards, shuffling the infection discard pile, and placing disease cubes. It requires players to reshuffle the previous infected cities into the infection draw pile, which increases the chance of infecting the same cities again. Consequently, the potential for Outbreaks increases. Since these events have large impacts on the game state, players have to stay aware of them to effectively strategize. They also need to adjust their strategies in time based on the urgency of the new changes. However, as the game progresses and increases in complexity, carrying out these changes can be time consuming and require both manual and cognitive workloads. Handling complex sequences of infections can also be quite confusing since one event can trigger multiple other events. For example, an infection may trigger an outbreak, which may then trigger another outbreak, making them chained events.

3.5.2 Digital Adaptation of the Pandemic Game

Our digital tabletop adaptation version of Pandemic provided automation to help reduce manual workload and to enforce rules. For example, the system automated game board (the opponent) actions by placing disease cubes based on infection cards drawn, or *outbreak* and *epidemic* events. It also automated the drawing of player cards. The digital game adopted the same rules to leverage the original designer's expertise in encouraging collaborative activities and providing a fun gameplay. Moreover, we minimized the training time required in the user study by recruiting experienced Pandemic players.

There was one divergence in the digital game rule. Due to the nature of automation, the automated game events happened instantly and there was no way for players to pause them. There are five special cards in the game that give players one-time special actions. In the physical game, players are allowed to use it at any time. Since the digital game did not provide a way for users to pause the automation, players had to use this card either before or after the automation. Considering that people

[10] In the official game rule, players can choose the number of Epidemic events in a game from four to six Epidemics. More Epidemic events make the game more difficult.

have no control over when dynamic changes happen in many other contexts, we decided to not to allow for pausing automated events.

Moreover, the digital game did not provide the same level of flexibility as the physical game. Players cannot make up their own house rules, and there was a fix set of rules to follow. Due to the time constraint in implementation, the game did not provide an undo function. However, undoing an action is considered as cheating by some board game players.

We modified the visual design of the game to reduce clutter. For example, most of the decorative graphics on the map were removed to reduce clutter. While we kept a consistent colour scheme as the physical game, we adjusted the contrast and brightness of the colours used to make them appropriate for tabletop systems. The visual icon designs and terminologies were kept consistent to leverage participants' existing knowledge of the game. We informed our participants about the differences in the digital game in our study, and there were no major problems with the slight alterations.

Any events that permanently changed the game state were reflected in the game interface including both automated changes and actions conducted by players. The game conveyed the changes through the following three system features.

Board. The changes were reflected on the game board including displaying disease cubes on the map and counters around the map (e.g., remaining cards, epidemic counters, and remaining cubes), see Figure 3-3A to Figure 3-3D. Moreover, after automated system events, three seconds of system animations appeared to highlight the changes on the relevant cities (see Figure 3-3E to Figure 3-3G). Different types of system animation were used to represent infection, outbreak, and epidemic events.

Infection Discard Pile. The system provided a limited history of previous infected cities in a textual log format, contained in the infection discard pile (see Figure 3-3H). The pile was periodically emptied into the infection draw pile when an epidemic event occurred so it only contained limited history since the last epidemic. Players could open the discard pile via a button on the top left of the interface (see Figure 3-3B). It initially opened at the centre of the game map, and can be moved by dragging the pile.

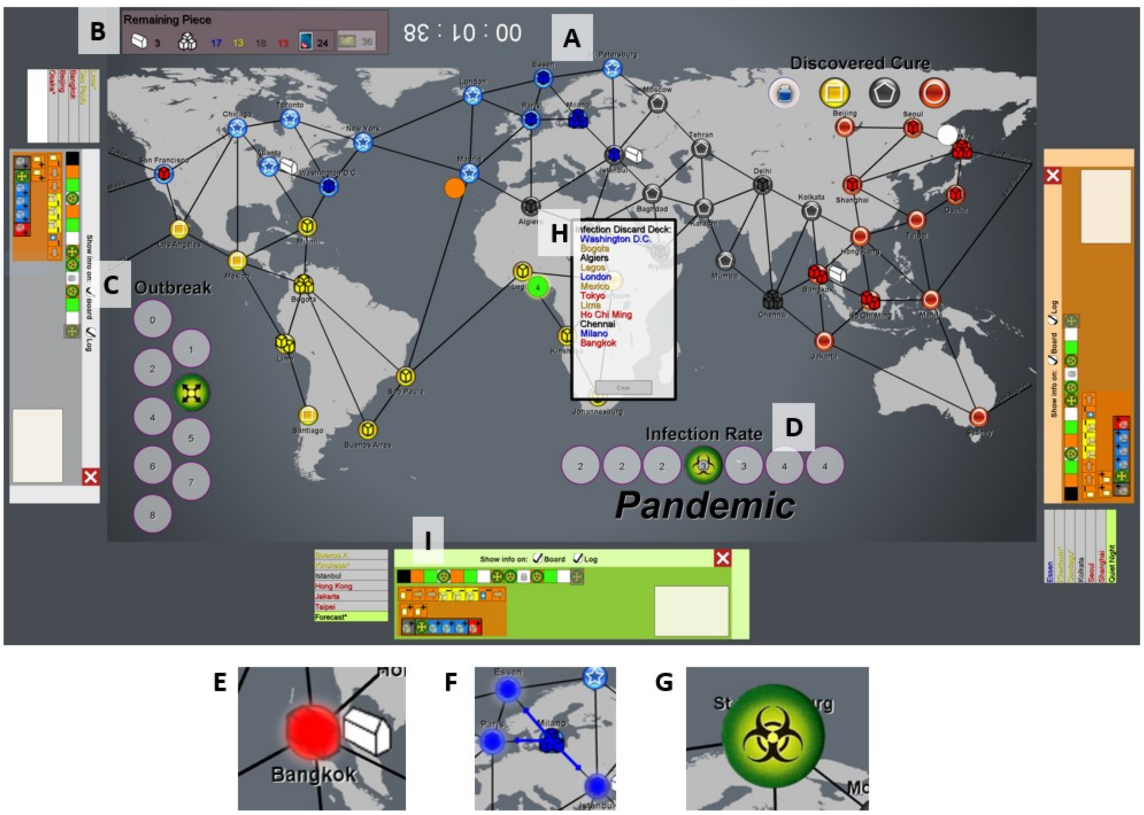

Figure 3-3: Mechanisms for providing feedback of the game state. A) The game map presented the current situation including player location, disease spread, and research stations. B) The remaining piece panel showed the current number of game pieces and cards in each category. C) The outbreak counter showed the number of outbreaks so far. D) The infection rate counter showed the number of epidemic events so far and the number of infection cards the system would draw for each turn. The system animations for automated events included E) infection, F) outbreak, and G) epidemic. Players could open the H) infection discard pile from the remaining piece panel (B) to see a limited history of previous infections drawn by the system. I) An interactive event timeline contained a full history of the system and player actions.

Interactive Event Timeline. The interactive event timelines provided a complete record of events that happened throughout the game, and is presented in Section 3.5.3 below (see Figure 3-3I and Figure 3-4).

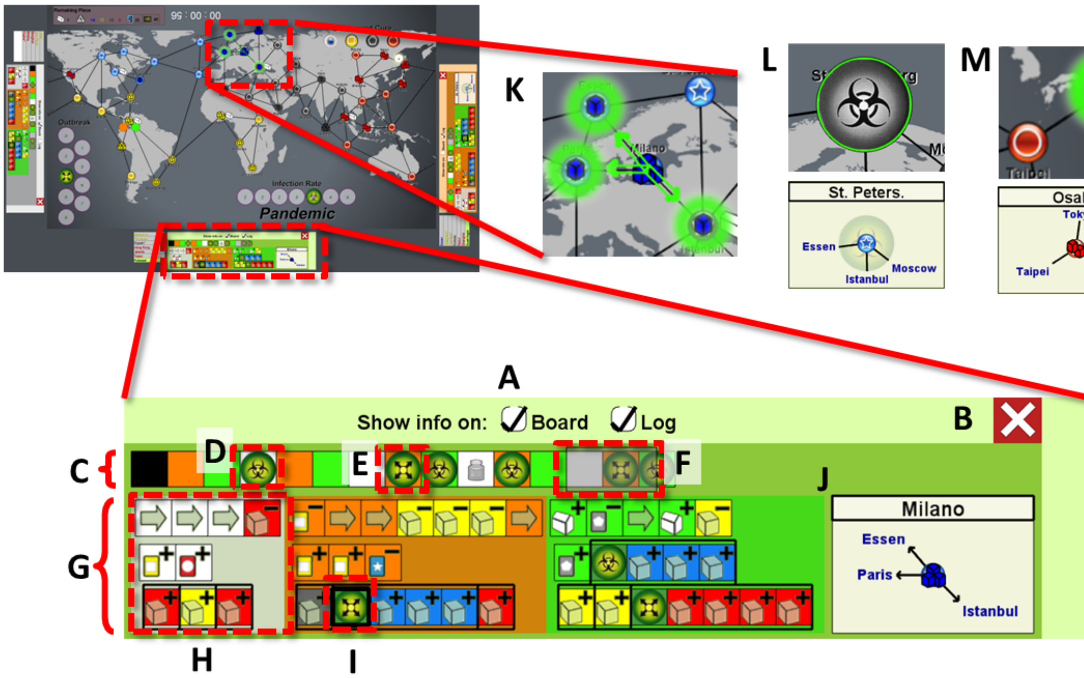

Figure 3-4: Design of the interactive timeline (configurable version). Users could A) toggle the feedback location on the board and on the timeline as well as B) close and open it at any time. C) The overview bar showed all players' turns so far with symbols denoting important game events such as D) epidemics and E) outbreaks. F) A viewport could be used for selecting a timeframe to show in G) the detail view. H) A player's turn contained three rows, corresponding to the three game phases. Each block represented an action carried out by either the player or the system, and black bounding boxes grouped related game events together (symbols denoting the type of the event e.g., arrow for moving to different cities, bottle for discovering a cure, and +/- for adding or removing game pieces). I) Selected event had a thick black bounding box. Location details of the selected event were J) shown on the timeline as a map cut-out and K) highlighted by a replay animation on the map. Different events had different feedback, J) and K) for an outbreak event, L) for an epidemic event, and M) for an infection event (plus a cube symbol on the timeline).

3.5.3 Interactive Event Timeline

We designed an interactive event timeline (Figure 3-4) to improve players' awareness of the game's automated actions. The design was based on a task analysis of experienced to expert players playing the physical Pandemic game, following the steps of goal-directed task analysis (Endsley, 2000). We first defined the goal of the game (i.e., win by discovering four cures). We then identified the sub-goals (e.g., keep diseases under control to allow time for collecting cards) and decisions to be made to achieve them (e.g., determining the top priority cities to treat next turn). Knowledge needed to make these decisions was then defined (e.g., disease distribution and infections coming up). See Appendix B.9 for the goals and knowledge defined through this process. Based on the information need, we considered different design alternatives.

Furthermore, the timeline was designed to fit into a player's personal territory on the tabletop, based on prior research on tabletop territoriality (Scott & Carpendale, 2010). Moreover, it persisted on the game board, allowing players to explore prior game events at any time including both player and computer actions. The timeline showed history for one game session.

The timeline consisted of two main components: an *overview* (Figure 3-4C) and a *detail* view (Figure 3-4G). The *overview* provided a high level view of the game progression, and the *detail* view provided information for all the game actions that occurred during the selected timeframe.

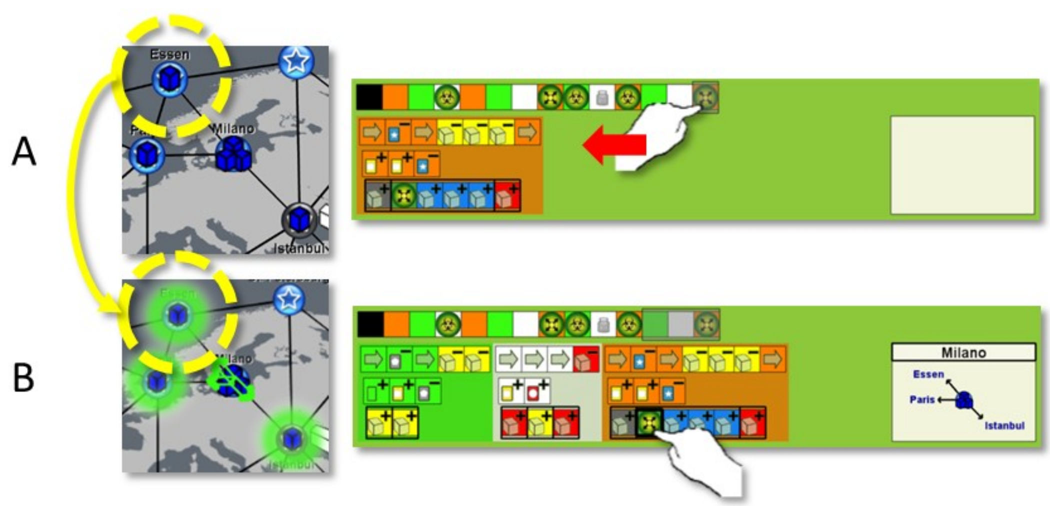

Figure 3-5: Interaction with the timeline. A) Users could drag a viewport to navigate through all past player turns, as shown in the *detail* view in B. B) Touching a game event in the *detail* view invoked Left) a replay of the changes on the map and Right) static location information on the timeline.

The *overview* showed each player's turn in chronological order, colour-coded by the in-game player colour (orange, yellow, and white). The first turn in black represented the initial game setup automated by the system. Symbols on the *overview* denoted special events (epidemic and outbreak) that happened during the particular turns. Players could drag the viewport (Figure 3-4F) or tap on a given player turn on the *overview* to navigate through the game history. Dragging the viewport updated the *detail* view in real-time (see Figure 3-5).

The *detail* view contained the player turns currently selected. Each turn consisted of three rows corresponding to the three phases in the game (i.e., act, draw, and infect) (see Figure 3-4H). The first row represented player actions. The second and third rows represented two types of automated actions: cards drawn for players and cities infected. Each block represented one game event (Figure 3-4I) with a symbol denoting the type of event. Related blocks are grouped by a black bounding box. The colour of each block was derived from the colour coding scheme used in the Pandemic board game. The timeline provided a compact history of game events.

The game event blocks were also interactive. When a game event block was selected, additional information was displayed on the game map and/or next to the timeline. Replay animations triggered by players were colour coded by the player colour, and different events have different animation. Figure 3-4J to Figure 3-4M illustrate the replay animation, and Figure 3-3E to Figure 3-3G illustrate system animation for automated events. Other than the new diseases, the replay animation for the rest of the game events was an arrow pointing at the related cities on the map. The arrows were pointing toward the centre point of the timeline that the interaction originated from, see Figure 3-6. We expected these cues to reduce confusion, provide awareness of users' interactions with the timelines, and facilitate searching for feedback on the game map.

The map cut-out on the timeline reflected the state of the city at the time of the particular game event including the number and types of diseases as well as any research stations on the city. We provided the game state information and the connected city to provide context to the game event selected. When new automated events happened, they were appended to all timelines in the game (e.g., Figure 3-7). Once users started a new turn by executing new actions, the timelines automatically scrolled to show the current game turn.

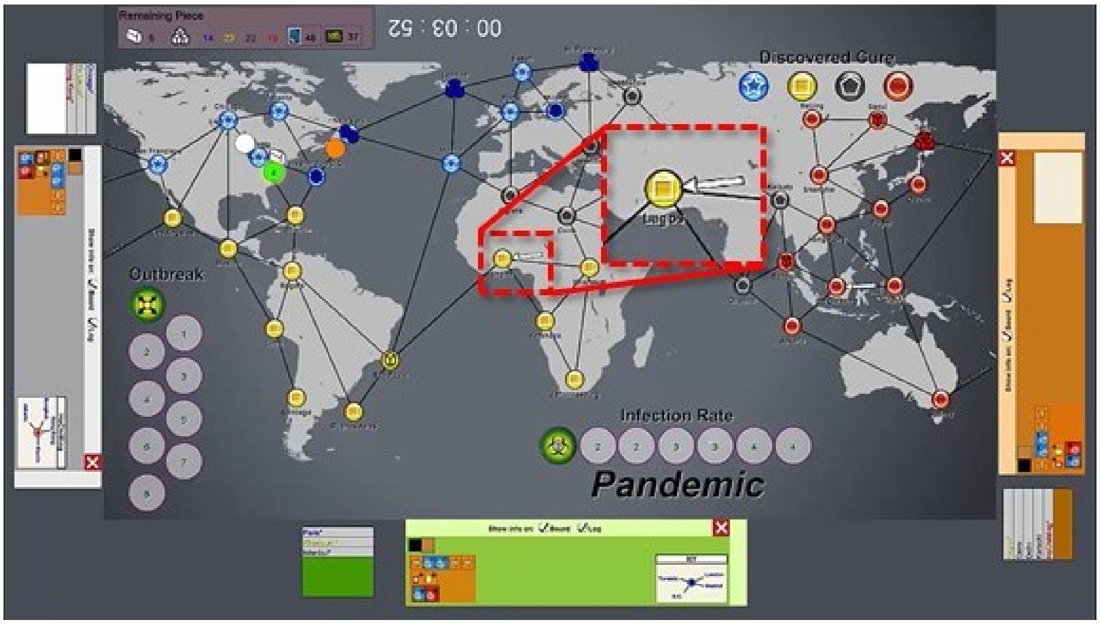

Figure 3-6: Arrow feedback that animated player actions. When users tapped on a player action or a player card timeline event, an arrow animation appeared and it pointed in the direction of the timeline. In this example, the white arrow was pointing at the white player's timeline.

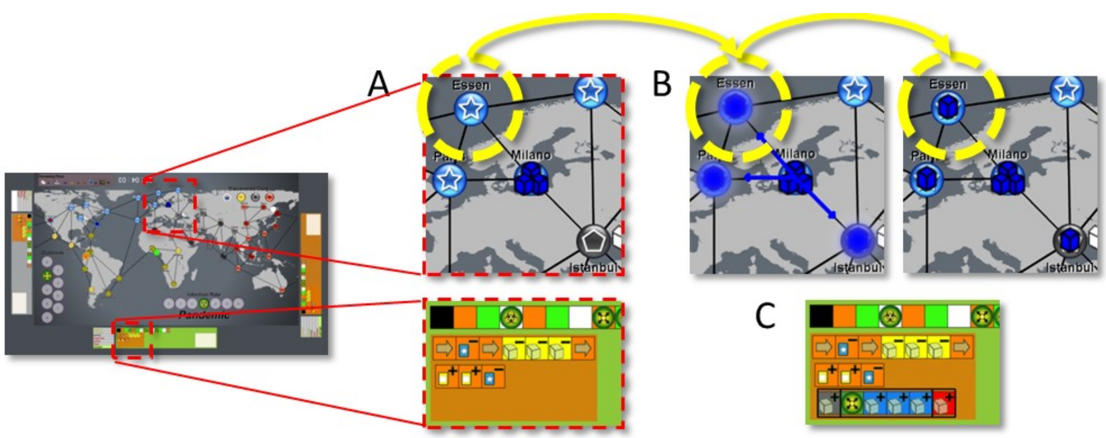

Figure 3-7: Interactive event timeline updated as new automated events were being animated. A) A cut-out of the initial state of the data and the timeline. B) Automated system changes (an outbreak) appeared with pulsing animation and then faded away. C) The changes were reflected on the timeline, shown in the last row.

3.5.4 Implementation Details

The Pandemic tabletop game was implemented in Processing[11] with the back-end logic using Java. A multi-touch library, Simple Multi-Touch Toolkit[12], was used for handling touch inputs. A logging library, Apache Log4j 2[13], was used to facilitate the process of generating the computer logs.

3.6 Study

We conducted a laboratory-based study to understand how the two design factors, *control placement* and *feedback location*, impacted users' situation awareness and timeline usage. Participants played the Pandemic game with different design alternatives of the interactive event timeline, and answered questionnaires for us to evaluate their situation awareness and experience.

3.6.1 Participants

Participants were recruited from the local community, specifically targeting experienced Pandemic players. Players had to sign up in groups of three. Thirty-six paid participants (twenty-three male, thirteen female, ages twenty-two to thirty-six) were recruited, with all team members having previous experiences playing Pandemic prior to the study. Our participants came from a wide range of background including students, researchers, accountants, engineers, and paramedics. All participants had used touch-enabled devices prior to the study. For this chapter and the results in Chapter 4, the participants are denoted as $P_{\text{group number, seating position}}$. For example, $P_{1,\text{ right}}$ denotes the right player in Group 1 (based on the orientation of the game map).

3.6.2 Equipment & Setting

Each group of participants was seated in the lab around a 148 × 95 cm digital table (3840 × 2160 pixel, 121 × 67cm for screen size) with an embedded PQ Labs frame to detect touch input. Two participants sat at the short edge, and one participant at the long edge, to avoid the

[11] https://processing.org/
[12] http://vialab.science.uoit.ca/smt/
[13] http://logging.apache.org/log4j/2.x/

situation of one participant seeing the game board upside down (see Figure 3-2). The computer was running 64-bit Windows 7 using an Intel® Xeon® CPU E5-1603 @ 2.80 GHz with 4 GB of RAM.

Two digital camcorders were placed at different angles to capture the game sessions (frontal view and over-the-shoulder view, see Figure 3-8). Three additional laptops were used for administrating the questionnaires. We used the online survey tool, Survey Monkey[14], for our study.

Figure 3-8: Two camera views in the user study. Top) Frontal view. Bottom) Over-the-shoulder view.

[14] https://www.surveymonkey.com/

3.6.3 Study Design

There were two study phases. Phase 1 (Pandemic Challenges) sought to understand how the following two factors affected participants' situation awareness, using a mixed design (see Table 3-1):

- *Control placement* (between-participants): 2 levels (shared, individual)
- *Feedback location* (within-participants): 3 levels (next-to-timeline, on-board, both)

		Control Placement	
		Shared	Individual
Feedback Location	Timeline	1	4
	Game Board	2	5
	Both	3	6

Table 3-1: Factors and levels in Phase 1 of the Timeline Study. *Control placement* is a between-participants factor, and *feedback location* is a within-participants factor. All team members use the same timeline configuration.

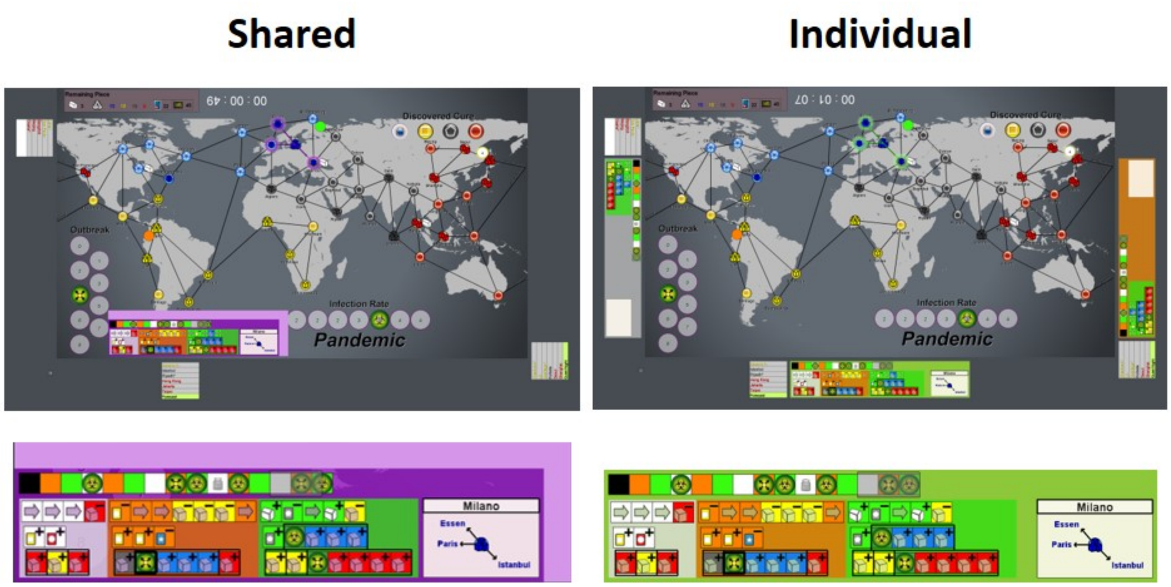

Figure 3-9: *Control placement* consisted of two levels. A) A movable timeline shared among a group. B) Replicated individual timelines with fixed locations in players' personal spaces.

For *control placement*, half of the groups used the shared controls (Figure 3-9A) and the other half used the replicated individual controls (Figure 3-9B). All players in the same group used the same type of controls. The order of the three feedback locations was counterbalanced. Players played three partial games, called Pandemic challenges, with either shared or individual controls, and they saw all three types of feedback locations. Typical Pandemic games increase difficulty as the game progress. By challenging participants to start half-way through a game, they were presented with a more difficult situation where they had to work together to understand previous game events and strategize to decide on future actions. We intended to observe more intense discussion and complex behaviour. Moreover, we created a situation where participants may use timelines to understand historical events. Another practical concern was to keep the study within a reasonable length of time (under three hours) to reduce the impact of fatigue. As a playthrough of a physical Pandemic game typically takes about 45 minutes, playing a full game for each condition would limit the number of design alternatives that can be tested in one sitting.

The widgets for toggling feedback locations and opening and minimizing the timeline (Figure 3-4A and Figure 3-4B) were removed in this phase. The shared timeline could be moved and rotated at any time, and the individual timelines were docked to the fixed location on the players' personal area. The replay animation matched with the timeline colours (i.e., purple for the shared timeline and white, green, or orange for individual timelines). Given that this study was focused on determining what the impacts of *control placement* and *feedback location* design alternatives were on awareness in a collaborative tabletop context, a no-timeline condition was omitted from the study design as it was less relevant to understanding this research goal.

In Phase 2 (Full Game), participants played a full game with a configurable version of the timeline (Figure 3-10), and all groups had the same game setup. Phase 2 provided more realistic usage data of the configurable timeline to inform further improvements and to understand how it was used to facilitate situation awareness maintenance. A full game typically takes six to eight rounds. A configurable timeline allowed participants to open and minimize their individual timelines at any time (Figure 3-4B). A group could open up to three timelines, and the timelines were movable to anywhere on the tabletop. Each timeline allowed players to customize the feedback location (no feedback, next-to-timeline, on-board, or both) via the toggle widgets at the top of the timeline (Figure 3-4A). Minimizing and reopening the timeline kept the feedback-location configuration the same.

Configurable

Figure 3-10: The configurable timeline used in Phase 2.

3.6.4 Procedure

The study sessions lasted approximately two and a half to three hours. The researcher first welcomed the participants and provided them with the overview of the study and asked them to complete the consent forms (see Appendix B.2–B.3 for the information letter and consent form). Participants then completed the background questionnaires and the two study phases: 1) Pandemic Challenges and 2) a play through of a full game. Figure 3-11 depicts the flow of the study.

Phase 1 - Pandemic Challenges

After the researcher explained the game interface (see study script in Appendix B.5), participants played with the Pandemic game without any timelines for ten minutes and completed the game-play questionnaire. Study questionnaires are discussed in Section 3.6.5 below. Then, with the same procedure, participants practiced on the same timeline variant they would see in the first Pandemic Challenge.

For each Pandemic Challenge trial, participants started in the middle of an ongoing Pandemic game. In the initial study design, the participants started half way through the game, and the map and the timelines were already populated with the historical events. However, the pilot tests showed that, participants tended to ignore historical events and strategized based on available information on the game map. The perceived manual and cognitive work of navigating and understanding historical events may be the barrier. After testing several alternative designs (e.g., quizzing participants at the start of the game), the animated walkthrough approach was most efficient for the participants. Thus, the game first animated through all previous historical events on the map, and the events are

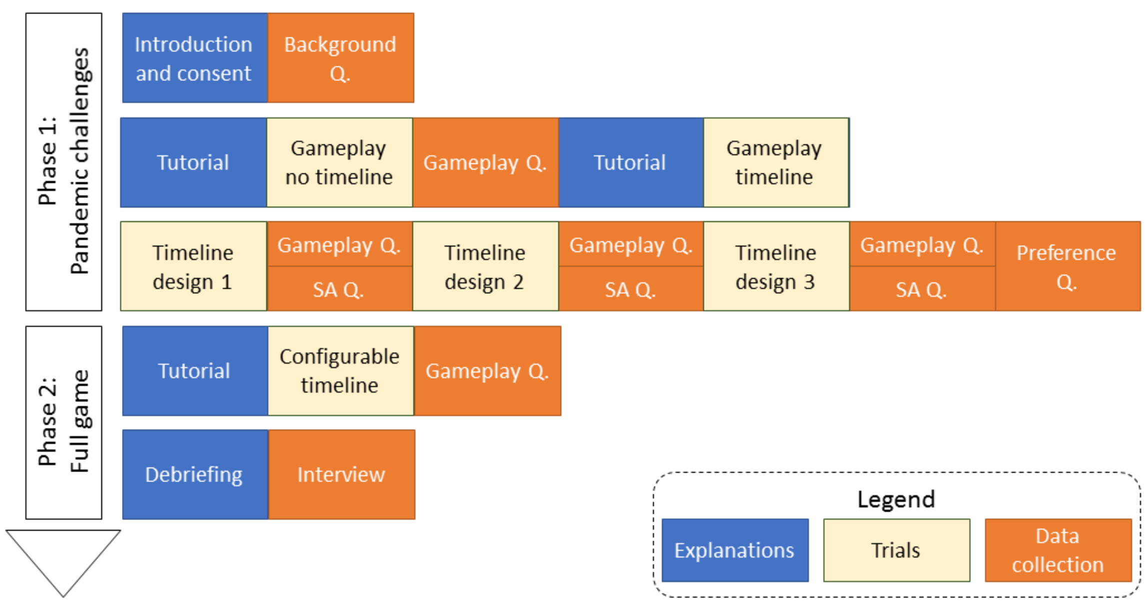

Figure 3-11: Flow of the Timeline Study. The Timeline Study consisted of two phases: Phase 1 (Pandemic Challenges) and Phase 2 (Full Game). Phase 1 asked participants to play three partial games, each for 2 rounds. The three conditions varied in the feedback locations. Phase 2 asked participants to play a full Pandemic game with timelines that could be freely configured in its feedback locations and could be opened and minimized at any time.

appended to the timeline one by one as the animation took place. The animation drew users' attention using a spotlight metaphor by greying out the unrelated part of the game board, see Figure 3-12. We constructed three initial game states (scenarios) from real gameplay with some controlled parameters such as the number of critical events that happened and the number of cures discovered. The order of the initial game states was randomly selected. The animated walkthrough took about three and a half minutes.

Figure 3-12: A screenshot of the animated walkthrough at the beginning of the games. The animated walkthrough used a spotlight to highlight changes to walk users through the initial game setup and the three scenarios.

Participants played for two rounds (two turns for each player). Then, the game stopped at a random time during the beginning of the third round, and participants were asked to fill out a post-condition questionnaire individually. The cut-off time for each trial was random (but within a period of time) to minimize the behaviour of memorizing game state. We did inform participants about the situation awareness test at the beginning of the first trial due to an observed learning effect in our pilot studies. The post-condition questionnaire consisted of a gameplay and a situation awareness (SA) questionnaires (discussed in Section 3.6.5 below). The order of the three SA questionnaires was randomly selected. Participants were asked to rank their preferences of the timeline alternatives at the end of this phase and to provide free-form feedback.

Phase 2 - Full Game

After the researcher explained the configurable timeline, participants played a full game. The game carried out the initial setup and animated them, which took a minute and forty-seven seconds. All groups had the same game scenario. They completed the gameplay questionnaire with a free form area for any additional comments after the game.

By allowing participants to play uninterrupted, we could gather more realistic data on the timeline usage. We sought to observe a more realistic usage of the timeline to gain insights into how it was used for situation awareness maintenance to inform further improvements.

At the end of the study, the researcher debriefed the participants with the goal and details of the study (see Appendix B.4), and conducted an unstructured interview to receive any additional feedback.

3.6.5 Data Collection

Various types of data were collected during the study including video recordings from two different angles, screen recordings, computer logs, audio recordings, and questionnaires. The computer logs captured all touch interactions on the timeline, e.g., tap, rotate, open, and close timelines as well as toggle feedback locations. In additional to the timeline interactions, the logging also recorded all touch points in the game interface (e.g., moving a player pawn and opening a menu). We also logged the automated events and player commands.

Questionnaires

Several questionnaires were used throughout the study. The background questionnaire can be found in Appendix B.6. A gameplay questionnaire and situation awareness (SA) questionnaire were used as post-condition questionnaires to understand players' situation awareness, gaming experience, workload, and general preference in each condition. A preference questionnaire was used at the end of Phase 1, and it asked participants to rank their preference of the three timeline feedback locations (see Appendix B.7). Players filled out a gameplay questionnaire at the end of the Phase 2 as well.

The gameplay questionnaire consisted of three parts. First, a Player Experience of Need Satisfaction (PENS) (Ryan et al., 2006) survey was used to measure players' gaming experience. Second, a NASA Task Load Index (NASA-TLX) (Hart et al., 1988) survey was used for measuring workload. Third, there were questions on their general awareness of the game and the team members. See Appendix B.8 for the exact questions used.

We developed the situation awareness (SA) questionnaire by following the steps outlined in the SAGAT methodology (Endsley, 1988, 2000). The goal-directed task analysis was conducted as a part of the iterative design process during the timeline design. See Section 3.5.3 for the description of the process and see Appendix B.9 for the goals and knowledge defined through this process.

We created an initial set of twenty-two SA questions (see Appendix B.10) based on the knowledge required. Three researchers then independently classified the SA questions into three levels of situation awareness (SA1–SA3) as defined by Endsley (1995). The three raters agreed on thirteen questions (inter-rater reliability (Fleiss' Kappa) = .54, $p<.001$), and the remaining questions were discussed to determine their classification and iterated until consensus was reached. Through this process, three additional questions were derived, resulting in a total of twenty-five questions (thirteen for SA1, seven for SA2, and five for SA3). Because six unique questions were required for each SA level (three sets of two questions per SA level), two researchers devised one final SA3 question. Questions were in the form: "name one city/colour/player that…", or "estimate the number of turns away from…". For example, "Name one city that was just infected last turn." (SA1), "Name one set of cities (if any) that may create a chained outbreak." (SA2), and "Which colour is at the top priority for the current game state?" (SA3). See Appendix B.11 for all of the SA questions. Since participants played three timeline alternatives in Phase 1, we divided the SA questions into three questionnaires with equal number of questions for each SA level (see Appendix B.12 for the three SA questionnaires). See Appendix B.13 for all surveys used in the printed format as in Survey Monkey.

We conducted four pilot studies to iterate on the designs of the interactive event timeline, the game interface and interaction, and the user study. The pilot participants confirmed that the questionnaires required intense thinking but that the questions were clear.

3.6.6 Quantitative Analysis

For the quantitative analysis, we focused on the gameplay and SA questionnaires as well as the computer logs. The SA questionnaire results were scored as correct (1), partially-correct (0.5), and incorrect (0) for each question. For the computer logs, we extracted two types of player interaction with timelines: *navigation*, when participants explored different turns by dragging the viewport or tapping the overview (Figure 3-4C); and *invocation of detail*, when participants tapped or brushed game events in the detail view (Figure 3-4G).

Although we iterated on the SA questionnaire through our four pilot studies, during the data analysis, we had to reclassify one SA question and drop two SA questions due to potential misinterpretation of their meaning. For one SA2 question, participants were asked to name the colour that required the most attention now, which we intended to be the colour with the fewest remaining cubes, (i.e., comprehension of changes, SA2), but participants interpreted this as the colour that would likely be depleted in the upcoming few turns (i.e., forecasting, SA3). Since participants uniformly interpreted the question differently than intended, this question was reclassified as SA3,

We found that two other questions might have been misinterpreted and lead to incorrect assessment of the participants' SA. One question asked players to estimate the number of turns until the next epidemic game event, but none of the participants received the "correct" score. There were thirty-two out of thirty-six players (88.9%) who received the "incorrect" score. Although the game only automated game mechanics, participants' comments during the gameplay and in the questionnaires showed distrust toward the game. Participants believed that the computer was malicious and was intentionally making the game more difficult when shuffling and triggering epidemic game events. This distrust may have led to an unrealistically pessimistic outlook of the situation.

The second dropped question contained an error, which referred to a different game phase than intended. It was unclear how the participants may have interpreted this question. The questionnaire in our final analysis nonetheless had an even spread of questions across SA levels (six in SA1, five in SA2, and five in SA3).

A player's SA score for each condition is computed by taking the average of all questions. We analyzed the SA questionnaires using a 2 *control placement* × 3 *feedback location* repeated measures analysis of covariance (RM-ANOVA). Since the SA score is an average, this measure is interval data, which is most appropriately analyzed by a parametric test such as ANOVA (Norman, 2010). An intraclass correlation analysis showed that situation awareness scores of the participants in the same group correlate ($ICC_{2,3} = .66$, $p = .02$), so we have included group as a covariate when the data is analyzed at the individual participant level (i.e., using ANCOVA when appropriate). When analyzing correlations, a first-order partial correlation controlling for group effects was used to test the relationship between situation awareness scores and interaction count. When relevant, scenario order and SA questionnaire order were included as between-participants covariates to mitigate order effects.

3.6.7 Qualitative Analysis

For all the free-form comments participants provided in the questionnaires, one researcher constructed an affinity diagram to understand their feedback and form themes for our findings. It was also used to understand the benefits and disadvantages of the different design factors.

For Phase 1 (Pandemic Challenges), the users' interactions with the timelines were extracted from the software log to plot the traces of interaction. This was done to gain insights into what timelines were used for by our participants in different conditions.

For Phase 2 (full game), two researchers analyzed eight full game sessions with an open video coding process. One researcher watched the videos and took notes of participants' discussions and activities related to timeline usage and situation awareness maintenance. An initial set of codes was then established, and two researchers coded for players' interactions with the features in the system and their discussion with teammates, e.g., interacting with timeline and discard pile, pointing at the game board, using deictic references for game cities, as well as announcing, narrating and discussing of automated events. The codes were revised until an acceptable inter-rater reliability was reached (79.39%), and then the rest of the videos were coded. See Table 3-2 for the codes used and their definitions, and see Appendix B.14 for a more detailed code description.

Code name	Code description
Timeline	Checked information in the timelines by looking at timelines or interacting with the any cubes in the overview and detailed view.
Open timeline	Players opened their timelines.
Minimize timeline	Players minimized their timelines.
Timeline - log feedback	Players toggled the log feedback on the timelines (either turn on or off the feedback on the log).
Timeline - board feedback	Players toggled the board feedback on the timelines (either turn on or off the feedback on the shared game map).
Discard pile	Opened discard pile to check cards in the pile.
Point	Players used their hands to point at a particular city or area of the map for the purpose of drawing other players' attention to the map.
Look at board	Looked at the map on the tabletop.
Announce	Announced automation results after watched system animations, watched others' timelines, watched others' replay animation, or interacted with timelines. Or narrated automation results while watching system animations or replay animations.
Deixis	Referred to a location on the map by using deictic expressions that cannot be understood out of context (e.g., go there; treat here).
Explicit reference	Explicitly mentioned a location's name (e.g., go to Tokyo).
Implicit reference	Players referred to a location without mentioning a location's name or use deixis. For example, one player could say move, treat, and build research station, and another player could carry out the actions at the appropriate cities. The locations were assumed, usually based on previous discussions.
Discuss automation results	Players asked others for information about automated game actions.
Correct each other	Players corrected each other's knowledge of the automation.
Strategize	Players proposed a strategy and explained why.

Table 3-2: Definitions of the video codes. We coded for awareness information maintenance behaviours and interactions among players.

Next, we focused on codes most relevant to participants' situation awareness maintenance including 1) looked at or touched the timelines, 2) opened and closed the timelines, 3) toggled feedback locations, 4) opened the infection discard pile, 5) discussed automated game events, and 6)

Category	Results	Definition
Purpose of interaction	Investigating automation results	Participants sought to find out the type and location of an automated event that took place as well as connections between automated events.
	Prioritization	The participant action was for the purpose of gathering information to predict future game state and prioritize player actions.
	Initial timeline tweak	Participants interacted with the timeline to understand its functionality and configure it to their preferences.
	Automated game setup	Participants sought to understand the initial game state that was automatically set up by the game.
	Other	The coded instance was for any other purposes, such as played and rotated the timelines. This category also included instances that could not be classified by the researchers (i.e., insufficient information).
Outcome of interaction	Correct	Participants successfully obtained correct information.
	Incorrect	Participants successfully obtained information, but the information was incorrect.
	Incomplete	Participants attempted to seek information but were unable to obtain it or gave up on seeking the information (or asked the researcher).
	Unknown	The researcher was unable to determine the outcome of the interaction based on the available information in the videos.
	N/A	Players had no intention of seeking information.

Table 3-3: Classification definitions of the video codes. We classified the codes most relevant to situation awareness maintenance based on the purpose and outcome of the interaction.

corrected each other's knowledge of the automated events. For all instances, we classified the purpose behind the observed actions and discussions as well as whether the participants achieved their goals as listed in Table 3-3.

Furthermore, to understand how players made use of various system features for situation awareness maintenance, we sequenced the codes based on game events investigated by the participants. We also extracted the treat diseases game actions from the software log and included them in the sequence to understand the impact of various system features' usages on decision making. With the coded actions and the treat disease actions, we examined whether players' investigation of particular game events led to game commands to address them, for example, a player asked about the new infections, another player checked the timeline and found that Moscow had an infection, and the infection was treated in the same turn. We classified each sequence based on its purpose of interaction and the purpose has been achieved (refer to Outcome of Interaction in Table 3-3).

Through the video analysis, it became apparent to us that the codes classified under automation results were most closely related to the perception and comprehension levels of situation awareness. In the process of maintaining situation awareness of automation, participants were investigating and verifying the exact new automated events that took place to understand the overall game state. On the other hand, the prioritization actions were most relevant to the projection of future game states as participants gather information to determine their urgency.

3.7 Summary

This chapter presented the design of the interactive event timeline and the user study design for the goal of understanding how to adapt it to a collaborative tabletop setting. The study design also sought to provide empirical data to evaluate the effectiveness of the timeline design and gain insights into how it was used for situation awareness maintenance. The next chapter presents the findings from our quantitative and qualitative data analysis to understand the impacts of the design factors tested and participants' usage of timelines for situation awareness maintenance. Design lessons learned through this study is also presented.

Chapter 4

An Interactive Event Timeline for Tabletop Systems Involving Automation: Findings and Discussion

Our analysis revealed that the timeline was beneficial for situation awareness[15]. Individual timelines resulted in higher situation awareness, and amount of interaction with the timelines positively correlated with situation awareness. The feedback at both the game board and the timeline was ranked as the most preferred mode of timeline alternatives in Phase 1, and it was also the most utilized mode in Phase 2. Groups' combined situation awareness was high despite of the different levels of *control placement* and *feedback location*. While this consistently high group situation awareness suggested the success of the timeline design, participants might have used other mechanisms in the game to maintain their situation awareness and/or leverage each other's knowledge. Thus, we conducted a follow-up video analysis on Phase 2 data to gain insights into how the timelines were used for each level of situation awareness and how various system features, including the timelines, were used for situation awareness maintenance. The analysis revealed that the timelines were useful as both static and interactive visualizations. They were mainly used for level one situation awareness (perception) to investigate recent dynamic changes automated by the system. The timelines were used only occasionally to strategize and prioritize actions while another system feature, the discard pile, was used primarily for this purpose. We found that in addition to being used for understanding automation

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[15] Material ideas, figures, and tables from this chapter have previously appeared in Chang et al. (2014, 2016). Appropriate permissions have been obtained for the re-use of these materials, and can be found in Appendix D. This chapter presents collaborative work done with the collaborators mentioned in the Statement of Contribution on page vi.

results and strategizing, the timelines provided an accurate historical account for the team members to clarify confusion with the game state or conflicting understanding within the group.

The rest of this chapter presents the quantitative and qualitative findings on the impacts of the timeline alternative designs on situation awareness and participants' usage of the timelines. We first present the results from Phase 1 analysis, which focused on the quantitative findings based on the two design factors: c*ontrol placement* and *feedback location*. Next, we examine the timeline interactions and situation awareness at the group level to understand how the timelines affected group situation awareness. We then present the results of the video analysis from Phase 2 data. We conclude this chapter with discussion and design implications based on the findings.

4.1 Phase 1 Findings

The Phase 1 results showed that timelines were generally beneficial for participants' situation awareness. Although we did not test a control condition without timelines, observations made during the pilot studies and training sessions showed that participants had difficulties keeping up with system automated events without the timelines.

The computer logs revealed that players mainly interacted with the timeline to discover the results of automation. Figure 4-1 shows traces of interaction for all participant trials with *individual* controls and feedback in *both* locations (see Appendix B.15 for more interaction traces plotted). The interaction traces are overlaid on top of a timeline's silhouette, and the darker shades indicate more interaction events were started at that particular game cube. As shown in Figure 4-1, most interaction occurred at the bottom-left corner, where the latest automation results were displayed (since the timeline automatically scrolled to new player turns).

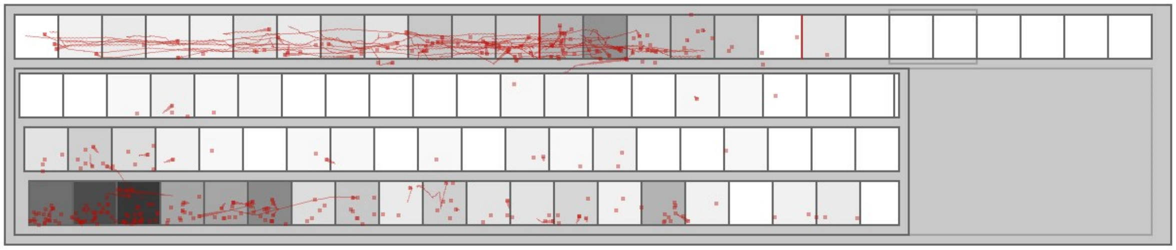


Figure 4-1: Interaction traces of timelines. Aggregate traces of player interaction (points = touch down, lines = touch move) for individual control placement and feedback on both. Cells (game event cubes) are shaded by interaction count (darker = higher). The traces showed that understanding automation results (bottom-left corner) was the major use of the timelines.

This shows that the timelines were frequently used to investigate automated computer actions, as confirmed by our observations and exemplified by the following comment:

> $P_{12,middle}$: I mainly used the game log to identify the individual cities that were infected when I missed the on-board animations.

The interaction traces also show some instances of reviewing previous turns (see the top overview bar in Figure 4-1) and checking the cards automatically dealt to players (see the third row in Figure 4-1). This is consistent with our observed usage of the timelines.

The timelines were also beneficial for strategy formation, as evidenced by the comments:

> $P_{7,middle}$: It allowed us to look back at the previous moves to determine the best move.

Timelines were also a fun experience for some of our participants, as $P_{7,right}$ commented:

> $P_{7,right}$: It was really fun to move it and show people what I was talking about while feeling like I was in the Matrix.

In the subsequent sections, we provide more details on the impacts of *control placement* and *feedback location* on situation awareness as well as the group interactions of the timelines.

4.1.1 Control Placement

With an understanding of the high level timeline usage, we examined impact of the *control placement* factor on situation awareness. The RM-ANCOVA on the awareness score revealed a main effect of *control placement* ($F_{1,28} = 4.7$, $p = .04$, Figure 4-2, left). On average, players using *individual* controls had higher situation awareness scores than players using *shared* controls, suggesting that individual timelines are more beneficial for participants' situation awareness. See Appendix B.16 for SPSS outputs of statistical analyses conducted.

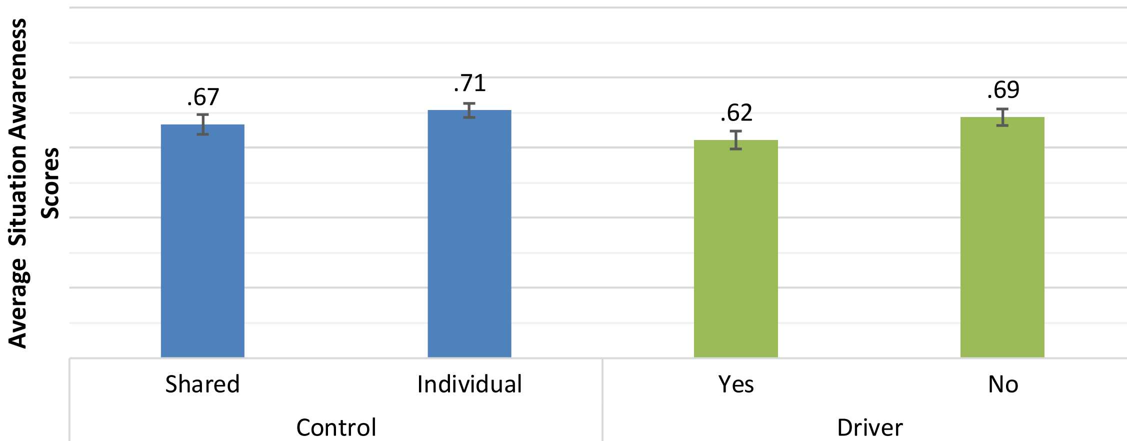


Figure 4-2: Situation awareness scores. Left) The average situation awareness scores for shared and individual controls were significantly different. Right) The average situation awareness scores for drivers (primary users) vs. non-drivers in the shared condition were not significant.

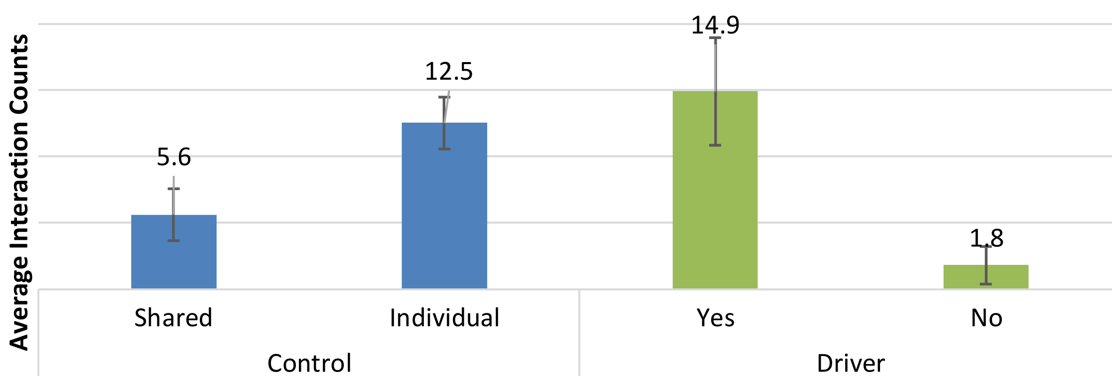


Figure 4-3: Interaction counts of timelines. Left) The average interaction counts for shared and individual controls were significantly different. Right) In the shared condition, the average interaction counts for drivers (primary users) was more than the average of non-drivers.

The RM-ANOVA on timeline interaction also revealed a main effect of *control placement* ($F_{1,10} = 6.2$, $p = .03$, Figure 4-3, left), that is participants with *shared* controls used the timelines significantly less, suggesting that individual timelines encouraged more interactions.

Next, we conducted a partial correlation analysis on timeline interaction and SA score (control for group). The analysis revealed a positive correlation ($r_{105} = .20$, $p = .04$). This is consistent with our expectation that more interactions with the timeline would lead to higher situation awareness. This result also confirms that the timeline may be beneficial for improving situation awareness.

4.1.2 Feedback Location

For the *feedback location* factor, we conducted RM-ANCOVAs on awareness scores and RM-ANOVA on interaction counts, and the analysis showed no significant main effects or interactions. However, qualitative differences were observed, and participants reported preferring feedback both on the timeline and on the board.

Feedback Next-to-Timeline

With feedback located *next-to-timeline*, this setup allowed for quick investigation across multiple game events as commented by six players. Since the players' fingers and the feedback location are in close proximity, players could focus on the feedback on the timeline while tapping or brushing through several events. This benefit was confirmed by the following comments:

$P_{8,right}$: having the information close to where I placed my finger was most convenient.

$P_{2,right}$: I was able to quickly flip through them [game events] without having to take my eyes off the game log box [with the *next-to-timeline* feedback].

However, as seven participants pointed out, this setup provided little context of the overall game state and the timeline was disconnected from the game. $P_{3,middle}$'s comment illustrated this problem:

$P_{3,middle}$: having information only in the log [timeline] lacks the direct feedback of having information available on the board.

Feedback on The Game Board

On-board feedback allowed for greater awareness of the surrounding cities to a game event, and thus, provided more contextual information to a particular game event, as commented by six players. However, this setup was the least favourite condition for 58% of the participants. Participants reported that the tabletop surface was large (3 players) and visually searching for the feedback was difficult (8 players). $P_{1,left}$ precisely summarized the trade-off between contextual information and search time with the following comment:

$P_{1,left}$: The highlights gave geographic context while taking longer to locate.

On the other hand, having feedback on the board sometimes created confusion over who triggered the replay animation, as commented by 6 players. $P_{11,left}$ commented that:

$P_{11,left}$: on the game board makes things clearer, where people are in relation to the site in question, etc, but gets distracting when three different people are querying.

Moreover, players sometimes confused replay animation triggered by other players as system automated changes. For example, $P_{3,middle}$ commented that

$P_{3,middle}$: when displaying information on the game board it was occasionally confusing if it was someone triggering log information or a game action taking place.

We also observed this confusion during the configurable version, and it impacted players' choice of feedback location during the gameplay. Section 4.2 provides more details to the behaviour change.

Feedback at Both Locations

Feedback in *both* locations was ranked as the favorite setup by 81% of the players. This was the best of both worlds as it supported duplicate information and allowed for both quick navigation and geographical context. The following participants' comments illustrated the benefits of the *both* setup:

$P_{1,left}$: The combination of the two allowed for both immediately accessible feedback as well as more information if needed.

$P_{11,middle}$: Information displayed on both the board and near the log was the most useful, since I could see information quickly while still seeing what area of the board was being affected.

$P_{8,middle}$: Seeing the log [the information] in both the game log and the board makes it easier to see where future potential outbreaks could happen.

As participants commented on the searching time and contextual information trade-off for the *on-board* setup, we ran an RM-ANOVA on the time spent per turn, calculated as the time between the end of system animation and when the next player made the first move. This analysis revealed a significant main effect of *feedback location* ($F_{2,20} = 4.2$, $p = .03$). Post-hoc pairwise comparisons showed that players spent more time between each turn with *on-board* feedback than with feedback in *both* locations ($p = .03$). This result suggests that players spent more time searching for and understanding the automation results when they were using timelines with only *on-board* feedback.

4.1.3 Group Interaction

During the study, we observed that as a group, situation awareness seemed to be very high, although individual players may not have a comprehensive knowledge of the game state. Thus, we decided to further investigate this phenomenon by analyzing the groups' situation awareness. We were also interested in how participants' usage of timeline affected other participants' situation awareness. Specifically, we investigated the difference in interaction count and situation awareness for the primary users of the timelines (drivers) in the *shared* condition versus for the non-drivers and players using *individual* timelines.

Combined Situation Awareness

We calculated a group situation awareness score by taking the best situation awareness score achieved by any one member for each question and then taking the average of these best scores. We ran a RM-ANOVA on this data. The results showed that the main effect of *control placement* was not significant ($F_{1,10} < .1$, $p = .94$, $\eta_p^2 < .1$) nor was the *feedback location* ($F_{2,20} = 1.2$, $p = .33$, $\eta_p^2 = .11$). All groups scored high in situation awareness ($M = .87$, $SD = .06$).

Shared Interaction with Timelines

Although there were no main effects of the design factors on the group SA, we observed qualitative differences in how groups processed automated changes for *shared* and *individual* controls. When a timeline was *shared*, players interacted with the timeline as a group. One player was typically the primary user for interacting with the timeline (i.e., the driver). The rest of the group was watching, narrating, and understanding the game together. The following excerpt illustrates how players narrated together while trying to understand the automation results with a s*hared* timeline:

[After seeing an epidemic animation, players were discussing strategy]
$P_{6,left}$: Is an epidemic due?
$P_{6,middle}$: [Touched timeline on epidemic city] It's there [Epidemic animation played on the board @ Miami]
$P_{6,left}$: Yeah
$P_{6,middle}$: Then 3 more black [cubes]. [Continued to touch the timeline]. Algiers
All players: Karachi and Istanbul.

Since drivers were the primary people interacting, they had a higher interaction count than the non-drivers (see Figure 4-3, right). Figure 4-3 depicts the average interaction counts for drivers in *shared*, non-drivers in *shared*, and players in *individual*, and it illustrates that the drivers in *shared* have similar level of interaction count (14.9) as the players in *individual* (12.5).

We were then interested in understanding how the drivers' situation awareness impacted other players (i.e., the differences between player types). We performed a 3 *feedback location* × 2 *player type* RM-ANOVA on averaged individual SA scores per player type. The main effect of *player type* was not significant ($F_{1,5} = 2.93$, $p = .15$, $\eta_p^2 = .37$), see Figure 4-2, right. The *feedback location* ($F_{2,10} = .15$, $p = .86$, $\eta_p^2 = .03$) was not significant, either. This result extends our earlier correlation between SA and interaction count, suggesting that interactions of drivers still led to higher awareness in non-drivers. Together with the observation that players using shared timeline tended to explore the automated changes sequentially as a group, we believe that while the driver was interacting with the timeline, all group members were actively engaged in the process.

Individual Exploration with Timelines

With *individual* timelines, participants tended to explore the automation results simultaneously to work together to understand the game state. The following excerpt illustrates players working together to collect information from their individual timelines to investigate automation results:

$P_{8,right}$: Did Ho Chi Minh get hit as well? [Tapped on the Ho Chi Minh game event on P22's timeline] and what was the yellow one?

$P_{8,middle}$: [Tapped on the yellow game event next to Ho Chi Minh on $P_{8,middle}$'s timeline] Lima.

As the previous section discussed, the situation awareness for drivers and non-drivers in *shared* was not significantly different. However, players in *individual* had higher situation awareness than players in *shared*. Together with the observation that players in the *individual* condition often conducted simultaneous investigations, supporting participants with individual timelines may better support their awareness needs.

4.2 Phase 2 Findings

The Phase 1 analysis revealed that groups' combined situation awareness scores were high, and there were no main effects across different design alternatives. Moreover, there was no difference in the individual situation awareness score between the drivers and non-drivers of the timelines. We hypothesized that the information participants gathered from the timelines was shared with the group; thus, the non-drivers benefited from the drivers' interactions. Moreover, participants might have gathered situation awareness information through other components in the tabletop interface. Thus, we decided to follow-up with video analysis on the Phase 2 data to better understand how participants used various system features, including the timelines, to maintain situation awareness.

The frequencies of the coded instances were visualized with graphs and tables using Tableau[16] (see Appendix B.17). These visualizations helped to recognize different patterns of usage. Overall, the video coding process revealed participants' usage of various timeline alternatives and how they used the timelines to support their situation awareness, group discussions, and strategizing. In this section, we first describe the timeline configurations used by participants. Next, we provide an overview to how various system features were used for situation awareness maintenance. We then describe the details of system feature usages in each of the three situation awareness levels.

4.2.1 Timeline Configurations

To understand the usage patterns of the interactive event timelines, we examined the percentage of time each feedback mode was kept for individuals and groups in Phase 2. Our data analysis revealed that participants made use of the configurable timelines, and kept it open for most of the time. In Phase 2, participants could choose the timeline configurations at any time so we further examined the configurations used to understand the utilities of the c*ontrol placement* and *feedback location* factors. We calculated the time that players spent based on the number of timelines open, and the results showed that three timelines were open in the interface most of the time (M = 85.30%, SD = 27.37%), followed by two timelines (M = 10.51%, SD = 15.62%), one timeline (M = 3.80%, SD = 12.35%), and no timeline (M = 0.38%, SD =1.14%). Upon further investigation of this data, it was apparent that most participants had their timelines open throughout the gameplay, with the exception of two participants, both from the same group. One did not use the timeline and kept it closed during the game, and another opened and closed the timeline frequently, leading to the instances of one and two timelines respectively (the third group member kept her timeline open most of the time). On average, participants interacted with the timeline 14.00 times (SD = 8.71, Min = 0, Max = 29) across the entire playthrough of the game. Since participants were playing a collaborative game, they could often rely

[16] http://www.tableau.com/

on their teammates to understand the game state through discussion, rather than interacting with the timelines.

We then investigated the percent of time each feedback mode was kept on. When participants first started the gameplay, the timelines were set to show no feedback and were closed. However, if the game crashed and restarted (happened to two groups), the timelines were opened with both feedback locations on by default. The time during game crash was excluded from the analysis. For one group, the participants' timeline configurations before and after the game crash were different, and they did not all reconfigure their timelines. Thus, for this group, the time after the game crash was excluded.

As depicted in Figure 4-4 Left, *Both* feedback was the most popular mode (M = 60.82%, SD = 42.02%), followed by *Timeline Only* (M = 30.05%, SD = 40.32%) and *Closed* (M = 6.38%, SD = 17.93%). *Board Only* feedback (M = 1.37%, SD = 7.31%) and *None* (while the timeline was open) (M = 1.37%, SD = 1.59%) were the least kept mode. This distribution was consistent with participants' feedback and our observations, since the *Both* configuration was also rated as most preferred in Phase 1. Some participants reported interference between their own feedback and others' feedback on the board, which was likely why the second-most frequent configuration was *Timeline Only*. While one player used *Board Only* more extensively ($P_{4,right}$: 14.35 minutes), the rest of the participants almost never kept their timelines in this mode (M = 2.6 seconds, SD = 3.69 seconds). This was likely due to the need to search for the replay animation on the map as well as to avoid the interference problem. Although the percentage of time in the *None* configuration might be a result of intermediate time between toggling feedback locations, the video analysis presented in Section 4.2.3 below showed some benefits of the timeline as a static visualization.

Participants occasionally switched to different timeline alternatives throughout the game, but it was difficult to determine their intention based on the observable actions as there was no verbal explanation in most cases (only 6/31 cases could be clearly identified as related to understanding automated events).

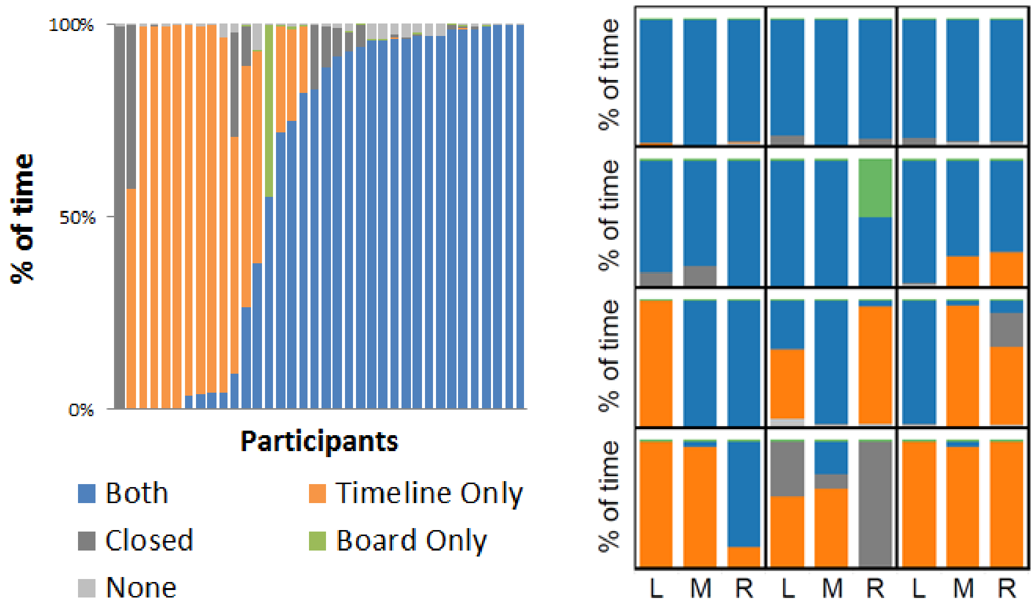


Figure 4-4: Percentage of time each timeline configuration was kept by each participant. Left) Sorted by percentage of time a participant kept the Both configuration. Right) Sorted by the average percentage of time a group kept the Both configuration. Each cell shows a group (12 groups in total) and each bar shows one participant, arranged by their seats (L: Left, M: Middle; R: right).

We further examined participants' usage of timeline configurations as groups, and found that most groups had at least one player keeping *Both* feedback mode on for most of the gameplay (see Figure 4-4 Right). The last three groups (Group 2, 5, and 8 on the last row of Figure 4-4 Right) all explicitly discussed the potential interference of displaying feedback on the map, while participants in Group 2 specifically agreed that only one player would be displaying feedback on the map.

4.2.2 System Feature Usage for Maintaining Situation Awareness

As the timeline was designed to improve users' situation awareness of dynamic changes, we examined the usage of the timelines in supporting the three levels of situation awareness (i.e., perception, comprehension, and projection) as defined by Endsley (1995). The first level of situation awareness, perception, refers to the knowledge of the changes that happened. In the context of the digital Pandemic game, the perception level refers to knowing what the dynamic changes are, as well as whether the new changes are casual. The comprehension level refers to participants' understanding of the overall situation and of the changes that they just learn about to know their significance. Finally, the projection level refers to making predictions about the future game states.

The three levels of situation awareness are internal cognitive processes. Thus, they are not directly observable without participants' verbal communication, physical interaction with the application interface, and visible body language. For example, participants may be exploring the timeline and thinking about the automated game events' impact on the overall game state. However, without verbal communication, it is impossible to definitely determine whether the interaction facilitated participants' comprehension. For this reason, few observable actions occurred for the comprehension level. Moreover, we incorporated decision making into the third level, projection, although it was originally modeled as a separate process by Endsley (1995). Participants' strategizing and prioritization behaviour represented participants' decisions in response to their projection of future game states. Since our data only recorded participants' visible and audible behaviours, we were constrained to determining how the timelines supported situation awareness based on observable actions.

We were also interested in how other system features were used for maintaining situation awareness. The video analysis revealed that the game map and the discard pile were the most relevant features used by participants. The game map included the connected cities as well as all information contained within it, e.g., the disease cubes on cities, locations of player pawns, and system animations that highlighted particular cities. The discard pile contained a limited historical log of cities infected by automated events, and it was periodically emptied after epidemic events. It could be opened by tapping on a button, as previously described in Section 3.5.2 above.

In the following sections, we present data pertinent to how the timelines, the game map, and the discard pile were used by our participants to gather situation awareness information for each level of situation awareness: perception, comprehension, and projection (as depicted in Figure 4-5, Figure 4-6, and Figure 4-7).

4.2.3 Perception

At the end of each game turn, the system automated the drawing of new player cards (i.e., shared resources) and the new disease infections on the game map (i.e., changes in the system state). The new changes were reflected on the associated cities and were highlighted on the map by a brief system animation. Moreover, they were appended to the timelines (players had to tap on the new changes to see the associated locations). Participants should aim to find out the types of events that took place, their locations and quantity, and if the events were causal.

The analysis revealed both static and interactive uses of the timeline. For simple automated changes, participants observed both the system animations and the timelines to gain awareness of dynamic changes. However, participants sometimes only caught parts of complex changes or completely missed the changes, and the timelines were then used to investigate the changes. The timelines were considered as the correct historical account, and were used to negotiate participants' knowledge especially for complex changes. This section describes the strategies employed by the participants for perceiving simple and complex changes, as depicted in Figure 4-5.

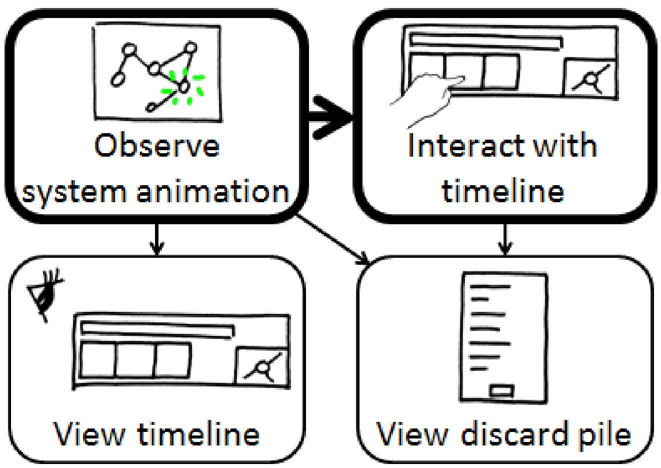
Perception	
System Feature Usage	Communication
	• Narrated new changes based on observations and interactions • Discussed with the team to fully perceive the changes

Figure 4-5: System feature usage and player communication at the perception level. At the perception level, participants typically first observed system animations and then interacted with their timelines to verify or further investigate changes. Changes were often narrated, and participants also discussed changes based on information gathered to negotiate their knowledge.

Observations First Then Interactions

Participants often narrated new changes as the system animations appeared on the game map. Due to the large size of the tabletop display and the fact that players were not constantly attending to the interface during gameplay, players sometimes missed seeing the system animations in time or only noticed that some changes took place without knowing the details (e.g., they noticed an animation occurring in their peripheral view). Complex changes that involved chained events could also be difficult to follow. Thus, participants typically first observed the available feedback then interacted with the timelines. For example, after the system finished animating changes on the map, $P_{1,middle}$ noticed a new epidemic event but did not know the exact associated cities from observing the map. He said to the group: “hmm… Something went pop!” He then used his timeline to locate the epidemic event by tapping on the event and narrated the result to the group: “San Francisco.” As he had *Both* feedback on, $P_{1,left}$ then pointed at the replay animation triggered and said: “right here.”

The design of the timeline was useful as a static visualization for perceiving new changes, especially because it automatically scrolled to show the current turn and placed the changes in a readily accessible location for users. There were only 9/333 cases of such usage that we coded. The actual usage could be much higher due to the constraints in precisely determining the eye gazes of participants (see Table 4-1).

Usage Categories	**Counts**
Tap on events in the current turn	272
Navigate to and interact with historical events	22
Learn to use the timeline	14
Interact with the timeline for fun	10
View the timeline (static usage without interaction)	9
Count critical events on the overview bar of the timeline	6
Total	**333**

Table 4-1: Summary of timeline usage counts. Interacting with current turn game events was the most common type of timeline usage.

Although the visual design of the timeline did not provide detailed location information of the game events, the colour-coding of game events provided a general sense of regions. The icons indicated the types of events (i.e., infection, outbreak, or epidemic), and the amount of game events provided a hint to the complexity of changes. Moreover, there were a few cases where participants opened and closed their timelines only to view the changes without interacting with any specific game events (evident from their narrations). Participants sometimes narrated the colour of the player cards (shared resources) received by collaborators, showing the value of providing awareness of the changes in shared resources automated by the system. As users tended to first observe without any interactions, making changes apparent is important. While this strategy was effective for simple changes, more complex changes often required interactions with various system features.

Interact to Resolve Complex Events

For complex disease spread, participants' process of learning the changes was often a joint, iterative effort among the team members. While the game map provided a reference to the current system state and allowed participants to notice changes, the timelines were the main tools for participants to understand how the system automation arrived at the new state, see the *observe system animation* to *interact with timeline* states in Figure 4-5.

Participants interacted with the timelines to verify what they observed on the game map or what they overheard from collaborators. The timeline was also used to investigate new changes. This was the most common type of timeline usage (272/333 cases). It was also common for multiple players to investigate their timelines and announce the results at the same time. We hypothesize that players did so to make sure they, as a group, had the correct knowledge of the automation that took place.

When a group was confused with complex changes reflected on the game map, they used the timelines to investigate and verbalized their perceptions to negotiate and reach a common ground of the events that happened. In this process, the timelines were considered as the "correct" history and were used to correct each other's "theories" of the changes. For example, while the system animation was still playing, $P_{3, \text{right}}$ noticed that two outbreak events just took place by viewing his timeline, and he announced this to the group. As there were two outbreak events, participants tried to determine if one caused the other. It was a complex event as three types of events happened during the same turn: an epidemic event at Chennai, two independent outbreak events at Bangkok and New York, and an infection event at Moscow. As $P_{3, \text{right}}$ was investigating this on his timeline, the rest of the team looked at the game map on which they could see the new disease-spread system animation that was still playing, in addition to the replay animations triggered by $P_{3, \text{right}}$. After $P_{3, \text{right}}$ identified that the first outbreak event occurred at Bangkok, by checking his timeline, $P_{3, \text{left}}$ mistakenly thought that it caused a chained outbreak event in Chennai. $P_{3, \text{middle}}$ then jumped in and tapped on the second game event with an outbreak icon, and this triggered a replay animation on the game map at New York. $P_{3, \text{right}}$ then continued to check game events on the timeline but provided an incorrect reasoning to why the two outbreaks were not chained. As $P_{3,\ right}$ had an incorrect reasoning, $P_{3,\ left}$ finally started interacting with the game events on his timeline and announced the correct set of events that took place: “It's with Bangkok and then New York. Those are the two outbreaks.” This observation showed the importance of the timelines for the correct perception of changes.

Our results showed that some participants appreciated the replay animation on the game map and commented that it was beneficial for keeping track of others’ exploration on their timelines. However, some also noted that it distracted and confused them. Although the system animation and replay animation looked different (see Figure 3-3F and Figure 3-4K for an example), participants had difficulties distinguishing these two types of animations quickly. For example, $P_{5,\ left}$ mistook the animation triggered by $P_{5,\ middle}$ as new outbreaks by the system, and announced “Bogota just outbroke!” He then quickly realized that it was a replay animation triggered by $P_{5,\ middle}$, and said “oh no, you are just smashing things. I hate you! I hate the board thing! Turn your board off, please!” $P_{5,\ middle}$ then turned off the feedback on the map. This confusion resulted in a negative response to the replay animation feature. Participants continued their discussion and pointed out that the key issue was the lack of awareness of collaborators’ actions.

$P_{5,left}$: Inform us when you are going to turn it on; otherwise, I go, ‘oh no Bogota just outbroke!’

$P_{5,right}$: It’s kinda funny, but I also found it distracting when people do it.

$P_{5,left}$: It’s okay as long as you tell people you are doing it.

Due to the potential interference, some players manually toggled the feedback locations. However, this resulted in mode errors (Sellen et al., 1992) where participants forgot about the current timeline mode and were confused when the replay animations were not triggered on the game map. Such observation showed a need to provide further support for workspace awareness of collaborators’ timeline interactions.

The discard pile system feature was used for perceiving new changes as well, although infrequently (8 cases vs. 281 cases for timelines). In 3 of these 8 cases, the discard pile was used in conjunction with the timeline to verify the changes. For example, after new changes took place during one group’s gameplay, $P_{9,\ middle}$ was confused about why there was an additional disease cube on Moscow. He first navigated through the game history on his timeline to find out when it first happened. $P_{9,\ left}$ then opened the discard pile to check. Then, $P_{9,\ middle}$ and $P_{9,\ left}$ found that the Moscow card was drawn and thus had a new disease in the most recent turn through the timeline and the discard pile, respectively. The discard pile acted as an alternative information source.

Overall, players reached the correct perception of the automated events most of the time (293/397 cases, 68.26%) even though participants had to correct themselves or each other in 22/293 cases, 7.51%. There were 99/397, 24.94%, cases in which we were unable to determine whether their perceptions of changes were correct and 5/397 cases, 1.26%, where participants gained incorrect information or could not find the information needed.

The analysis also revealed that the participants employed flexible work patterns. Participants sometimes ignored the system animations and continued to discuss strategies. Moreover, since advance planning of actions was common and necessary in the game, the current player sometimes focused on executing the actions agreed upon by the entire group beforehand, and relied on team members to observe and report the new changes. This finding showed the importance of providing persistent timelines for individuals to enable such flexible work patterns.

4.2.4 Comprehension

With the new changes explored, the comprehension level refers to making sense of the new changes and the overall game state. The players should seek to determine how the new changes impact the overall game state. As participants were all experienced Pandemic game players, they generally understood the meaning of the changes. In some cases, the new changes did not have urgent impacts on the game state, while in other cases participants started strategizing about how to address the changes right away. We based our analysis on observable behaviours, and our data showed that the game map was used as a reference point for the groups to comprehend the overall game state.

The game map was the most frequently used feature in the comprehension level to understand the overall state as well as to detect inconsistencies in their understanding of the game state, as depicted in Figure 4-6. After new changes took place, participants commented on overall game state based on the game map. For example, in one session, $P_{5,\ middle}$ commented on the overall spread of the blue colour diseases on the game map: “Oh my goodness, there’s a lot of blue going on!”.

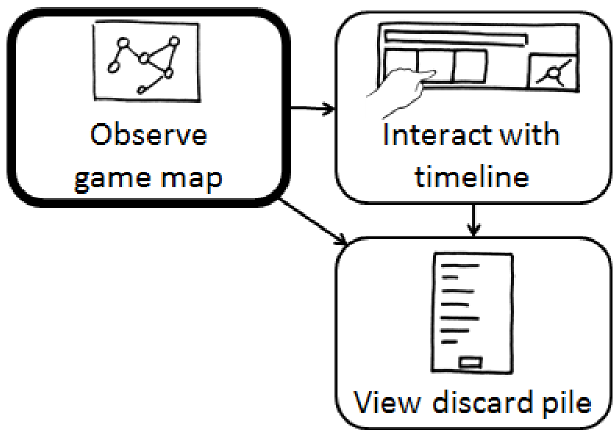
Comprehension	
System Feature Usage	Communication
	• Commented on overall game state • Clarified inconsistencies found on the game map

Figure 4-6: System feature usage and player communication at the comprehension level. At the comprehension level, the game map was used most frequently to discover inconsistencies between participants' understanding of the game state and the actual game state. The timelines and the discard pile were then used to gather information, which allowed them to collaboratively understand the game state.

The game map was sometimes used in conjunction with the discard pile and the timelines for players to correct their understanding of the system state. For example, $P_{1,right}$ noticed that on the map Bogota had more disease cubes on it than expected, and she asked "have we been noticing that Bogota is a problem?" Then, $P_{1,left}$ opened the discard pile for the entire group to view, and $P_{1,middle}$ looked at the discard pile and clarified that "no, it's just out [in the last turn]."

In another example, after new changes took place, $P_{3,right}$ first checked his timeline. Later on, while inspecting the game map, he found that the narrated events were inconsistent with the number of disease cubes on the map. This prompted $P_{3,right}$ to further investigate using his timeline to correct the group's knowledge, and he announced the correction to the group. Overall, the game map provided an overview of the situation for the comprehension of changes and understanding of the system state.

By the end of the comprehension stage, participants had usually reached agreement about the changes that took place and their meanings to the game. Next, they negotiated with each other on the strategies and on which actions to prioritize

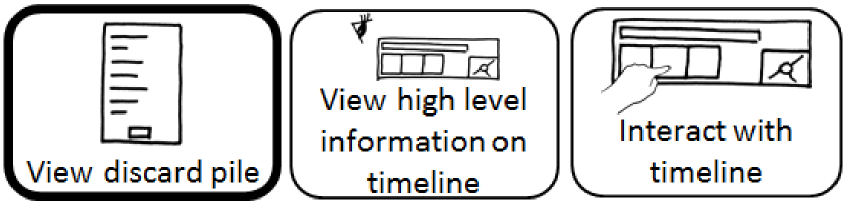
Projection	
System Feature Usage	Communication
	• Negotiated strategies

Figure 4-7: System feature usage and player communication at the projection level. At the projection level, the discard pile was used most frequently to prioritize actions, and participants negotiated their strategies with each other based on the information gathered. The timelines were beneficial for participants to view high level information, but they were used less frequently.

4.2.5 Projection

The projection level refers to predicting the future game states. Generally, in Pandemic, players need to strategize based on when critical events would happen at which locations. This information can be estimated based on the current and past disease spread as well as when previous critical events take place. During the gameplays, our participants strategized, prioritized actions, and managed resources, based on their predictions. While the timeline and the discard pile were both the key system features used to help remember historical events and forecast future game states, the discard pile was the primary feature used, as depicted in Figure 4-7.

We found that the timelines provided high-level information that was beneficial for forecasting game states. For example, players counted the number of turns since the last epidemic event using the overview bar at the top of the timelines (6/333 cases of timeline interactions). As a fix number of epidemic events was roughly, evenly distributed in the game, the number of turns since the last epidemic was a good predictor of the next epidemic event. Epidemic events signaled that previous infected cities may be infected again soon to create wider disease spread, so it was important for players to accurately predict when the next epidemic event might occur and adapt their strategies accordingly. Players also navigated through historical events to determine if any cities might be potential problems in the future. Since all other system features only provided limited amounts of historical information (e.g., the discard pile only listed the infected cities since the last epidemic event), players had to rely on the timelines for much older events.

The analysis showed that very few timeline interactions were conducted for the purpose of strategizing (used only 6 times in 88 cases of prioritization). The amount of effort required to navigate through many game turns to locate the target game event likely contributed to the limited use of the timeline for this purpose. More often, participants opened and read the content of the discard pile to prioritize their actions (used 82 times). The discard pile provided a quick way to access recent cities that were affected by disease spreads by providing all information in a single textual log with minimal interaction required (other than to open, and potentially reposition the widget). This information allowed players to decide which cities needed more attention by comparing cities in the discard pile and the current game state on the map. This shows that the design of such a textual log was more beneficial for the projection level of situation awareness.

The following example illustrates a usage of the discard pile for the purpose of prioritizing actions. $P_{1,middle}$ went through a list of cities that could potentially create outbreaks based on the current game state (i.e., cities that needed more urgent attention). $P_{1,middle}$ first named Moscow and $P_{1,left}$ opened the discard pile for the entire group to see (default location was at the centre of the map). After confirming that it was not in the discard pile and thus was potentially high in priority, $P_{1,middle}$ continued to inquire the group about the status of Mumbai and Bangkok. $P_{1,left}$ opened the discard pile again, and $P_{1,right}$ viewed the discard pile and confirmed that they were in the pile, meaning that players only needed to attend to them when the next epidemic event was near. $P_{1,middle}$ thus concluded that Moscow was the only problematic city: “which is to say, Moscow is the only thing [to be concerned about].” $P_{1,left}$ agreed and reiterated on the urgency of Moscow: “that [Moscow] really needs to be dealt with right now.” Players then continued to discuss how to spend actions to move to Moscow, and eventually treated diseases on Moscow in the same turn.

The discard pile was sometimes used as a tool to suggest potential actions to consider. However, this sometimes failed because there was too much information to parse through (i.e., too many cards in the discard pile), or it was simply not helpful due to the game state at the time.

4.3 Discussion

Based on our findings in participants’ usage of the interactive event timelines and the timelines’ impacts on situation awareness for a decision-making-and-planning task, this section presents the lessons learned in supporting awareness of co-located collaborative task on digital tabletop systems.

4.3.1 Promote Interactivity

The statistical analysis in Phase 1 revealed that the participants with *individual* timelines interacted with their timelines more and had higher situation awareness than participants with *shared* timelines. Furthermore, situation awareness and the amount of interaction were positively correlated. Our results suggest that that more interactions with the timelines can improve situation awareness. While the participants observed the system animation to perceive new changes, it was insufficient for complex automated changes. Interactions with the timelines facilitated the perception level of situation awareness, and the timelines were also the most used system feature for perception. This further showed the benefits of the timelines as an interactive display for perceiving complex changes. The design of collaborative tabletop applications involving automation should consider promoting this kind of interaction for complex changes. Based on our study results, individual awareness displays that can be accessed conveniently and simultaneously are more effective.

Shared and *individual* timelines changed how participants resolved new automated changes. Participants in the *shared* condition employed a more sequential and tightly coupled approach to understand new changes, while *individual* controls allowed for more and simultaneous interactions. The *shared* timelines resulted in a process that more closely resembled the physical gameplay, while the individual timelines allowed for a higher level of situation awareness without requiring the same amount of manual work needed in the physical version of the game. This shows a promising direction for improving situation awareness of automated changes driven by computer systems. Processing all new updates manually and updating them for the group to stay aware of the situation are physically demanding. Although automated changes can reduce the physical workload, it also changes the previously familiar tasks. Without appropriate feedback, staying aware of the system changes can be cognitively difficult. Designers must consider the design of the awareness feedback and allow for flexible interactions with the feedback in a group setting to fully leverage the benefits of automation.

4.3.2 Perception: Make Changes Readily Available

The timelines were mainly used for perceiving new automated changes, and several aspects of the timelines helped participants gather this information. The timelines appended new changes and automatically scrolled to the current turn, making the most recent information readily available for exploration. The visual design of the timelines structured the game events based on their types into three rows (i.e., player action vs. system automations) to facilitate the process of locating game events. The colour-coding and icons provided overview information. Moreover, each timeline was placed at an individual's personal area to provide quick access to new changes, both visually and physically.

In contrast, the discard pile was used less frequently for perceiving new changes, and this may be due to the fact that reaching out to open the discard pile took more physical effort or required more coordination to ask the player on the left (the position closest to the discard pile button) to open it. The convenience factor may also explain why the shared timelines were used less frequently and resulted in lower situation awareness in Phase 1 of the study.

In light of the benefits of the timelines, potential redesign may consider how to further streamline the perception of new changes. For example, presenting detailed information of the most recent changes on the timeline can help minimize the interactions needed for investigations.

4.3.3 Projection: Provide Critical Event Overview and Summary View

While the overview of critical events on the timelines helped participants determine the overall strategies, the discard pile was used much more for forecasting events and prioritizing actions. The interactivity of the timelines was beneficial for reducing clutter. However, it required a high level of cognitive and physical effort for users to gain an overview of the historical events to predict the relative urgency of problems. Moreover, the discard pile appeared by default at the centre of the game map, and this might have better facilitated information sharing and strategizing for a tightly coupled collaboration (Tang, Tory, et al., 2006) such as in our context.

Future designs of tabletop applications involving dynamic changes should consider providing a way for users to get the overall picture of the historical information quickly and in a manner convenient to share. The application may provide a separate feature for a summary view of recent events or the timelines may incorporate a different view to support projection of future system states.

4.3.4 Support Awareness of Collaborators' Commands

The interactive timeline provided information of the participants' game actions that had permanent impacts on the game states. However, the participants' game actions on the timelines were rarely checked by the collaborators. Most of the timeline usage was related to system automated events. This may be attributed to the fact that since the collaboration style was tightly coupled, players could remember each other's actions within the one game session. While the historical information on automation demonstrated its value, providing collaborators' previous commands may not be worthwhile the screen space for a tightly coupled collaborative work. However, consider timeline usage for debriefing purpose or cases when users step aside from the tabletop temporarily, the collaborators' commands are still beneficial for those contexts.

We observed that there was a need to provide more awareness of the shared resources. The current system provided limited support for participants to get a sense of the player cards other collaborators had. Participants viewed and interacted with the timelines to perceive the player cards other participants just received from the system automation. Through frequent communication and physically leaning toward other players' hands to see them, players got a sense of the overall composition of each other's hands. They then strategized based on the cards they each possessed. Although participants each owned a hand of cards, the player cards were essentially shared resources in the context of this game. Our observation indicated a need to support a more holistic view of the shared resources for management. This is also consistent with the idea of providing a summary view of the historical events.

4.3.5 Support Flexible Work Patterns with Individual Timelines

When given configurable timelines in Phase 2, participants primarily chose to keep their timelines open. Our data analysis revealed several work patterns in this setting. Although groups' collaboration styles were mostly tightly coupled, they often investigated their timelines concurrently to investigate changes and verify information observed from the game map or overheard from other players. Moreover, they sometimes split the workloads by having one participant carry out strategies previously agreed upon and having the rest of the team investigate changes. Phase 1 and Phase 2 data analysis revealed the benefits of individual timelines on improved situation awareness as well as the flexibility to allow participants to investigate changes at their own pace. Moreover, the configurable timelines allowed users to toggle the feedback locations. This feature allowed the groups to use different strategies for invoking highlights on the shared tabletop workspace as a group, and allowed for different strategies across groups.

Designers should consider the interplay between the design of awareness support and groups' work patterns. In collaborative tabletop systems, the timelines as persistent awareness displays provided flexibility in terms of the pace of work. In Phase 2, the analysis showed that participants sometimes noticed the system animations with their peripheral vision, but did not capture the details of changes in time. This is consistent with what we observed in the training session and what Wallace et al. (2012) observed in another version of the digital Pandemic game. By using animations as the only feedback mechanism for displaying new changes, it enforced players to pay attention to it during a limited timeframe. If players missed it, then they had to visually search the tabletop interface or discuss with other team members to determine the changes. Thus, such feedback would be inappropriate for displaying dynamic changes, and leads to low situation awareness as Endsley (1996) pointed out.

4.3.6 Timelines for Supporting Group Work

The timelines were designed to support situation awareness for collaborative work. Participants exhibited different behaviours in their timeline usages as a group. They sometimes relied on other players to interact with the timelines and report the findings, rather than always checking the timelines. For some other instances, participants investigated simultaneously and worked together to form a complete picture of the automated changes. These results show that participants can also benefit from other players' interactions with the timelines, and the timelines were used collaboratively to achieve higher performances.

Our analysis revealed that the timelines were often used in conjunction with the game map. While the game map reflected the current system state and helped participants notice new changes, the timelines were used primarily as the correct historical accounts to negotiate users' perceptions of the changes.

We designed the replay animation as a way for users to gain more detailed information of new changes and as a way to virtually point on the map for information sharing. While both use cases were found in the data, there were only a few clearly observable instances. Participants mostly physically pointed at the game map to aid their conversations, and we believe that this is due to the turn-based nature of the game and the difficulties in searching for the replay animation due to the current design and the large size of tabletop displays. Designers may consider how to support the need of sharing findings from explorations.

Moreover, the replay animation sometimes confused the participants and they mistook the replay animation as showing new system automated events. Since replay feedback on the map and map cut-out on the timeline were the most popular configurations, future designs should incorporate more direct identity information in the workspace awareness cues for the replay animation to facilitate feedthrough (Pinelle et al., 2003). Consider participants' feedback in Phase 1 that the timelines felt disconnected from the game, we may consider a design where the timelines are visually associated with the replay animation to create a redundant encoding of invoker identity and to allow for quicker associations. Furthermore, as participants tried to manually manage the feedback locations, they sometimes forgot about their current setting. As a result, they were confused about why their replay animations did not show up on the game map. A potential solution would be to use a user-maintained mode (Sellen et al., 1992) for the replay animation, meaning that users need to trigger the replay animation every time for it to play on the shared workspace. For example, touches and taps on the game events would only show feedback in the map cut-out on the timelines. Dwell interactions would show feedback on the timelines and trigger replay animations on the map. This design concept can provide more flexible controls of feedback locations without manually toggling the feedback mode.

4.4 Summary and Further Exploration on Workspace Awareness

We investigated the impacts of *control placement* and *feedback location* on situation awareness and the usage of interactive event timelines through a laboratory study using the Pandemic game. Our data analysis showed that the timelines were beneficial for situation awareness maintenance. Moreover, individual timelines supported flexible work patterns and allowed for higher levels of situation awareness. However, the replay animation triggered by individual users sometimes confused the collaborators even though it was designed to be visually distinctive from the system animations triggered by automation. These findings suggested that the feedback for collaborators' current interactions still needed further investigation and improvements. Moreover, the awareness cue design needed to balance between providing essential awareness information and reducing its distractions to the collaborative work. Thus, we decided to follow up with a second study that focused on workspace awareness and investigated a practical awareness cue design for collaborators to stay aware of each other's actions.

4.4.1 Exploring Workspace Awareness in Multi-Device Classrooms

A multi-device classroom context was chosen as the environment for the follow-up study for several reasons. First, studying another co-located workspace allowed us to combine the insights from both investigations and provide a set of more generalized design recommendations for awareness support in co-located environments. Second, although tabletop systems can augment face-to-face collaboration with digital capabilities, they have several limitations including the difficulties in scaling for collaboration of large groups and in allowing for shared and individual work concurrently. In multi-device classrooms, students have individual devices and are connected through a virtual collaborative workspace. Minimizing the constraint of the physical tabletop sizes, larger groups of co-located users can work together concurrently, and they can carry out individual work through their own devices. Third, individual devices are already ubiquitous in current co-located collaborative workspaces, and people often bring their personal devices to meetings. Moreover, there is also an increasing push towards introducing individual devices into classrooms to improve lesson engagement and students' collaboration skills (Project Tomorrow, 2013). Fourth, with an opportunity to collaborate with SMART Technologies[17], we were able to study a real-world application and apply our research findings to make practical impacts. While a laboratory experiment allows for precise control of the study factors and potential confounds, it provided an artificial setup. To confirm the lack of workspace awareness problems observed in the Timeline Study and to design an awareness cue with high ecological validity, we wanted to study a real-world environment with workspace awareness challenges. A real-world application and the access to teachers and students through our collaborating company allowed us to evaluate the design in the field. Finally, students in a multi-device classroom face even more challenges in maintaining workspace awareness since they may be sitting in different arrangements such as face-to-face, shoulder-to-shoulder, or in rows in a classroom. The physical separations between users can make observing each other's actions difficult as the devices may be occluded. The screens of individual devices may also be too small for users to keep track of each other's actions on their devices. Therefore, a multi-device classroom was selected as the study context for further investigating workspace awareness support in co-located technologies.

[17] http://home.smarttech.com/

Chapter 5

A Workspace Awareness Cue for Multi-Device Classrooms

In our follow-up study to understand workspace awareness support for co-located technologies, we decided to use multi-device classrooms for the benefits mentioned in Section 4.4.1[18]. In this study, we provided a workspace awareness cue, Callout Bubble, to address the students' workspace awareness deficiency. We sought to balance awareness and distractions since distraction can be a more severe problem in a multi-device classroom context. As there can be a large number of collaborators, there is a higher potential for interference between students. Although the physical separations between students make awareness maintenance difficult, providing all workspace awareness information can overwhelm students and distract them. Given that children, even during adolescence, are still developing their ability to control their attention and focus (Petersen & Posner, 2012), a chaotic workspace distracts students from their top priority: learning.

With an opportunity to collaborate with SMART Technologies[19] in Calgary, Alberta, Canada, we decided to use the SMART amp™ software as our case study. It provided a web-based shared canvas, similar to Google Docs, for students below university level to work together in class (approximately

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[18] Material ideas, figures, and tables from this chapter have previously appeared in Chang et al. (2015). Appropriate permissions have been obtained for the re-use of these materials, and can be found in Appendix D. This chapter presents collaborative work done with the collaborators mentioned in the Statement of Contribution on page vi.
[19] http://home.smarttech.com/

Figure 5-1: Posters to remind students of good behaviours in the shared canvas. The highlighted text says “Don’t shout out to the whole class” and “Practice patience with peers and technology”.

ages six to seventeen). Students could be brainstorming, solving math problems, sharing experiences, and constructing diagrams.

In this environment, students were often times very focused on their individual devices and had difficulties observing other students due to the physical distance and occlusion. In fact, based on teachers’ feedback gathered by the program manager at SMART Technologies, students experienced a high level of frustration since objects in the workspace were mysteriously moved or edited by peers. This experience was as if a ghost was sabotaging their work. Since the system did not provide any awareness information, students had to make extra effort to observe each other by going near another collaborator and asking questions verbally. Some students would shout out to the entire class. Teachers had to focus on behavioural issues by deploying various strategies such as posting signs about workspace etiquette, verbally reminding students not to shout out to the class, and asking students to be patient with peers and technology while working together (see Figure 5-1).

The student frustration was identified by the SMART amp™ product team as the top priority to address, which showed the extent of this problem for the teachers and students. However, it was unclear how to address the problem as the previous work on workspace awareness support focused on remote collaboration, and, thus, many of the awareness elements may not be applicable for a co-located setting (Gutwin & Greenberg, 2002). The previous work in multi-device environments primarily investigated providing awareness feedback on large displays, rather than on individual devices (Marquardt et al., 2012; Scott et al., 2014). As a collaborative project with SMART Technologies, the SMART amp™ environment allowed us to investigate the design of a practical workspace awareness cue for students in a multi-device classroom setting. We could also rapidly test the design with teachers and students.

We sought to develop a practical awareness cue that balanced awareness and distractions while providing the essential information. To do so, we took a highly iterative approach and consulted teachers throughout the project. We started with low fidelity sketches to explore the design space, and we evolved the design through informal testing sessions, consultations with teachers, and evaluations with teachers and students. The final design was an animated cue, Callout Bubble, which was positioned near an object and showed the identity of the interactor. The final evaluation in four classrooms provided realistic feedback on the awareness cue. Our results showed that the awareness cue was noticed, understood, and used. It did not distract students from their tasks at hand. Moreover, it allowed for coordination and self-monitoring behaviours among the students, and it in turn also reduced workloads for teachers.

The rest of this chapter first gives more information on the SMART amp™ web-application and explains the student frustration issue in more detail. The design requirements are presented next, and they were derived from observations as well as discussions with teachers and stakeholders in the company. The overall iterative design process is described next followed by a discussion on the key design changes based on the findings from evaluation conducted throughout the iterative process. Following the final classroom evaluation's study method, the study's findings are presented, focusing on the Callout Bubble's impacts on students' behaviours and teachers' classroom management. Finally, this chapter concludes with lessons learned in supporting workspace awareness in a multi-device classroom setting.

5.1 SMART amp™: Online Collaborative Workspace

SMART amp™ provided students with a collaborative learning environment, in the form of an online shared canvas (see Figure 5-2 and Figure 5-3). It was designed for multi-device classroom (or Bring-Your-Own-Device (BYOD) classrooms), and it targeted students below post-secondary levels (aged approximately from six to seventeen).

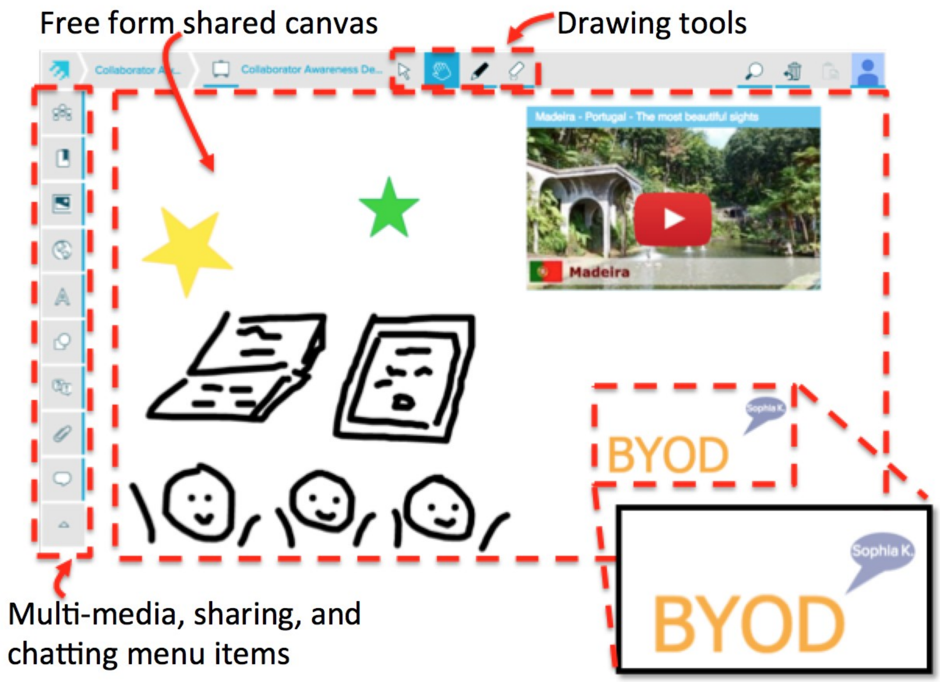

Figure 5-2: Screenshot of SMART amp^{TM}. SMART amp^{TM} was a commercial web-application, and it provided an online shared canvas for multi-device classrooms. Sophia K. was interacting with the "BYOD" text.

The primary usage scenario was that each student used a laptop or tablet in the class, and SMART amp^{TM} was a shared virtual canvas that connected all students. Teachers could also join the shared canvas on their laptops or tablets. A digital whiteboard by SMART Technologies (SMART Board) could also be connected to the workspace, but the application did not require a digital whiteboard. While the application was primarily used for co-located students in a classroom, remote students could, individually or as a group, participate with equal access. This was useful for students who were sick or had to stay home for other reasons. Small groups could work in the same or different canvases, which was useful for splitting the class into smaller groups for team activites and then converaging at a later time.

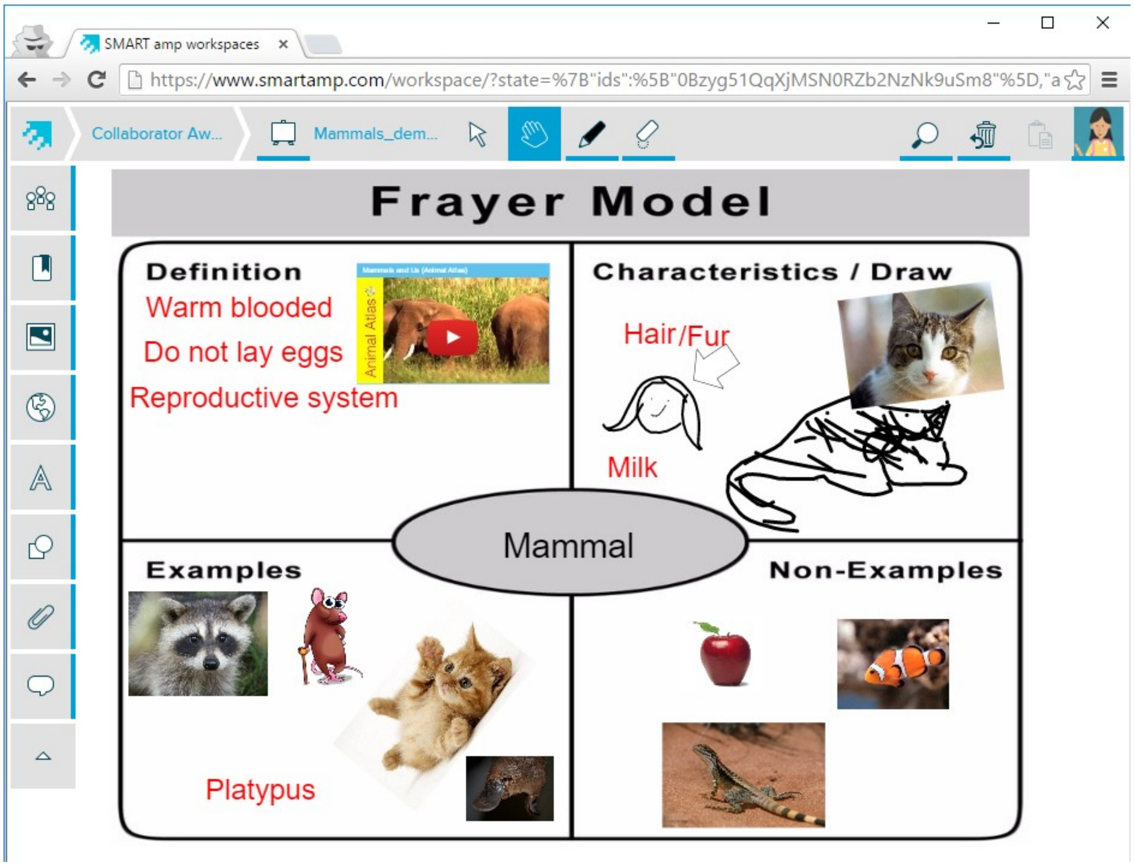

Figure 5-3: Sample usage of SMART amp™. Teachers asked students to do a variety of activities in the shared canvas. One example was to collaboratively brainstorm. In this case, a teacher pasted a Frayer model for students to brainstorm on mammals (as shown in the centre circle). Students had to answer the question in each quadrant: definition, characteristics, examples, and non-examples.

The shared canvas allowed multiple students to work together at the same time. A teacher might ask students to collaboratively brainstorm ideas, solve group questions, correct each other's writing, and construct diagrams. Figure 5-3 shows a sample usage, where a teacher asked students to collaboratively build a *Frayer model* (Educator, 2015) based on mammals, as shown in the centre text. The students needed to answer four questions on mammals: definition, characteristics, examples, and non-examples. The teachers might divide students into smaller groups to work on the same or different topics, and then converge the groups for a whole class discussion later.

In terms of the functionality of the system, students could add text, shapes, drawings, pictures, and website links as well as embed online images and videos in a free form manner. Thus, the content was not restricted to a particular order or alignment, unlike a textual document. The contents could also be moved, edited, and resized. The system also provided view controls such as pan and zoom. The system was designed with touch devices in mind including tablets and digital whiteboards. Thus, students could freely zoom and pan the view with gestures as well as sketch with fingers. A chat system was provided for student discussion within the workspace.

The original system provided limited workspace awareness support. The system reflected real-time changes done by any students within a student's view. For example, when a student moved an object from one location to another, all students connected to the same workspace saw the object moving across the screen, as opposed to seeing the object jump to the destination instantly. If a student happened to be focusing on other parts of the canvas, then they would not see this movement. This real-time update mechanism was enabled by the underlying structure, Google Realtime API[20], and any manipulation in the canvas was being broadcasted immediately. However, one drawback was that the data being transmitted must be kept at minimal since the API only allowed for a limited amount of storage space.

5.2 Issues Identified in Multi-Device Classrooms

Through discussions with teachers and in-class observations, we found that students' frustration while working in the SMART amp™ workspace was due to the following two reasons: *ghosting* and *action conflicts*.

Ghosting: Since no identity information was shown to students when their peers were adding and editing content in the workspace, objects were being moved, modified, and deleted without students' awareness or permission. Students only saw real-time updates of the manipulated object's states. This was as if a ghost was sabotaging students' work in the shared canvas.

Action conflicts: Students' manipulation of objects might collide with each other. For example, multiple students might simultaneously move the same object, or one tried to move an object while another student tried to rotate it. The underlying algorithm resolved the conflict and decided on the final results based on the timing and the type of changes conducted. However, the system did not

[20] https://developers.google.com/drive/realtime/

provide any information on the conflicting actions and why the objects changed unexpectedly seemingly caused by a student's manipulations.

Students had to verbally communicate with other students to find out who was causing problems for them, and students often yelled out to the entire class or talked in the built-in chat system to figure out. Teachers reported that the students' yelling out to the entire class was disruptive. However, resolving conflicts through chat system overflowed it and prevented it from being used for learning purposes. These problems also increased teachers' workloads in classroom management. Although students did not intentionally disrupt other students' work, the system provided no awareness information for students to prevent conflicts, leading students to unknowingly distract others and get into conflicting situations. Students only found out about the conflicts when it was too late. The lack of awareness information resulted in frustration and more coordination efforts for both teachers and students.

5.3 Design Requirements

Based on the prior research in the benefits of workspace awareness (Gutwin & Greenberg, 2000), we hypothesized that providing students with peers' interaction information would help mitigate the frustration and confusion they experienced while working together. Thus, it would allow students to focus on their tasks at hand rather than being distracted by the ghosting and action conflicts. While another potential approach was to enforce locks on objects and turn taking, teachers preferred to let students learn to respectfully collaborate in a digital environment rather than automatically enforcing a particular behaviour. Thus, we decided to pursue the direction of supporting workspace awareness of collaborators in a shared virtual canvas. Through discussions with teachers and stakeholders within the company, we derived the following requirements to guide our design process.

Balancing Awareness and Distractions

As students' main objective in the workspace is learning, the awareness cue design should not distract students from their tasks at hand. The free-form canvas could be quite cluttered so the visual design of the awareness cue needs to be noticeable and distinguishable enough while subtle enough to minimize distracting students and cluttering the workspace. Students should also be able to visually associate the cue to the correct object, given that objects may be in various orientations and may only be partially on-screen. The current literature in balancing awareness and distractions advices to creating a minimalist and abstract awareness cue (Dabbish & Kraut, 2004; Obermayer & Nugent, 2000).

Appropriate for Classrooms

As the target students' age range spanned across twelve years (from six to seventeen years old), the cue needed to be understandable and appropriate for a wide age range. The design also needed to consider students' unique work patterns. Our in-class observations revealed that, unlike adults, students were easily distracted and they rapidly and repeatedly switched between working and socializing with other students. The cue should also take teachers' pedagogy concerns into consideration and not discourage students from contributing to the workspace.

Moreover, the cue needed to be suitable for various study subjects (e.g., language, science, history, and math) as well as activity formats (e.g., individual work, small group, and large group, whole class brainstorming). In one lesson, teachers might transit between different activities and split students into smaller groups and regroup students several times. Students only had a limited amount of time in the workspaces since teachers typically utilized the class time for several activities. Thus, the awareness design should not require a lot of students' effort and time. Teachers might also use several software applications and various websites in addition to the shared canvas for one activity.

Applicable to a Wide Variety of Devices

Schools used a wide variety of laptops and tablet devices with different hardware specifications such as processor speeds and display resolutions. The awareness cue design should consider only the basic support and could not assume a certain display resolution, the presence of mouse pointers, or the existence of a hover state. The cue also needed to be efficient enough in terms of data communication and performance to account for the slower low-cost devices.

5.3.1 Conceptual Design

Based on the design requirements, we would like to provide a transient awareness cue to show the current states of objects that were being manipulated. Figure 5-4 illustrates our conceptual design. When John is manipulating an object in the workspace (e.g., text, shape, image, and video), all other students see a visual cue appearing next to the object and showing John's name, if the object is on their screen (see Figure 5-4C). The visual cue then fades away over time (see Figure 5-4D).

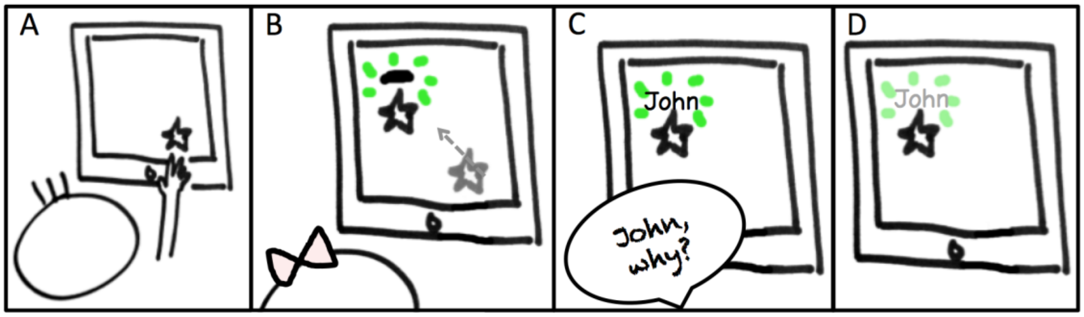

Figure 5-4: Conceptual design of the student awareness cue. A) Student John was interacting with a star on his tablet. B) Another student saw that the star began to move. C) With the awareness feature, she found out that John was moving it. D) The awareness cue faded out and disappeared after some time.

Showing identity information of the student manipulating the object would address the ghosting problem and let students know who is acting on the object. Moreover, as John's cue appears next to an object, it signals to other students that the object is busy and John is working with it. This information could help students to decide if they should still interact with it. Students may know that their action does not conflict with what John is doing based on their split of tasks. Alternatively, students may know that they should refrain from interacting with the object to avoid conflicting actions. Thus, we expected that providing the identity information would address the action conflict problem.

Students' active selection and interaction with an object would trigger the awareness cue, and the cue conveys the students' identity and location in the workspace. The real-time updates of the object state would give a sense of the current actions done by the student. Since we used students' selections, rather than hovering, this approach also worked for the devices that did not have mouse pointers. Moreover, if an area already had many awareness cues, students could coordinate their space usage and find a less crowded space to work. This could further prevent student conflicts. The cue could also help to convey students' attention. It could be used by teachers to know where students were currently paying attention to, and this could inform teachers' subsequent teaching activities.

5.4 Methodology: Design Iteration Overview

We approached the challenge of designing a workspace awareness cue that balanced awareness and distractions for students by employing a highly iterative approach. As there were many iterations, this section provides an overview of our design process, from low- to high-fidelity and the final redesign (see Figure 5-5). The next section focuses on how the findings from the various evaluations with teachers and students were used in our iterations.

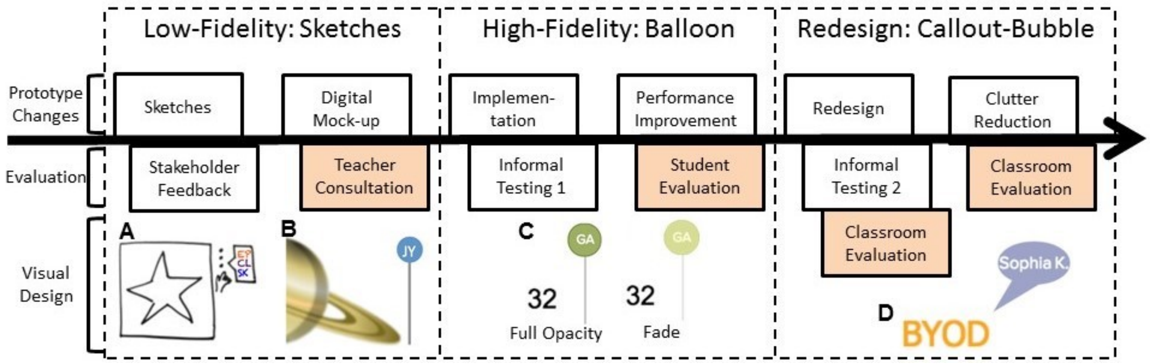

Figure 5-5: Iterative design process used for the Callout Bubble Study. We used a highly iterative design process to ensure the balance between awareness and distractions. There were three major stages, in the order from low- to high-fidelity. Boxes above the arrow depict the actions taken to revise the prototypes, and boxes below the arrow are the evaluations conducted. Boxes in orange denote evaluations with teachers and/or students. Pictures at the bottom are the design selected for further iterations: A) Dots - sketched; B) Balloon – PowerPoint mock-up; C) Balloon – implemented with animated fading; and D) Callout Bubble – released in the product.

5.4.1 Low-Fidelity Iterations: Sketches

We started exploring the design space through hand-drawn sketches. In this iteration, we considered a wide range of design factors such as interactivity, persistency, location, as well as amount of details related to the identity of collaborators and actions being performed. Figure 5-6 and Figure 5-7 show the diversity of ideas brainstormed. We explored several different approaches such as the following:

- interactive visualization to show information on demand (Figure 5-6 and Figure 5-7A and Figure 5-7B);
- varying amount of information (Figure 5-7C and Figure 5-7D);
- location of the awareness information (Figure 5-7A vs. Figure 5-7C vs. Figure 5-7E);
- historical, aggregated information, e.g., heat map based on users' location which faded out over time after a user moved (Figure 5-7G) and edit history of the workspace (Figure 5-7H); and
- different types of awareness information, e.g., interaction (Figure 5-7A), potentially relevant events (Figure 5-7F), location (Figure 5-7G), and edit history (Figure 5-7H)

Section 5.5 discusses how the design decisions were made.

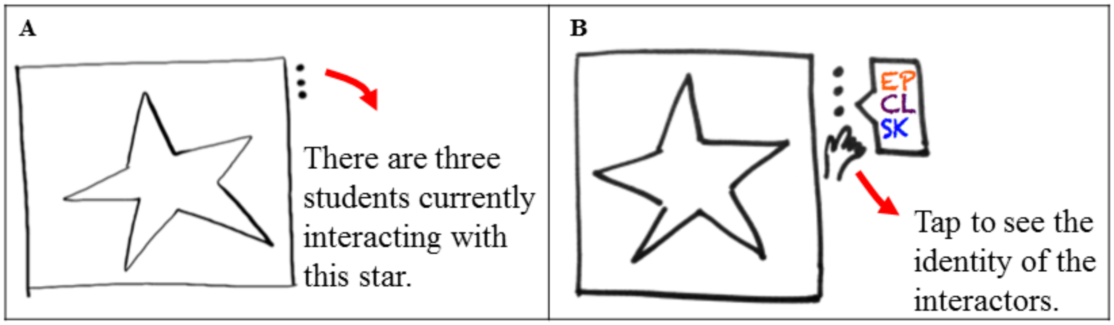

Figure 5-6: Initial sketches of the Dots design. The Dots design was selected to move forward to the digital mock-up stage. The dots next to an object represented the number of other students who were interacting with this object. Initials were shown when the users tapped on the dots.

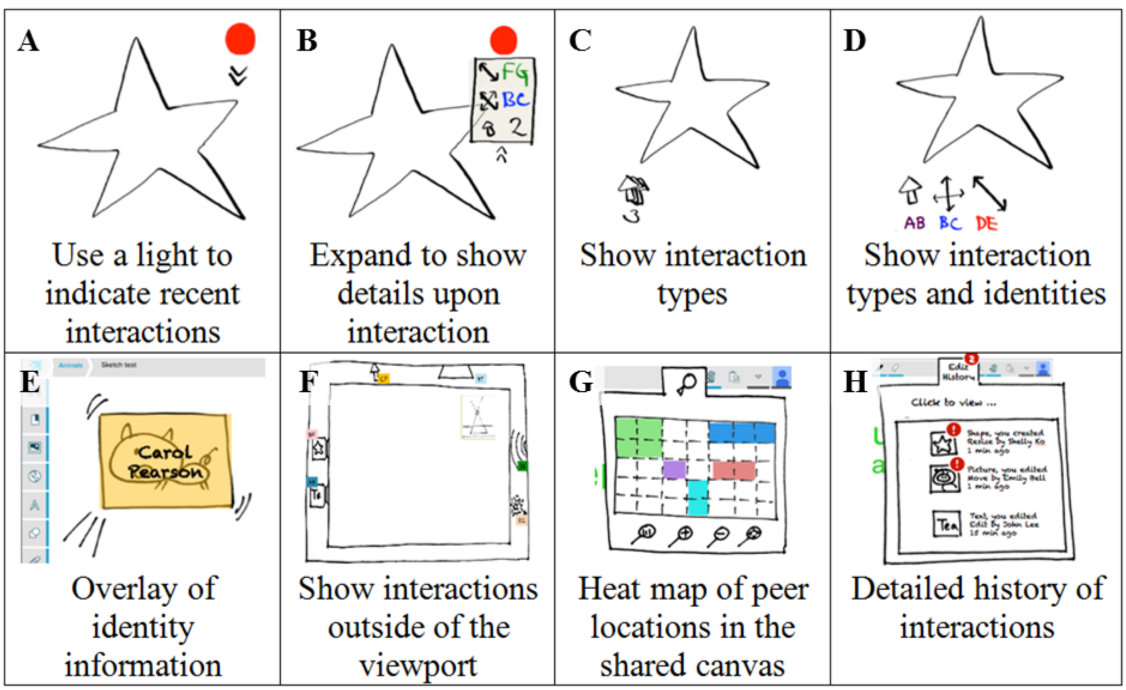

Figure 5-7: Some of the designs from the sketching stage. A wide range of design factors were considered, such as showing varying amount of identity, different interactions, historical edits, and different locations for awareness information.

Through several design feedback sessions with stakeholders from the company, the Dots design (see Figure 5-6) was selected to move forward based on our design requirements. The Dots design showed dots next to an object being manipulated, and the number of dots corresponded to the number of peers currently interacting with the object (see Figure 5-6A). A bounding box acted as a tether, showing the boundary of an object and associating the dots to the object. Upon interaction, a pop-up dialogue showed those collaborators' initials (see Figure 5-6B).

Next, higher fidelity digital prototypes were created using PowerPoint. We discussed the designs with other team members and stakeholders from the company, and we also consulted with three teachers. Through our iterations, the interactivity was dropped considering the fact that targeting small dots on screen was difficult. The visualization was also enlarged to increase noticeability. Instead of showing number of dots, we varied the thickness and length of the tether to create a subtler change. Figure 5-8 shows some of the variations of the digital mock-ups. During the consultation with the teachers, they preferred the Balloon design to minimize distractions (see Figure 5-8A and Figure 5-8B). See our design rationale in Section 5.5 below.

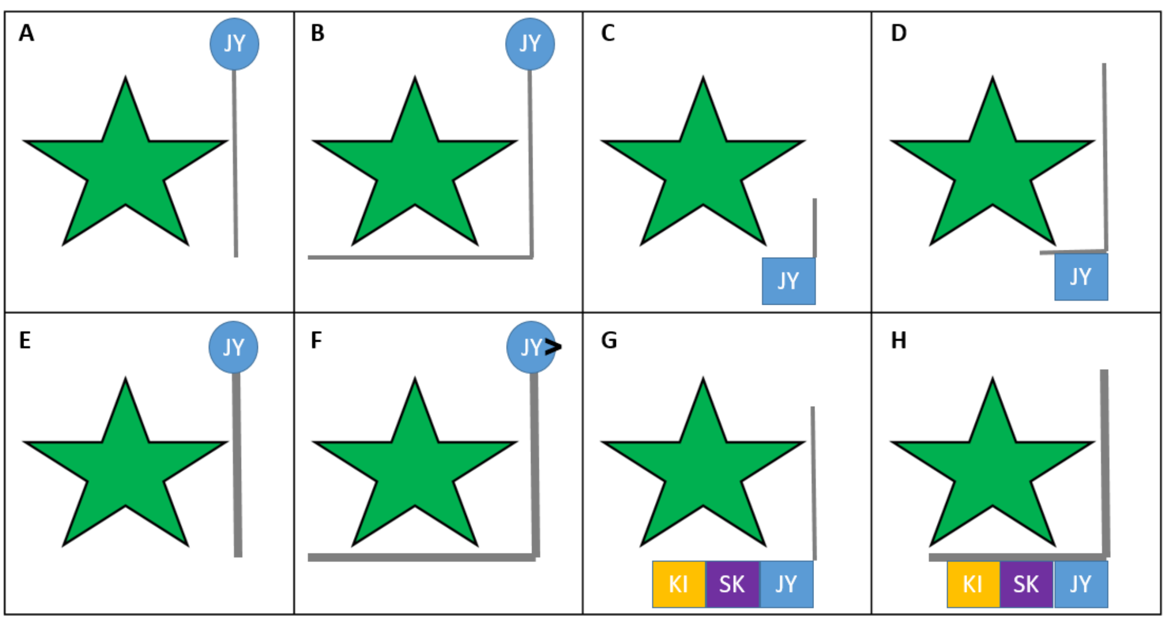

Figure 5-8: Some of the designs from the digital mock-up stage. We iterated on the Dots design, and came up with more variations of the awareness cue: A) Balloon, B) Elbow, C) Line, and D) Elbow 2. E), F), G) and H) depict when more than one user interacted with the object recently for A, B, C, and D, respectively.

5.4.2 High-Fidelity Iterations: Balloon

Next, we implemented the Balloon design (see Figure 5-4C). When a student manipulated an object, a Balloon appeared next to the object and faded out after a fixed amount of time. We first conducted an informal testing session with thirteen company employees using a mocked class. All participants had used the application without the Balloon cue. The lesson content was designed and taught by one researcher on the team who had over ten years of teaching experience. Based on the feedback, we improved on the performance and the persistency of the cue.

Student Evaluation

With the improved version, we conducted an evaluation to understand the noticeability of the cue and how it would be used by students. This evaluation was intended to get a sense of whether the visualization was useful for students in a multi-device learning environment.

The program manager of the project recruited one teacher and ten Grade five students (ages roughly ten to eleven) from the existing user base, and they had all used the SMART amp™ system with no awareness cues. Two ten-minute lesson plans on one workspace were created by the researcher with prior teaching experience. We designed two post-condition questionnaires, which contained five-point Likert-scale and free-form questions, and both questionnaires asked about students' experience in the workspace such as awareness of their peers, ease of task focus, and frustration level when conflicts arose. The questionnaire for the Balloon condition also asked specifically about students' usage of the cue and the noticeability of the cue. Since the student participants were in Grade five, the Likert scale questions also had emoticons below the rankings (inspired by (Bradley & Lang, 1994)) to prevent misinterpretation (e.g., Figure 5-9). See the questionnaires in Appendix C.3. The lesson plans and the questionnaires were piloted with five employees from the company.

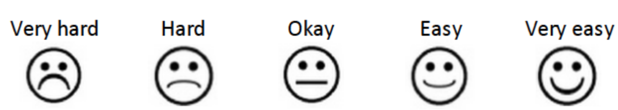

Figure 5-9: Emoticons used for the Likert-scale questions in the student survey. They were used to reduce the potential for misinterpretations of answers.

During the study, the teacher participant was asked to lead the two exercises based on materials developed by the researchers including the lesson plans, scripts, and a SMART amp™ workspace. Students were using laptops from their school. For the first exercise, students used the system without the Balloon cue on the topic of "What is your favourite food?" The second exercise "What are your favourite hobbies?" used the version with the Balloon awareness cue. Students completed a post-condition questionnaire after each exercise, and the study was video- and audio-recorded by the program manager and the developers who visited the school.

The recordings and questionnaires were brought back for the research team to analyze. The Likert scale questions were coded from 1 to 5, and the scores on conflict frequency and frustration level were reversed to so that higher score would correspond to more conflicts and higher frustration, respectively. One student's responses on all Likert-scale questions were excluded since the student did not fill out the Likert-scale questions on the second questionnaire.

Since there was only one group of students, we did not conduct any statistical analysis based on the data collected. It was used as an informal assessment of whether the design was heading in the right direction, and we sought to discover any major flaws in our design. Our results showed that although all students noticed the cue, they were unable to link the initials to the students in class and were confused about who the initials belonged to.

5.4.3 Redesign: Callout Bubbles

In the final iteration, we redesigned the cue visualization into a Callout Bubble, which incorporated users' first names and pointed toward its associated object (see Figure 5-5D). We conducted two rounds of informal testing sessions with fifteen and sixteen participants using a brainstorming task on favourite foods and a small-group collaboration task on Newton's Three Laws, respectively.

Based on the feedback, we shortened the cue's animation to reduce persistency. Moreover, we found that there was a need to prevent students from intentionally disturbing others and to better convey peers' attention. Thus, we only allowed one awareness cue per student. If a student who had recently manipulated an object started interacting with another object, the previous cue on other students' workspaces disappeared automatically and a new cue appeared on the more recent object. This change prevented students from invoking many cues to create distractions for their peers. It also better conveyed other students' attention in the workspace.

A final evaluation was conducted in four classrooms remotely. Due to the software release time, two classrooms used the version with multiple cues per students and the other two classes used the version with one cue per person (the method and results of the classroom evaluation are in Section 5.6 and Section 5.7).

5.5 Evolution of Main Design Factors

The findings from the informal testing sessions and evaluations with teachers and students guided our design evolution. Throughout the process, we iterated on several aspects of the awareness cue design to arrive at the Callout Bubble cue. This section presents the evolution of our design in four aspects: visual design, amount of identity information, interactivity, and persistency of the cue.

5.5.1 Cue Visual Design

Our awareness cue consisted of two main components: actors' identity information and a tether to specify the object being acted upon. Throughout our design iteration, we explored various visual representations of the collaborators' identities and the tether (e.g., shapes, colours, and locations). For example, the Dots design (Figure 5-4A) showed a rectangle box around the star as a boundary to implicitly link the dots to the object. The Balloon design (Figure 5-4C) used a grey tether and the Callout Bubble design (Figure 5-4D) had an explicit directional tether pointing to an object.

Throughout the iterations, the visual design of the cue became more minimalistic and more explicit. The Dots design evolved to become the Balloon design, which had smaller tether (one side of an object, instead of a box around an object). The Balloon design was preferred by the teachers as it balanced noticeability, distractions, and clutter. Our student evaluation results showed that all ten students noticed the Balloon cue, and there was a small positive trend in our measurements (see Table 5-1). Students' average awareness of collaborators was higher with the cue, and the rating for ease of task focus also improved. The rating of conflict frequency lowered, and the students' frustration level were also lower on average.

	Control	Balloon
How often did you know what others were doing in your amp workspace? (1: Never; 5: Always)	3.78	4.45
How easy was it for you to focus on what you were creating or sorting? (1: Very hard; 5: Very easy)	3.11	3.78
When you were working in the amp workspace, how often were other people in your way? (1: Never; 5: Always) *	3.44	3.22
When someone got in your way in the amp workspace, how did you feel? (1: Very happy; 5: Very frustrated) **	4.00	3.75

Table 5-1: The average responses for the Likert-scale questions in the student evaluation. The table shows students using the application without awareness cue (Control) and with Balloons (Balloon). Students' responses showed a positive trend. * The rating has been reversed so that higher rating corresponds to higher frequency. ** The rating has been reversed so that higher rating corresponds to more frustration.

Although the positive trend in the survey feedback showed that the cue improved students' work, the need to redesign the cue to incorporate students' first names was apparent based on our observation (see the Section 5.5.2 for more details). We decided to adopt a Callout Bubble metaphor in order to accommodate for the longer identity information (see Figure 5-10). The oval contained the identifier, and we used a directional triangle instead of the more abstract grey tether line.

Having a more explicit tether pointing at the object being manipulated simplified the association of the cue for a rotated object since the tether provided a strong association between them. In the previous designs, users needed to process the relative location of a cue to determine the associated object, and this can be difficult in a crowded workspace, especially for a free-form canvas. Moreover, the identifier in a cue stayed upright regardless to the objects' orientation and at which corner the cue is to the object (e.g., Figure 5-10C).

Figure 5-10: Final design of the awareness cue, Callout Bubble. A) Sophia K. was interacting with the "BYOD" text; B) cue faded out; C) cue re-adjusted its position when there was no sufficient space at the top.

5.5.2 Identity Information

The Balloon design (see Figure 5-8A) used the students' first and last initials as their identity information, and this representation provided many benefits. It required minimal screen space and was consistent with how identity information was displayed in SMART amp^{TM}. (An object's creator and editor were shown as initials in a square box at the top right corner of an object). Moreover, the cue was colour-coded to provide additional cues for identity, and the colour was uniquely generated based on a student's system login.

In the student evaluation, seven out of ten students reported looking at the Balloon when others got in their way. However, we observed that students were still confused about who moved an object. Based on the video recordings, students noticed the Balloon cue, but then they asked who it represented (e.g. "Who is JP [a student's initial]?"). Although the Balloons made a positive impact, the initials were not sufficient for students to maintain awareness.

Thus, in our redesign, the student's full first name and last initial was used (see Figure 5-10). The last name was abbreviated due to the observation during our study that students did not remember their peers' last names.

5.5.3 Interactivity & Interaction Information

We considered a variety of designs based on whether the cue was interactive and how much details to show for other users' interaction. In terms of the interactivity of the cue, we considered how abstract the information should be represented. For example, one design used a green-yellow-red light (Figure 5-7A) to show how busy this object was, and users could see more details by tapping on the light (Figure 5-7B). On the other end, some designs showed the specific type of manipulation being done by collaborators (Figure 5-7D), and the users got detailed information at a glance without interacting with the cue. Although a more abstract representation could help reduce clutter, it might not be noticeable enough. Selecting small targets on touch devices could also be difficult since the cue might even be moving with the object as a user was moving or resizing it. Thus, we chose not to use interactive cues.

The cue required no interaction from the users, so that it could be observed with peripheral attention. Both the Balloon and the Callout Bubble cues automatically appeared when a peer manipulated an object. It was triggered by any actions that modified an object's visual properties such as resizing, moving, and editing text. To convey potential subsequent actions and intention to interact, selection of an object also triggered the awareness cue.

As the cue was not interactive, all information needed to be incorporated in the static visual design, and this constraint challenged us to keep the design informative while minimalistic. The original Balloon design increased the thickness of the tether if more students recently manipulated the object (see Figure 5-8A vs. Figure 5-8D). Although it was implemented in the high-fidelity phase, our informal testing found that only a few participants noticed this thickness change. Therefore, we removed this feature to simplify the design and reduce clutter.

5.5.4 Persistency of Cue

The peers' interaction information quickly became irrelevant as they switched their attention to other objects or as time went by. Thus, we designed the awareness cue to persist for some time and then automatically disappear. This approach did not require students to release or unlock an object, and fitted students work pattern, as they switched between work and play rapidly. Moreover, it addressed potential technical problems such as unstable network connections.

We tested different duration of persistency throughout our iterations. The Balloon design in the first informal testing (see Figure 5-4, middle) faded away gradually in ten seconds. However, the initials were barely readable by the time the participants noticed the Balloons. Thus, the Balloon was adjusted to stay opaque for eight seconds and then fade out for two seconds.

The second informal testing (see Figure 5-4, right) with the Callout Bubble revealed that multiple Callout Bubble cues by the same student created more unnecessary clutter in the shared workspace. It also did not convey a student's attention effectively. Moreover, this implementation allowed a mischievous student to overwhelm the workspace by selecting or interacting with many objects in quick successions. Based on the feedback, we shortened the duration so that the awareness cue was opaque from eight seconds to five seconds. The Callout bubble then faded out in two seconds. We allowed only one Callout Bubble per student. If a student manipulated a new object while the previous cue was still present in other students' view, the previous Callout Bubble automatically disappeared and reappeared next to the new object.

To ensure the Callout Bubble remains visible next to the object being acted upon, when an object was too close to the edge or became partially off-screen, the cue appeared in a different corner of the object that had enough space for the cue (see Figure 5-10C). If an object was so big that there was no space in all corners, we displayed the Callout Bubble at the centre of the object.

5.6 Classroom Evaluation Method

With our revised Callout Bubble design, we deployed it to four real classrooms to understand whether and how the Callout Bubble impacted the students' workspace awareness. We wanted to know whether the cue was appropriate for such a real-world application; thus, we designed the study to maximize the ecological validity of our data. The teachers were teaching the lessons they designed as usual, and all the teachers and students were existing users of SMART amp™.

To understand the cue's effectiveness and balance between awareness and distractions, the application with the Callout Bubbles was deployed in four classrooms (four teachers and seventy-one students). Due to the company's internal software testing protocol, we had little control over the exact time of software release. While all groups used the SMART amp™ application with Callout Bubbles in their classes, there were two versions of the Callout Bubbles: thirty-eight students (two classes) used the earlier version (Callout Bubble persisted for ten seconds and multiple cues per student) and the other thirty-three students (two classes) used the later version (Callout Bubble persisted for seven seconds and only one cue per student). See Appendix C for the study materials including the ethics application, questionnaires, and coding results.

5.6.1 Participants & Apparatus

The program manager recruited five teachers from the existing SMART amp™ users. However, one teacher had difficulty in opening the application with Callout Bubble and was not able to complete the lesson with the feature. Thus, only four teachers and their students (seventy-one students) participated in the classroom evaluation. All participants had used our system prior to the study.

Students were in Grades three, four, five, and twelve (age roughly eight, nine, ten, and seventeen, respectively). The group sizes ranged from two, three, and six students, to the whole class (twelve and twenty-six students). Students used iPads, iPad Minis, and laptops.

5.6.2 Procedure and Data Collection

We wanted to collect data high in realism (McGrath, 1984) to ensure the practicality of the awareness cue; thus, we opted for a study design similar to a field study. The teachers conducted their daily lesson as usual, but used the version of the application with Callout Bubbles. The teachers reported a wide range of lesson topics including fractions, friction forces, World War II, and minerals. There was also a diverse set of activities including reading, solving physics questions, watching videos, researching historical events and figures, and creating board games. For the four classes studied, the lessons lasted between twenty-five to fifty-five minutes, and the average lesson time was 42.5 minutes.

At the end of their lessons, the students and teachers filled out an online survey on Google Forms[21]. All teachers were invited to participate in a phone interview session after the study; and one teacher participated in the call. The study was conducted remotely, and no other data was collected.

Questionnaires

The student survey focused on students' experience using the Callout Bubble, how they resolved conflicts, and their behaviour change. The student survey contained Likert-scale, multiple choice, and free-form questions. The Likert-scale questions were the same as the ones from the Student Evaluation described in Section 5.4.2. However, it did not use the emoticons since the particular online survey tool we used did not allow images for Likert scales. The multiple choice questions asked about whether students noticed the cue and how they resolved conflicting situations while working together with other students. The free-form questions asked about students' behaviour change when using the Callout Bubble (vs. no Callout Bubble), and for any additional feedback.

The teacher survey aimed to gather information about the lesson, group size, divergent of lesson plan, and their feedback on the Callout Bubble. See Appendix C.4 for teacher and student surveys.

5.6.3 Data Analysis

We conducted statistical analysis on the Likert-scale questions and coding on the teachers and students' free form answers. We formed hypotheses for the Likert-scale questions, and tested them with Pearson Correlations. For questions related to situations when other students got in their way, we allowed students to skip the question if they did not encounter any conflicts. For these questions, we excluded students who skipped the question so only fifty-eight data points were used.

[21] https://www.google.ca/forms/about/

Code	Definition
Who	Show knowledge of who is working on an object or who is also participating in the workspace.
What	Show knowledge of what a collaborator is doing or what objects they are working on.
Where	Show knowledge of where the collaborators are in the workspace.
Coupling	Show that the Callout Bubble helps the student notice and manage transitions between individual and shared work.
Communication	Show that the Callout Bubble helps the student simplify communication between them.
Coordination	Show that the Callout Bubble helps the student coordinate space usage or learning.
Anticipation	Show that the Callout Bubble helps the student anticipate peers' actions.
Assistance	Show that the Callout Bubble helps the student in assisting peers.

Table 5-2: Code definitions for the workspace awareness elements and activities. The definitions were adapted from the workspace awareness framework by Gutwin & Greenberg (2002).

We used Gutwin and Greenberg's Workspace Awareness Framework (Gutwin & Greenberg, 2002) to code the free-form answers from the students and teachers. We coded for the awareness elements (*who*, *what*, and *when* for present information) and awareness activity (*coupling*, *communication*, *coordination*, *anticipation*, and *assistance*). Two researchers coded the student answers and reached full agreement on the final coding. See the code definition in Table 5-2.

5.7 Classroom Evaluation Findings

In this section, we report the quantitative and qualitative results from our data analysis.

5.7.1 Awareness, Conflicts, Distractions, and Frustrations

For the quantitative analysis, we formed hypotheses and tested them through statistical analyses. See a summary of our hypotheses and statistical test results in Table 5-3 (see Appendix C.5 for the full output).

Hypotheses	Analysis results	Pearson correlation results
Having more conflicts correlates with higher frustration.	Confirmed with positive correlation	(r_{58}=.395, p=.002)
More awareness of collaborators correlates with more difficulties to focus on what students were working on.	Found that more awareness correlated with easier to focus	(r_{71}=.336, p=.004)
More awareness of collaborators correlates with students feeling less frustrated when other students got in their way.	Confirmed with negative correlation	(r_{58}=-.322, p=.014)
Feeling being able to focus easier on the tasks at hand correlates with less frustrated when other students got in their way.	Not significant	(r_{58} = -.032, p=.810)
Having more conflicts correlates with harder to focus.	Not significant	(r_{58}=-.191, p=.111)

Table 5-3: Summary table of our hypotheses and test results. We confirmed that having more conflicts while working together was a problem since it correlated with high frustration. Awareness of collaborators correlated with easier to focus and less frustration. This result showed the potential benefits of the Callout Bubbles. Other hypotheses tested were not significant. See Table 5-1 for the Likert-scale used.

First of all, we wanted to confirm that students' conflicts and their frustrations while working in the application were related. The statistical analysis confirmed that the frequency of conflict rated by students was correlated with higher level of frustration (r_{58}=.395, p=.002).

Next, we wanted to know if the Callout Bubble made improvement in students' awareness of peers' actions and their focus of tasks at hand, as well as whether it made reduction in their frustration level. Almost all students (66/71) noticed the Callout Bubbles, which showed that the cue was noticeable enough for our participants. In terms of resolving conflicts, nearly half of the students (33/71) reported looking at the cue when someone got in their way while fifteen students reported that nobody got in their way, as shown in Figure 5-11, left. This showed that the cue was used for resolving conflicts by the students.

As the Callout Bubble cue was noticed by most students, a potential disadvantage was that the cue might distract students from their work. Thus, we hypothesized that the students' awareness of peers' action would be associated with harder to focus on tasks at hand. However, the analysis revealed an opposite correlation: the students' awareness of peers' actions positively correlated with ease to focus

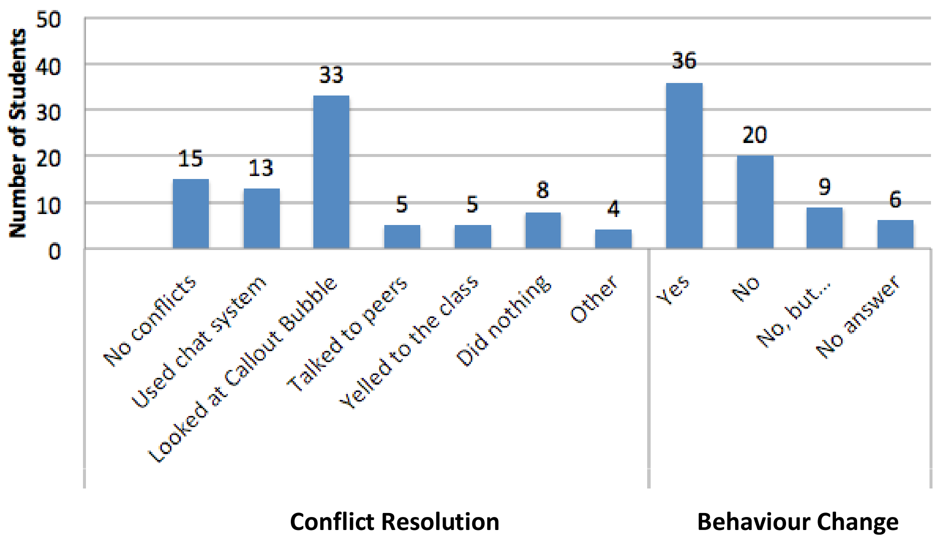

Figure 5-11: Students' answers to the conflict resolution and behaviour change questions. Left) Self-reported actions taken by students when conflicts arose. This was a multiple selection question. Right) Breakdown of students' answers to whether the Callout Bubble changed how they worked with other students. "No, but…" indicates students that responded no but then commented on how their behaviours changed.

on tasks (r_{71}=.336, p=.004). This finding might be explained by that when a student knew the identities of the ghosts in the workspace, they could dismiss actions that they already expected to happen. Thus, the awareness cue allowed a student to focus more on their tasks and not be distracted by the need to figure out who was editing in the shared space. This also showed that the Callout Bubble balanced the awareness information and potential distractions.

A teacher's comment confirmed that the students were more focused on their work with the Callout Bubble feature since students did not need to spend time and effort to find out who did what.

```
T4: It kept them moving on the project and not focusing on who was moving
    what.
```

This result suggested that the Callout Bubble may be beneficial in helping students focus in a shared workspace.

Furthermore, as the Callout Bubble cue was a new feature, we were concerned with the initial "wow" moments, which could be distracting for the class, especially with younger students. The teachers reported that the initial moments of seeing the awareness cue was indeed distracting, but that quickly subsided after students got used to the feature. The Callout Bubble balanced awareness and distractions appropriately.

We also hypothesized that the students' awareness of their peers would help reduce their level of frustration when conflicts arose, and our analysis confirmed this by showing a negative correlation between awareness of peers' actions and frustration level when conflict arose (r_{58}=-.322, p=.014). Students' comments showed that knowing who were the "ghosts" helped with their work, which may explain the lower frustration level with higher awareness.

```
S21: It is easy cause now we know if someone is just messing around cause
    [of] the bubble.
S58: This Callout Bubble has saved my life because this can tell me who
    has been touching my stuff and been doing stuff.
```

While Student 58's comment was dramatic, it revealed the level of frustration experienced by this student without the Callout Bubbles, and the improvements and perceived valued of the feature.

5.7.2 Comprehensibility and Behaviour Change

Next, we wanted to know if students understood the information presented by the awareness cue. Our results showed that students understood the cue and were able to act upon it. For example, a student commented that the identity information helped subsequently resolves conflicts that arose.

```
S34: … we now know who the source of the problem is so we can fix it
    easily.
```

One of the free-form questions asked students if the Callout Bubble changed how they worked with other students, see results in Figure 5-11, right. More than half of the students (45/71) reported the Callout Bubble changed how they worked with others, while twenty students reported that it did not change their behaviour. six students did not answer or responded with irrelevant comments.

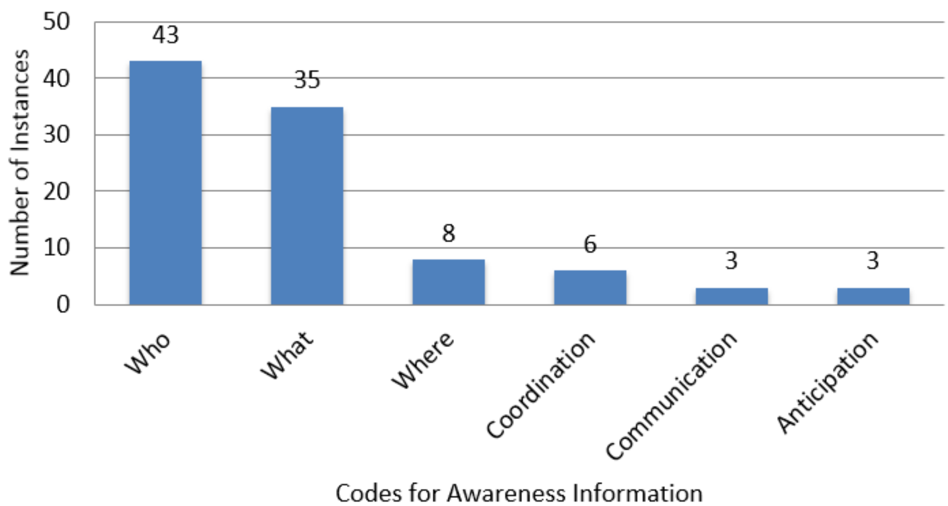

Figure 5-12: Counts of awareness elements and activities coded.

Moreover, students commented on the type of awareness information they have gained, see coding results in Figure 5-12. More than half of the students (43/71) reported knowing the identity of peers (who). Half of the students (35/71) reported knowing the types of actions being carried out (what), and they also showed the ability to link identity with the interaction observed. For example:

S17: Yes [Callout Bubble changed my behaviour] because if someone was making a picture the size of the workspace I could see who it was.

Finally, there were eight students whose comments showed that they knew where other peers were working in the shared canvas. These students' comments on their behaviour change and awareness gain suggested that students understood the meaning of the Callout Bubbles.

5.7.3 Student Coordination & Self-Monitoring

As confirmed by eight students' comments on knowing where other students were working in, the Callout Bubble helped students to know other students' locations and current focus of attention. The coding results showed that some students were able to make use of this information, and nine students commented that Callout Bubbles allowed them to anticipate peers' actions and coordinate their actions accordingly (see Figure 5-12).

S2: ... I knew where other people were working so I knew where to do my things so I wouldn't get in the way of others.
S40: Now it's easier to work so you know who's working on something so you don't get in their way.

We designed the awareness cue to help students coordinate the virtual workspace, yet we found that it was also useful for coordinating learning activities. One student commented the following:

> S3: If I seen someone working on that part [of the project] I would go to a different problem.

Although only one student commented on the ability to coordinate the order of solving a problem, this showed the benefits of providing Callout Bubbles to facilitate the coordination of learning activities and space usage.

In addition to coordinator, the awareness cue was also used as a way to monitor group members' progress, and the teachers' feedback indicated that the Callout Bubble had an additional benefit of allowing self-monitoring among the students. This also kept students accountable to each other during the collaboration, for example:

> T3: It kept them more on task and they kept each other more accountable for what was happening in the work space … [keeping each other accountable] helped improve efficiency of work and helping students identify where to work in the workspace...

5.7.4 Teacher Monitoring

While the Callout Bubble was designed for students, it also benefited the teachers. One teacher commented that the cue made troubleshooting easier since student activities were also visible on individual devices. Teachers did not need to get back to their device for a special teacher view to see attribution, which is a feature where teachers could click on objects to see who created and/or edited them.

> T4: It helped me for having to look and see who was doing what if a student had a problem because I could see it right on their screen.

Moreover, since the awareness cue automatically appeared when an object was being manipulated, this reduced the cognitive and physical workload required to monitor student activities.

> T2: I could keep tabs easier on who was doing what without having to check attribution [a feature in our system], and it was real-time.

5.7.5 Concerns with Showing Identity Information and Clutter

Although our findings showed that the Callout Bubble made positive impacts on both students and teachers' work, one teacher raised the concern of negative impacts on showing the student identity. Shy students might be reluctant to act in the shared workspace since other students could see their work. However, the teacher thought that the benefits of the awareness cue outweighed this concern.

```
T1: My only concern is that some reluctant collaborators will not be free
    with their responses if they know all others will see it? But really
    this shouldn't matter. The pros outweigh the cons for sure.
```

As we were working with teachers and students closely since the start of the project, we were cautious about not to discourage student participation while providing appropriate amount of awareness information. Thus, we designed the awareness cues to be transient, and required minimal user interaction to view and dismiss. We believed that the negative impact of showing identity information in this manner was minimal.

In terms of clutter, the Callout Bubble worked fine for the group sizes tested. However, a few teachers felt that having the ability to turn on and off the feature would be a nice-to-have feature for a cluttered workspace. We found a similar issue in our informal testing sessions. Awareness cue might not be useful depending on the lesson type and number of users in the workspace. For example, with a brainstorm type of activity, if the available area for working together was small with many users, students could not avoid bumping into each other. In this case, even if students knew the identity of other users, there was very little that students could do to negotiate the space usage. Moreover, if students' work only loosely depended on each other, there was not a strong need of workspace awareness other than being able to find empty spaces to add their ideas. Similar to what Conversy et al. (2011) found when studying tabletop interface for air traffic control, people do not maintain awareness automatically when no meaningful collaboration relationship exists in the workspace.

5.7.6 Summary of Results

Overall, our findings showed that the Callout Bubble cue fulfilled the design requirements. It achieved a balance between awareness, distractions, and clutter. The students noticed and understood the cue, and they were able to coordinate and self-monitor based on the identity information presented through the Callout Bubbles. The cue also improved the teachers' classroom management by allowing them to troubleshoot problems and monitor student activities easier.

5.8 Discussion

Our design process (see Figure 5-4) and the classroom evaluation revealed insights into designing a workspace awareness cue for a multi-device classroom setting. In this section, we discuss the lessons learned in terms of the design of the cue and designing for a real-world multi-device classroom.

5.8.1 Design Lessons

Visual Design and Amount of Information

As we refined the balance between awareness and distractions through our design iterations, the visual design of the cue evolved to become more minimalistic and precise. For example, in the Dots design, we used a rectangular box as a tether to associate an object with its dots. In the Balloon design, the tether was a gray stick, and it became a directional triangle in the final Callout Bubble design to more precisely associate the identity with an object, especially considering a cluttered background and rotated objects. In the Balloon design, the tether's changing thickness based on number of recent interactions on the object was dropped to reduce clutter since it was so subtle that only a few people noticed it.

We also iterated on the identity information, and found that the initials coded with users' unique colour were insufficient for our target population, students. Thus, we had to incorporate additional information, students' first names. Designers should consider the suitability of an identity representation for particular domains, e.g., initials vs. full names, or roles vs. names.

Interactivity and Persistency

Interactive visualization can help with reducing clutter by showing more detailed information on demand. Using more abstract representation can also help reduce distractions (Dabbish & Kraut, 2004). However, in the context of a shared free-form workspace, an abstract indicator may not be noticeable enough since it may be too small for students to use their peripheral attention to stay aware of their peers. In a crowded free-form canvas, distinguishing a small indicator from actual contents may be difficult. Moreover, students most likely want to check the identity information because another student is manipulating an object. In this case, selecting a moving indicator can be challenging, especially on touch devices. With these concerns, we decided to show identity information directly instead of using abstract symbols. Designers using abstract interactive visualization as workspace awareness cue should consider these drawbacks.

The persistency of the cue was iterated many times, and we found that having the cue stay opaque for five seconds and then fade out in two seconds achieved the balance between awareness and distractions. The cue had to stay visible for five seconds to give students time to notice and read the identity information before it faded away. An awareness cue's exact timing of visibility needs to be adjusted depending on the target user population, size of the workspace, structure of the workspace, and the existing visual clutter.

Conveying Attention on Touch Devices

Since touch devices used by many schools did not have stylus for hover support, the Callout Bubbles were invoked by a student's selection and manipulation of an object. This design still allowed other students to infer who was working on what where, and thus conveyed a student's current attention. The selection acted as a way to show that a student was intending to work on an object.

Our approach only showed awareness cue for active interactions with an object, and our design allowed us to show only the active period of student work. In a lesson, teachers sometimes used multiple applications in conjunction with the shared canvas. For example, students might be actively gathering information on our solar system in various websites and simulation apps, while they seemed to be idling in the shared canvas. Moreover, students switched between work and play repeatedly and quickly so even when they were working in the shared canvas, they were not always active. Thus, by representing a persistent object (e.g., mouse pointers) or a property of the workspace (e.g., current viewport), the visualization might be showing an idling object, which added to the clutter in the workspace and distracted students. Thus, we found the showing students' active interaction allowed the design to convey users' attention by providing only the necessary information, and our approach was more aligned with students' work practices. For awareness cues that wish to visualize persistent objects or properties of other users' workspaces, the designers need to consider other cues to represent the level of activity to communicate that there may be student activities outside of the workspace. This is especially important for domains that have long down times with intense work period as well as that have multiple applications used in conjunction such as emergency response teams.

Awareness for Collaborators and Moderators

In a multi-device classroom setting, students' activities and progress are difficult to monitor because students' bodies typically occlude their screens and there are too many screens for teachers to pay attention to. Although the awareness cue was designed for students, the teachers found that the cue helped them in monitoring students' activities since Callout Bubbles revealed the identity information. This showed the need to support moderators' awareness need in a multi-device environment. Applications with moderators should consider how the workspace awareness support facilitates or hinders their situation awareness.

5.8.2 Pedagogical Concerns

At the beginning of this project, we decided to provide workspace awareness to enable social protocols to mitigate conflict rather than enforcing coordination behaviour through locks on objects. This addressed the teachers' concern of encouraging learning of workspace etiquette, as opposed to enforcing a particular behaviour.

Using transient cues that automatically appeared and disappeared addressed the concern of showing student identity. If the contributors' identities were shown permanently, shy and low-performing students might be discouraged to participate, while high performing students might feel embarrassed to stand out in the class. The transient nature of the cue helped to minimize this issue, and our results showed positive improvements in students' awareness and coordination.

By showing awareness cue for active selection and interaction, our design supported student work patterns and teachers' usage of multiple devices in one lesson. As we frequently sought teacher input throughout our design process, we were able to understand teachers' pedagogy concerns and address the unique needs of our target users, students.

5.8.3 Practical Concerns in Designing for a Real-World Application

As the Callout Bubble was a feature in a real-world application, there were several practical concerns that impacted the approaches taken in our research and the Callout Bubble's design. For example, some of the concerns included ensuring the Callout Bubble's commercial value, effectiveness, robustness, performance, scalability, and ease of software code maintenance. Balancing these practical concerns and academic contributions of this research was essential to the success of the project. We did so by employing a highly iterative design process to frequently receive feedback from teachers, students, and various stakeholders in the company such as higher-level managers, program managers, user experience designers, and software developers. Furthermore, in our iterations and evaluations, the need to ensure commercial success also made the Callout Bubble's effectiveness in a realistic environment a top priority. Thus, a field study was chosen as it provides rich data with high ecological validity (McGrath, 1984), and we could leverage our access to teachers and students. In comparison, while conducting a controlled experiment would help in understanding the precise effects of Callout Bubble, it was perceived to be not as valuable due to the low realism and ecological validity. The practical challenges faced in this research resulted in a preference for research methods that allowed for more in-depth exploration and understanding of the design's real-world impacts.

In terms of the Callout Bubble's design, due to the underlying software architecture and potential network issues in many schools, it represented an interaction event rather than the state that a user was manipulating an object. With the potential clutter and distractions in mind, the cue disappeared automatically. We also limited the cue to one per student to better convey attention.

Due to the slower network and devices used by many schools, we decided to use more efficient but less accurate calculation for the awareness cue's location in edge cases, and the cue's location also updated less frequently than desired to optimize for performance.

5.9 Summary

This chapter presented an investigation on a workspace awareness cue for multi-device classrooms involving personal devices connected via a large shared virtual workspace. Through an iterative design process involving teachers and students, the final Callout Bubble design balanced awareness and distractions while reducing teachers' workloads by enabling students to self-monitor and coordinate. The Callout Bubble Study also provided important and practical considerations for designing a workspace awareness cue in the context of multi-device classrooms. The next chapter brings together the lessons learned from both the Timeline Study and the Callout Bubble Study to provide overall design implications for co-located technological environments.

Chapter 6

Discussion and Design Implications

The previous three chapters present two user studies: the Timeline Study (Chapter 3 and Chapter 4) on situation awareness support for collaborative tabletop systems involving dynamically changing data, and the Callout Bubble Study (Chapter 5) on workspace awareness support for multi-device classrooms. The design implications specific to these studies have been discussed in their respective chapters. This chapter presents the overall design lessons learned from the two investigations in supporting awareness for co-located collaborative systems.

6.1 Support the Secondary Task: Awareness

While maintaining awareness of the dynamic changes in the environment and of collaborators is important, these processes are not users' main objectives of collaboration. Their goals are accomplishing the work rather than attending to the states of the computer system and the collaborators. Considering that maintaining awareness is the secondary task, this research sought to provide awareness support without distracting users from the primary task and aimed to not be in the way of the collaboration process. In the Timeline Study, the timeline does not place restrictions of its usage based on temporal factors (e.g., the phases in the game). As a persistent display, it allowed users to interact with it at their own paces during the collaborative work. The design of Callout Bubbles allowed students to work with peers as they desire. Although they were not discouraged from behaviours that violated the common social protocols, the design aimed to minimize the effects of misbehaviours. For example, only one cue per student was allowed so that students could not invoke many cues to intentionally distract others. Designers should ensure that the awareness information seamlessly co-exist with the primary task and does not interrupt the primary task. Furthermore, while providing awareness information, designers should carefully handle the potential interference which negatively impacts the primary task. The rest of this section discusses the key design lessons learned in supporting a secondary task: awareness. First, awareness and distraction levels need to be balanced, and subtle visualization may create higher levels of distraction due to lack of awareness. Next, awareness information should to be integrated to foster quick recognition, and designers need to consider the persistency level of the awareness information.

6.1.1 Less Is Not Always More

As awareness maintenance is the secondary task, minimizing distractions created by awareness information was an essential design guideline in the two investigations. This design concept is in line with many other guidelines for information visualization (Tufte, 1983) and for awareness displays (Dabbish & Kraut, 2004).

During the design iterations in both studies, the visual design of the awareness displays became more minimalistic and more specific. For example, in the Callout Bubble Study, the tether changed from a vertical stick to a directional triangle in order to more clearly associate students' identity with the objects being manipulated. However, in some cases, the design became too minimalistic and thus ineffective. Users did not notice them or could not comprehend them quickly. For instance, the Pandemic digital game by Wallace et al. (2012) used animations to draw users' attention and guide them through the changes. The animation faded out and created no lasting clutter to the interface. However, it was ineffective for providing situation awareness due to the inherit constraints of collaborative work around tabletop systems such as distractions from collaborators and the constraint of not being able to see the entire large display. Similar challenge of minimizing distractions and clutter was also present in this research. In the Pandemic digital game developed in this dissertation, the replay animations were found to be insufficient for users to quickly identify who triggered them and distinguish them from system animation triggered by automated actions. The replay animation's colour-coding was too subtle to convey a collaborator's identity. As the result, users sometimes confused the replay animation with system animation.

Furthermore, in the Callout Bubble Study, the original SMART amp™ system showed real-time updates of changes in the workspace without any identity information. Even though this approach created minimal visual clutter in the interface, users were unable to make sense of the changes. They were distracted and confused by the seemly mysterious changes made by their peers, and they had to spend extra effort in verbal coordination to remedy their deficient awareness. In an attempt to minimize clutter and distractions, the early version of the awareness cue prototype (Balloon) used students' initials to represent their identity. Similarly, it was minimalistic, but ineffective for workspace awareness maintenance.

The investigations of awareness support in co-located collaborative environment showed that less is not always more. When the system provided little to no awareness information or when the visual design was too subtle, the awareness support became insufficient. Users had to spend additional effort and time to maintain the situation awareness and workspace awareness necessary for their work. Designers of co-located collaborative technologies need to consider balancing the awareness information and distractions to ensure sufficient noticeability and comprehensibility. Designers also need to be mindful of the clutter in the existing workspace to ensure that the awareness cue is noticeable enough.

6.1.2 Support Progression of Awareness Levels

The two investigations in this dissertation revealed that the design of awareness displays needs to foster the progression of situation awareness levels and the comprehension of workspace awareness elements. The three levels of situation awareness—perception, comprehension, and projection—present different information needs, and the design of awareness displays should support all three levels in a collaborative context. This is consistent with the previous design guidelines for situation awareness about supporting all levels of situation awareness (Endsley, 2012). While the interactive event timeline was designed to be useful for all three levels of situation awareness, the design focused largely on the perception level. The qualitative results from the Timeline Study showed the timelines were mostly used for perception. Its low usage for the comprehension and projection levels may be explained by the greater effort needed to gain information for higher level situation awareness with timelines than other system features. For example, when project the future system state and prioritize actions, checking the summary of recent automated events (in the discard pile) required less interaction than searching through the timeline (see Section 4.3.3). The discard pile was also used more frequently for projection. While one system feature does not need to support all three levels of situation awareness, the application as a whole needs to facilitate maintenance of all three situation awareness levels. Designers must be mindful of the needs of each awareness level to provide the appropriate information in an easily and quickly accessible manner.

Category	Element	Specific questions
Who	Presence	Is anyone in the workspace?
	Identity	Who is participating? Who is that?
	Authorship	Who is doing that?
What	Action	What are they doing?
	Intention	What goal is that action part of?
	Artifact	What object are they working on?
Where	Location	Where are they working?
	Gaze	Where are they looking?
	View	Where can they see?
	Reach	Where can they reach?

Table 6-1: Elements of workspace awareness relating to the present information of the collaborators. This table was reproduced from Gutwin & Greenberg's workspace awareness framework (Gutwin & Greenberg, 2002).

While Gutwin and Greenberg's (2002) workspace awareness framework did not explicitly discuss the progression of awareness levels, this research revealed a similar need to connect the awareness elements. The workspace awareness element of present information contained three main categories of information: who, what, and where (see Table 6-1). Even when all three types of information are provided, there can still be breakdowns in terms of the comprehension of multiple awareness elements. For example, in the Timeline Study, the replay animation triggered by collaborators incorporated all three types of information: who (i.e., colour-coding of player who triggered the animation), what (i.e., animated icons symbolizing the type of events happened), and where (i.e., the city being highlighted on the map). However, processing the colour-coding and synthesizing these different cues were difficult to accomplish in a short amount of time. As a result, users were sometimes surprised and confused by the replay animation triggered by collaborators. Thus, the replay animation was not effective for the comprehension of multiple cues.

In contrast, for the Callout Bubble, the identity information was attached to the objects being manipulated, and this design provided who, what, and where in a simple form. Through the iterative design process, the identity information became more explicit and appropriate for the students, and the tether for connecting the identity and the object was refined. Furthermore, the final design provided real-time information with minimal interactions from the users by animating the Callout Bubbles. The evaluation also showed that the minimal work to maintain the workspace awareness was beneficial for the teachers. Based on the two investigations, the design of a workspace awareness display needs to ensure that the different awareness elements can be comprehended quickly in a synthesized manner. Gutwin and Greenberg (2002) pointed out several benefits of supporting awareness such as coordination of actions and anticipation of future collaborators' actions. Fostering the rapid comprehension of awareness cues can help users maintain workspace awareness to allow for predicting future collaborator states and simplifying coordination.

6.1.3 Persistency of Awareness Information

Situation awareness and workspace awareness present two different types of needs. How long the information stays relevant should be considered to decide on the persistency level. In the context of synchronous collaborative work, as studied in this dissertation, workspace awareness focuses on the collaborator's current actions, and a transient cue is more suitable. The relevance of collaborators' previous interactions to the current work depreciates very quickly as new collaborator actions can overwrite the previous changes such as in the case of multi-device classrooms. In the case of browsing actions as in timelines, such interaction does not have permanent impact to the system state and are transient in nature. Thus, a transient cue is more appropriate. A persistent display of collaborators' actions on the shared workspace can be beneficial for providing a historical account of changes introduced by collaborators. Such history log can help collaborators catch up on the changes that happened while they were away from the workspace or during the time they could not attend to the workspace such as in loosely coupled work and in asynchronous collaboration. Designers must be aware of these two different needs of workspace awareness and address them accordingly.

A persistent information display was essential for maintaining situation awareness given the collaborative context and potential distractions in complex tabletop systems. While animations provided a quick and minimal-effort method for users to stay aware of the automated changes, persistent displays, such as the interactive event timelines, allowed users to gather situation awareness information at any time. Moreover, a non-persistent display (e.g., animation) only gave users a fix amount of time to capture complex changes and required users to recall information after the animation was complete. The complexity of data and amount of time required to notice, understand, and form discussion and prediction should also be considered when determining the persistency level of the awareness information.

6.2 Workspace Awareness Elements in Co-located Technologies

There has been significant research work on general workspace awareness elements (Drury & Williams, 2002; Gutwin & Greenberg, 2002). Unlike in a remote collaboration setting, in a co-located workspace, some awareness information can be gathered through observation without system support. Users can observe each other's actions, postures, and facial expressions to maintain workspace awareness. For users of the co-located systems studied in this dissertation, although they were co-located in the same room, there was some physical distance between them (see Section 2.3 for the classification of co-located systems). Such systems need to actively provide some amount of awareness information since it is difficult to obtain due to the physical distance between the collaborators. However, providing all possible workspace awareness elements through the system would create too much clutter and distractions. The investigations on tabletop systems and multi-device classrooms provided insights into what workspace awareness elements should be provided in these environments.

In contrast, most situation awareness requirements are derived based on the specific task and domain (Endsley, 1988, 1993, 2000), and there are established techniques, such as cognitive task analysis (Chipman et al., 2000), for gathering the requirements. Since situation awareness requirements vary drastically across domains, this section focuses on the workspace awareness elements. The rest of this section first describes the particular types of systems studied to frame the design recommendations. Next, based on the co-located technologies studied, the recommendations about which workspace awareness elements to provide are presented, followed by design considerations for this context.

6.2.1 System Features

In the traditional physical workspace, only physical medium is present, so the collaborators' interactions are restricted by the laws of physics. However, digital technologies have enabled more flexible interaction mechanisms. The users' interactions with the shared workspace in co-located technologies can be broken down based on how the following three key spaces coincide: physical input location, virtual input location, and virtual impact location.

Physical Input Location (Control Space). The physical input location represents where the physical input is occurring, i.e., the physical location of a user's body and hands in direct-touch surface environments. Users' actions in the physical input space enable consequential communication

(Pinelle et al., 2003). However, users may not always be able to observe each other's' physical body given their seating arrangement and distances in the co-located workspace.

Virtual Input Location (Display Space / Cursor). The virtual input location represents where the input is in the virtual world, and it is not always limited to the user's physical location. For example, users may be using a mouse or phone as an input device to a large display. In this case, their physical location is different from where their pointer (virtual input) is in the virtual world. Virtual embodiments that are used to represent users' virtual input locations provide a way for collaborators to observe consequential communication of their actions in the virtual space.

Virtual Impact Location (Display Space / Animation / Feedback Location). The virtual impact location represents the location of the resulting action in the virtual world. For example, users may press a command button on the border of a tabletop interface, and the changes are reflected in the shared tabletop area. In this case, the physical input location happens at the border, and the virtual input location is in that same border space. However, the virtual impact location is at the centre of the tabletop. When virtual impacts take place, the changes being reflected in the system allow for feedthrough. The observation of changes in the share artifacts helps a user to understand collaborators' manipulations in the workspace.

See Figure 6-1 for the three types of interaction derived from the different coinciding relationships of these locations, and see Table 6-2 for examples of each type. The proposed interaction types and the classification are by no means complete, but they act as a framework to contextualize the different types of interactions on tabletop and multi-device environments. Further research is needed to map out the design space and investigate a complete taxonomy of interactions in co-located technologies.

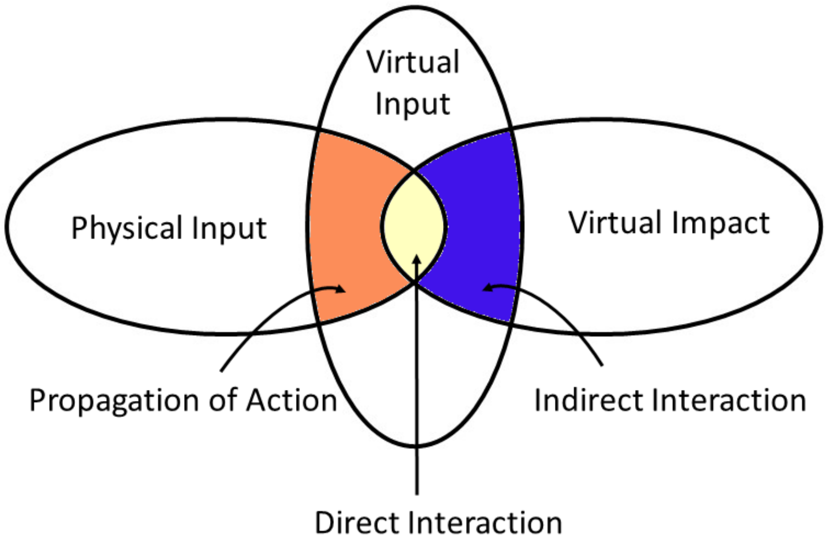

Figure 6-1: Three types of interaction in co-located technological environments. Three interaction types emerge based on how physical input, virtual input, and virtual impact locations coincide: direct interaction, indirect interaction, and propagation of action.

	Tabletop Systems	Multi-Device Environments
Direct Interaction	• Photo browsing (Otmar Hilliges, Dominikus Baur, 2007; Scott et al., 2005) • Collaborative browsing and editing (Morris et al., 2010)	• Pour data from phone to tabletop (D. Schmidt et al., 2012) • Use tablets to view slices of data on tabletop (Seyed et al., 2013)
Indirect Interaction	• Mouse input (Hornecker et al., 2008) • Laser beam (Nacenta et al., 2007)	• Personal devices as pointers to public displays (Masuko et al., 2015)
Propagation of Action	• Replay animation in timelines; • Photo tagging with replicated control (Morris et al., 2006)	• Student edits on their devices are reflected on other devices

Table 6-2: Examples of different interaction types.

Direct Interaction. Direct interactions are when all three spaces coincide, where the users' physical input, virtual input, and resulted effects are at the same location. Direct interactions are common in many tabletop applications such as photo browsing (Otmar Hilliges, Dominikus Baur, 2007; Scott et al., 2005) and collaborative browsing and editing (Morris et al., 2010). In multi-device environments, each device is perceived as an entity. Examples of direct manipulation techniques with multiple devices include using a personal device to pour data onto a tabletop (D. Schmidt et al., 2012) and to view slices of data on a tabletop (Seyed et al., 2013). Direct interactions require more explicit body movements such as reaching out to the objects in the group tabletop territories (Scott & Carpendale, 2010) or performing gestures and device movements in multi-device environments. Since the users' actions are more observable, direct interactions facilitate consequential communication (observation of collaborators' bodies) and feedthrough (observation of the shared artefacts). This is consistent with findings comparing direct-touch interactions and indirect multi-mouse interactions on tabletop systems (Hornecker et al., 2008).

Indirect Interaction. When only the virtual input and impact locations coincide, interaction techniques allow for indirectly manipulating the content. For example, there has been work examining using mice (Hornecker et al., 2008) as inputs for tabletops, rather than direct touch of the virtual objects. Several interaction techniques allow users to reach the entire workspace through interaction in their personal space such as laser beam, radar view, and virtual arm embodiments (Doucette et al., 2013; Nacenta et al., 2007). These interaction techniques typically allow users to interact at the border of tabletop systems. For multi-device environments, indirect interactions may involve individual devices acting as pointers or controllers to the public large displays, for instance Masuko et al. (2015). Observing consequential communication may be more challenging for indirect interaction than for direct interaction since users may have difficulties observing collaborators' actions in their personal territories (Scott & Carpendale, 2010) or on their individual devices.

Propagation of Action. When only physical input and virtual input locations coincide, this type of interaction represents a propagation of action. A user's action in one location can result in changes in other parts of the system. The replay animation triggered by timeline interactions is an example of propagation of action. When users tapped on events of interest on the timeline, they also invoked highlights in other parts of the system, e.g., the game map in the shared workspace. For the multi-device classrooms studied, a student's edits on their device were reflected in other locations (i.e., other students' devices), which is another example of propagation of action. Propagation of action presents challenges both in terms of consequential communication and feedthrough. For consequential communication, the actions conducted in users' personal territories and individual devices are difficult to observe. Without feedthrough support in the system, the propagated changes invoked by users can be confusing or may be completely missed.

As the three locations coincide less, observing awareness information without system support becomes more difficult, and thus raises higher awareness demands for the system. For propagation of action on tabletops, while the small gestures for invoking replay animation through timelines required less physical effort to carry out relative to physically pointing at the board, it provided little information for consequential communication. The users' confusion confirmed what previous work found about the trade-off between physical effort and workspace awareness (Ha et al., 2006; Hornecker et al., 2008; Pinelle et al., 2008). While propagation of action allowed for minimal physical effort to reach more of the tabletop interface, maintaining workspace awareness became more difficult than with direct interactions. Furthermore, Hornecker et al. (2008) found that collaborators using direct touch on tabletop interfaces experienced more interference, but were able to resolve interference more quickly relative to groups using mice (indirect interaction). The latter groups reported lower workspace awareness. Similarly, this thesis investigation found that the lack of information about *who* changed workspace awareness elements in the replay animation caused users to spend more effort coordinating and resolving confusion verbally.

Much existing work has focused on comparing direct and indirect input methods (Ha et al., 2006; Hornecker et al., 2008). Little work has examined the awareness needs for propagation of action. While the investigations conducted in this dissertation did not explicitly compare the different types of interactions, they provided valuable lessons in informing the awareness needs. The next section presents recommended awareness elements to support tabletop systems and multi-device environments, specifically for direct interaction and propagation of action.

6.2.2 Workspace Awareness Elements

The results of this research confirmed the importance of the overall three workspace awareness categories proposed by Gutwin and Greenberg's workspace awareness framework (2002), also shown in Table 6-1. However, explicitly supporting all elements in a co-located workspace would create too much clutter and distract users. As Gutwin and Greenberg also noted, co-located groups will already know some of the awareness information; thus, fewer elements need to be provided by the system in co-located environments. Based on the two studies presented in this dissertation, Table 6-3 and Table 6-4 present the recommended elements to provide in tabletop systems and multi-device environments. In both tables, the awareness elements are based on the workspace awareness framework by Gutwin and Greenberg (2002), adapted to expand two elements to provide more specificity. The *intention* element under the *what* category is broken down into *interaction* and *command*. *Interaction* represents actions that do not have permanent impact to the system state in the shared workspace such as exploration of information. *Command* represents actions that permanently modify the system state such as issuing commands through the interface and editing contents in the workspace. The *location* element under the *where* category is broken down into three categories, physical input, virtual input, and virtual impact, as discussed in the previous section. Table 6-3 shows direct interaction and propagation of action for the tabletop environment, and it provides a ranking of whether a piece of awareness information is easy to observe without additional system support and whether supporting this awareness information is recommended.

For direct interaction in a digital tabletop environment, most of the user actions happen in the shared workspace and are plainly observable by collaborators. Thus, very minimal support for the current actions is needed. However, given the potential distractions in the environment for complex domains, historical supports of commands that modify the system states can become useful for collaborators to catch up and for debriefing purposes.

For propagation of action, the presence and identity information are observable as well as collaborators' location, gaze, view, and reach since the collaborators are co-located in the same physical space. However, the rest of the information can be difficult to gather in great detail. Since actions that triggered further events in the shared workspace are typically done in users' personal space, observing the exact actions being carried out by the collaborators are hard such as knowing exactly which buttons were pressed. Consequently, knowing exactly who just made a specific change (authorship) for what reason (intention) can be difficult.

Category	Element		Tabletop – direct interaction		Tabletop – propagation of action	
			Ease to observe	Recommend to support	Ease to observe	Recommend to support
Who	Presence		easy	no	easy	no
	Identity		easy	no	easy	no
	Authorship		easy	no	hard	yes
What	Action		easy	no	medium - hard	yes
	Intention	Interaction	easy	no	medium - hard	yes
		Command	easy	yes for historical events	medium - hard	yes
	Artifact		easy	no	medium	no
Where	Location	Physical input	easy	no	easy - medium	yes, connect the two
		Virtual input		no		
		Virtual impact		no	hard	
	Gaze		easy	no	easy	no
	View		easy	no	easy	no
	Reach		easy	no	easy	no

Table 6-3: Recommended workspace awareness elements to provide for tabletop systems. For direct interaction, users can observe the collaborators' actions so minimal awareness support is needed. For propagation of action, the system needs to provide more awareness information since users do not tend to observe actions that take place in personal territories.

Furthermore, knowing where the impact of collaborators' actions can also be difficult since collaborators do not typically monitor others' actions in the personal spaces (Scott & Carpendale, 2010). For systems that involve propagation of action, designers need to carefully consider how to connect users' physical location and the consequent events invoked in other locations (i.e., connect physical input and virtual impact locations). Considering the previous design recommendation on supporting progression of awareness levels, designers need to consider users' comprehension of multiple cues to connect the information. In addition to the location information, designers should also support users' awareness of who did what, while clearly distinguish the different collaborators and actions.

Designers should also consider that there is a varying degree of granularity in collaborator's awareness of each other. Although they may not be able to observe the exact details of collaborators' actions, they can usually gain a rough sense of what others are working on (actions) with which tools (artifacts) at which area of the workspace (location). While these elements are recommended to support, designers should be aware of the level of support needed given the particular task domain. Collaborators may not always need to know the exact details.

Table 6-4 illustrates the ease of observation for workspace awareness elements and whether an element should be explicitly provided in multi-device environments. Here, only the propagation of action interaction type is considered as it is assumed that users are distributed across devices in this co-located setting. Thus, not all information can be easily observed. Collaborators may also sit in various arrangements, rather than sitting around a table. They may be sitting shoulder-to-shoulder next to each other or one behind another. Thus, presence and identity information are harder to observe in this context. The collaborators' actions and intentions as well as the artifacts they are using also become difficult to observe due to the small screen size and physical separation. Consequently, authorship is difficult to observe as well. While users' physical sitting location can be observed, their virtual location cannot be observed without system support. In the case of the shared online canvas for multi-device classrooms, students cannot easily know where the collaborators are in the virtual canvas without verbally communicate this information. The ability to observe the virtual impacts made by other collaborators is largely constrained by a user's viewport and whether they happen to spot the changes in time. In terms of users' gaze, view, and reach, since they can be in both physical and virtual world, they are broken down to physical and virtual in Table 6-4. Although a user's physical gaze and view can be difficult to observe due to the seating arrangement, their physical reach can be inferred based on where they are in the physical space. However, the virtual gaze, view, and reach cannot typically be observed given the small screen size.

Category	Element		Multi-device environment – Propagation of action	
			Ease to observe	Recommend to support
Who	Presence		medium	no
	Identity		medium	no
	Authorship		hard	yes
What	Action		hard	yes
	Intention	Interaction	hard	nice to have
		Command	hard	yes
	Artifact		hard	yes
Where	Location	Physical Input	medium	no
		Virtual Input	hard	yes
		Virtual Impact	depending on the size of the viewport	yes
	Gaze	Physical	medium	no
		Virtual	hard	no
	View	Physical	medium	no
		Virtual	hard	nice to have
	Reach	Physical	medium (inferred)	no
		Virtual	hard	nice to have

Table 6-4: Recommended workspace awareness elements to support for multi-device environments. Since users are distributed across devices in a room, most of the awareness information is hard to observe. Several key awareness elements are recommended, and some are ranked as nice to have to avoid clutter.

Although many awareness cues are difficult to observe, supporting all of them would create too much clutter. Furthermore, not all of them present enough value to outweigh the additional distractions. The Callout Bubble Study showed that who made what modifications (authorship, action, and command) on which objects (artifact) at which locations in the shared workspace (virtual input and impact) is important to support. In the case of a shared canvas, the virtual input and impact locations are the same in the virtual canvas although they are presented on different physical devices. Several information elements are ranked as nice to have for they are not as urgent and do not require the same level of saliency in the interface. Knowing what other collaborators can view and reach in their virtual space as well as their interactions can help users to further predict peers' actions and coordinate actions. However, designers need to be cautious of potential distractions created by these awareness cues. These elements were explored in the early design phases in the second study, but were dropped due to the potential distractions and technical difficulties (e.g., no mouse cursors on tablets and difficulties in detecting out-of-app interactions).

6.2.3 Factors for Design Consideration

Gutwin and Greenberg (2002) noted that awareness elements do not all have equal weight in the interface. This research found similar results. Since users can gain a rough sense of some of the awareness information, designers may consider prioritizing information that is difficult to gain such as the changes triggered through users' actions in their personal space.

Furthermore, depending on the task domain, some awareness elements are more important and need to be more salient than others. Not all scenarios require the same level of awareness support. Gutwin and Greenberg (2002) suggested designers to consider two factors when deciding on the importance of each element: the amount of interaction between participants and the amount of dynamic changes to an awareness element. Similarly, Conversy et al. (2011) observed dyads in an air traffic control task and found that when no meaningful collaboration is present, the dyads kept very little awareness of each other. Awareness is only a need when there is a meaningful dependency among the users. For example, when students are doing a brainstorming exercise, they only need enough awareness information to avoid and resolve conflict in space usage. In comparison to more intricate collaborative scenarios, less awareness information is needed. For instance, when students are researching on physical laws or social science issues together for an in-class presentation, the task requires more collaborative effort and there is more dependency among the members. In this case, the awareness information is important for users to anticipate collaborators' actions and coordinate accordingly.

In the co-located context, users are both physically and virtually present, and this distinction provides another dimension for design considerations. For example, in terms of providing awareness of user identity, a user may be identified by their names or work roles. As they are collaborating, there may be a temporary role associated with the session or the activity such as the area of responsibility for the particular collaboration session or the virtual character's name or role in a gameplay. Designers should consider how to represent users in the session and whether their permanent identities in the real-world or temporary identities in the virtual workspace are more appropriate. In terms of a user's location, designers should consider if physical or virtual locations are more relevant. Users are located both in the physical and virtual space. Virtual locations may be where a user's viewport is in the virtual workspace, which problem a user is working on, or where a user's virtual embodiment is located (e.g., an avatar). The physical location may sometimes provide more contextual information to the users. For example, when trying to provide awareness information for propagation of action in a digital tabletop application, a visual that points directly at where a user is physically sitting may be more effective than pointing at a user's virtual location such as virtual game position and the embodiment's location. In multi-device environments, users' virtual view and reach based on location and size of their viewports are more important to support than their physical view and reach.

6.3 Bridge Situation Awareness and Workspace Awareness

This dissertation focused on the concepts of situation awareness and workspace awareness, but they are not mutually exclusive concepts. Gutwin and Greenberg (2002) described workspace awareness as "a specialized kind of situation awareness" (p. 418). For a collaboration occurring in a digital workspace, other users are also part of the workspace. Their interactions contribute to the dynamic changes in the workspace and are also part of the situation to maintain awareness of. In Gutwin and Greenberg's (2002) view, workspace awareness focuses on the cases where the other users' interactions are the situation to maintain awareness of since many collaborative tasks do not involve high level of dynamic changes. In the collaborative tabletop contexts that they were concerned with, such as co-design, co-brainstorming, and co-writing, changes in the workspace are solely driven by collaborator actions. Similarly, the Callout Bubble Study in multi-device classrooms found that supporting workspace awareness was sufficient for students since almost all of the changes were driven by students' peers. However, in the case of tabletop systems involving automation, considering the concept of situation awareness in addition to workspace awareness was essential to inform the design of the timeline, due to the amount and complexity of the automated events.

Automation can sometimes be seen as a collaborator, e.g., an artificial intelligent partner in a shooter game. However, due to the nature of the automation used in many complex domains, there are different design considerations. For example, the automated events are not negotiable in scenarios such as command and control and emergency response. In contrast, a human collaborator's actions can usually be negotiated and influenced. Research from the human-automation interaction literature has also indicated several key problems related to working with automated systems such as distrust and over-reliance of automation (Endsley, 1996; Lee & Seppelt, 2009). While these problems may also be found in collaboration with humans, handling them with an automated system calls for different solutions. Furthermore, the workspace awareness framework (Gutwin & Greenberg, 2002) was developed specifically for human collaborators and does not fully apply to maintaining awareness of automation. As the co-located collaborative systems seek to support more sophisticated application with increased levels of automation, situation awareness is an important design consideration.

Even when all changes in the workspace are driven by human collaborators, some scenarios can still benefit from the concept of situation awareness such as teachers maintaining awareness of students' work progress in a multi-device classroom, and workshop organizers maintaining awareness of participants in small groups. Such scenarios are similar to the supervisory control of automated systems (Cummings & Bruni, 2009; Sasangohar et al., 2014). Although no automated actions are present, the supervisors are monitoring individual entities (e.g., students and participants), which closely resembles the situation of monitoring automated devices. As multi-device environments with many co-located users become a prevalence form of a collaborative workspace, situation awareness is an important consideration for the supervisors.

6.4 Summary

The investigations conducted in this dissertation revealed insights into the design of awareness support for co-located collaborative systems in several aspects. First, while awareness maintenance is a secondary task, supporting such a need requires careful considerations in balancing awareness and distractions. Furthermore, the system should foster the understanding of different aspects of awareness elements and provide information with appropriate persistency level. In the context of co-located systems, providing all awareness information, as a remote collaboration needs, would create too much clutter and distractions to the main task. The investigations presented in this dissertation revealed key workspace awareness elements to provide in tabletop systems and multi-device environments, specifically for direct interaction and propagation of action. Finally, this research brought the literatures in situation awareness and workspace awareness together, and these two bodies of literature are important considerations for co-located collaborative systems.

Chapter 7

Conclusion and Future Work

This dissertation has presented two investigations into awareness support for co-located collaborative technologies. The investigations focused on environments where the physical separations between users increase the difficulties in observing the collaborators and the environment. In such contexts, the awareness of system states and collaborators' actions is potentially deficient. The literature review presented in Chapter 2 revealed a gap in providing situation awareness of automated events and workspace awareness of collaborators in co-located collaborative environments. For the design of situation awareness displays, the existing work focuses mostly on supporting individuals' situation awareness, with little attention paid to the collaborative aspects (John, 2008; Sasangohar et al., 2014). Tabletop systems are increasingly being applied to complex task domains. However, existing work tends to focus on interaction techniques for collaborating over real-time data and provides limited support for situation awareness and historical information (Bortolaso et al., 2013; Conversy et al., 2011). Furthermore, most of the research on workspace awareness focuses on remote settings, and there lacks understanding in balancing awareness support, potential distractions, and clutter in co-located collaborative contexts. This dissertation presents the first step in providing insights into the design of situation awareness and workspace awareness support in co-located collaborative workspaces.

The Timeline Study (Chapter 3 and Chapter 4) was motivated by the observed user confusion and frustration while users collaborated in digital tabletop systems. Through the literature review in the areas of situation awareness, automation, and interruption recovery, an interactive event timeline was designed and implemented since it was shown to reduce response time and improve decision accuracy for single-user applications involving automated system changes (John et al., 2005; Sasangohar et al., 2014). A two-phase user study was then designed and conducted to understand how two design factors, *control placement* and *feedback location*, impacted situation awareness and how to adapt the timelines to the context of collaborative tabletop systems. The study results showed the effectiveness of individual timelines in improving situation awareness and revealed that the timelines were used as a tool to perceive dynamic changes. Furthermore, the study provided insights into designing situation awareness displays for collaborative tabletop applications.

The results of the Timeline Study also showed that users were sometimes confused or distracted by the feedback triggered by collaborators and displayed on the shared tabletop. Although users were co-located, there was a lack of workspace awareness of collaborators' actions due to the difficulties in observing each other's actions. Furthermore, the feedback on the shared workspace was too subtle due to the result of seeking to minimize distractions. A follow-up study, the Callout Bubble Study (Chapter 5), on workspace awareness support was conducted in a multi-device classroom since such environment has similar challenges for collaborators to maintain awareness of each other's actions. In the multi-device classroom setting studied, the teachers and students reported a high level of frustration due to the lack of awareness feedback of collaborator actions. Through an iterative design process, a visual cue named Callout Bubble was designed and developed to support workspace awareness maintenance in multi-device classrooms. Through a field study, the results showed that Callout Bubbles provided a balance between awareness and distractions, promoted self-monitoring behaviours, and reduced workloads for teachers.

7.1 Contributions

The Timeline Study and Callout Bubble Study contributed to the design of situation awareness and workspace awareness displays by providing empirical data to understand their effectiveness and usage. Based on the lessons learned in both studies, this research also provided a set of overall design recommendations for awareness support in co-located collaborative systems. This section presents the contributions of this research.

7.1.1 Design of the Timeline and Understanding of Its Impacts on Situation Awareness in A Collaborative Tabletop Application

The Timeline Study contributed in the design of an interactive event timeline for situation awareness maintenance on collaborative tabletop systems involving automation. It empirically evaluated two design factors of the timelines to advance the understanding of timeline adaptation in this context. The Timeline Study revealed the benefits of individual replicated timelines for improved situation awareness, and showed a correlation between timeline interactions and improved situation awareness. The video analysis of the configurable timeline usage found that the timeline was beneficial for group work since it acted as a correct historical account for individual perception of automated changes and for team members to negotiate their knowledge of the changes. The results suggested providing timeline designs that make information of automated changes readily accessible, encourage interactions for complex automated changes, and allow for flexible work patterns in a group. The Timeline Study also provided insights into how to further improve the timeline design and highlighted the importance of workspace awareness support even in a co-located environment.

7.1.2 Balance Awareness Support and Distractions in Multi-Device Classrooms

The Callout Bubble Study contributed in the design of a practical workspace awareness cue for an online shared canvas in the context of multi-device classrooms. Through a field study, it provided empirical results showing the effectiveness of the Callout Bubble cue in enabling students' self-monitoring and coordination behaviours. As a result, the teachers' workloads in classroom management were reduced. The iterative design process provided insights into design considerations for balancing the workspace awareness support and potential distractions brought forth by the cue.

7.1.3 Design Implications for Co-located Collaborative Systems

Through these two investigations, this research also contributed to a set of overall design implications for co-located technologies in terms of the how and what to support in this environment. Designers of co-located collaborative systems should aim to provide awareness information that seamlessly co-exists with the primary task and foster the understanding of different awareness elements. Both situation awareness and workspace awareness are crucial design considerations for co-located collaborative environments.

7.2 Limitations

Although the two investigations were fruitful and provided insights into designing awareness supports for co-located collaborative work, the studies had several limitations. For the Timeline Study, the Pandemic game used as the study context provided a platform for rapid prototyping, and it was effective in eliciting complex planning and decision making behaviours. Moreover, its turn-based mechanics simulated the long down time and short spurs of urgent discussions that were similar to other contexts such as emergency response and military training. However, when applying the interactive event timeline to other domains, it would need to be adapted to represent real-time data that may impact its effectiveness. Nevertheless, the Pandemic game provided a context for quick iterations and resulted in important design lessons that other co-located collaborative tools should also consider, and *control placement* and *feedback location* were valuable factors that other designers can apply.

The study recruited only experience Pandemic players, which helped to minimize necessary task training and reduce the overall study time. The player types are expected to provide different insights into timeline usages. While the novice players may rely on the timeline more than the expert players and provide more data on the learning curve of timelines, this decision allowed for the collection of rich data of complex strategizing behaviours in a reasonable amount of time. Given the potential concern with the sample population, the study broadened the pool of participants by recruiting from the local community.

The Timeline Study was conducted in a laboratory setting to maximize control of the study factors. However, in the field, such as in a person's home or in a game shop, there would be more distractions in the environment and people may not always be around the tabletop systems. These factors may affect users' timeline usage and the type of historical information that was the most important. For example, users might navigate to check previous history more or investigate collaborators' previous action. Thus, with more interruptions to the work, the importance of the timeline may increase since it is a persistent display can help people gather situation awareness. Although different usages of the timeline would be expected, the timeline would still be an essential awareness tool for the task.

The Callout Bubble was evaluated in the field to gain realistic data of students' response and usage of the feature. Consequently, there was very little control over the variables in the study. Students came from a wide variety of age range, and were working in various study subjects, activities, and group sizes. This limitation also restricted the types of statistical analysis that were appropriate to conduct on the data. However, the data was high in ecological validity, and it resulted in rich qualitative data to support the effectiveness of the design. These data also helped to validate the practicality of the design for a real-world application.

7.3 Future Work

While valuable insights were gained in this research, more work is needed to fully understand how to address awareness needs in co-located technology setting. This section presents potential future research directions stemming from this work.

7.3.1 Extending the Analysis of Timeline Interactions

The Timeline Study produced rich data of participants' collaborative activities using timelines. In the future, it is possible to use different framework to analyze the data to gain further insights. For example, the distributed situation awareness theory (Stanton, 2016; Stanton et al., 2006, 2010) indicates that individuals and computer systems are subsystems that all store awareness information, and they are coupled by the interaction and information transaction among them. This presents new ways to view and analyze the interactions among users and various awareness devices in the system.

In the future, the Pandemic game may be deployed in the field such as in a game cafe. There may be more interruptions in a realistic environment, which may make the collaboration style loosely coupled. Currently, participants checked the actions of other collaborators infrequently and mostly used the timeline to understand automated events. While this finding showed the importance of the historical information contained in the timeline for gathering situation awareness, it also showed that not all historical information is equal in the co-located tightly coupled context studied. Since users collaboratively discussed and decided on the strategies, they had little need to check this information. If the Pandemic game were deployed in the field, different needs might arise such as catching up on other collaborators' actions. The use of animation may be less effective when people are not always around the tabletop systems, and different elements on the timeline may become important. Future research can explore the timeline usages in this case and gain new insights on the timeline design.

7.3.2 Enhancing the Interactive Event Timelines

In the Timeline Study, participants confused the collaborators' replay animations as system automated game events. Further research may investigate how to improve the replay animation's visual design to better support workspace awareness. The design will need to provide a stronger link between the user's interaction on the timeline and the shared game board.

Moreover, the current timeline design left the burden of managing the feedback location on the users. Future work may investigate other ways of managing the feedback location such as gesture control. Overall, further research can investigate how to provide feedback through of collaborators' current actions in a co-located setting when automation is involved.

While the interactive event timeline was designed for situation awareness maintenance, it could potentially be a device for sharing discoveries of crucial information or events. Future research can explore ways for users to share information through timelines and how timelines can be improved to better support strategizing activities. A tabletop application can also enter a sandbox mode for simulating various strategies, and it will be important for timelines to adapt to different modes.

7.3.3 Enhancing the Callout Bubbles

From the Callout Bubble Study, the informal testing sessions and teachers' feedback revealed that the Callout Bubble may not be effective for activities involving a large group of users such as brainstorming. In this scenario, the workspace can be crowded with large amounts of user-created contents, and the awareness cue may add to too much clutter or may be difficult to be distinguished from contents. Furthermore, students do not necessarily want to maintain workspace awareness since their goal may simply be to find empty space to place their contents. Future research may investigate Callout Bubble's effectiveness in such extreme cases and iterate on the Callout Bubble's design.

Another direction is to examine the task taxonomy for different learning activities in the large collaborative virtual workspaces to support specific phases of the learning process. A task taxonomy could provide deeper understanding of the tasks that need to be supported at different phases of the learning process such as brainstorming, researching, exchanging ideas, connecting ideas, and presenting results. By gaining deeper insights into the tasks, Callout Bubbles can be iterated to tailor to the different phases.

Considering the vastness of virtual workspaces and that students may be distributed across multiple workspaces, they may not know the relevant actions occurring outside of their viewport. Further research may investigate a relevancy model for new changes. Appropriate algorithms for notifying students of relevant actions can be developed to provide awareness of relevant actions or contents while minimizing distractions.

7.3.4 Investigating Multi-Modal Feedback

The research presented in this dissertation focused on investigating visual cues to display awareness information. Other modalities, such as sound and tactile feedback, can also be explored. Many games make use of vibrations from the game pad and sound to provide feedback of the surrounding (e.g., coming close to a boss fight) and partners' status (e.g., a partner avatar that has died and needed to be revived). Future work may explore their effectiveness in providing awareness information for co-located synchronous work.

7.3.5 Consider Role-Based Support

The investigations conducted in this dissertation also called for more role-specific support in the collaborative environment. The Callout Bubble Study revealed that teachers also had difficulties maintaining awareness of student actions. There is a need to provide supervisory awareness displays for teachers in the multi-device classroom setting to better inform their time and attention allocation among the groups of students. Teachers have different objectives in the workspace, and thus have different awareness needs (e.g., (Do-Lenh et al., 2012; Martinez-Maldonado et al., 2012)). An awareness display with aggregated information of the class will help them determine how to best allocate their attention and guide the class activities. It can also act as a debriefing tool for teachers to review student activities after the lesson. As the teachers are constantly moving around in the classroom, such visualization can be presented on the teachers' private device. Alternatively, it can be presented on the digital whiteboard in the classroom, which would make this information publically available to the entire class. Future work also needs to consider teachers' awareness needs and the data that is pedagogically appropriate for all students to see.

Although the design of the interactive event timeline and Callout Bubble did not incorporate the roles of the different members in the team, they can be redesigned to highlight the different information need. In the Pandemic game, each team member has different special ability concerning their usage of shared resources and more convenient ways to carry out particular actions. Due to the differences in their ability, it is possible to make different parts of the timeline more salient and also to remind them of their special ability. In other contexts, the timelines may be highlighting information to suit the different permission level and area of responsibility, or timelines may show only relevant and permissible information. Timelines can also be applied to students' collaboration to give them a high level overview of the work progression and timelines can highlight relevant events or present information in different structure based on roles. The Callout Bubble can also have different visualizations to highlight more relevant edits.

7.3.6 Support Different Styles of Collaboration Workspaces

While the research presented in this dissertation focused on co-located synchronous workspaces in the two studies, the concepts of interactive event timeline and the Callout Bubble can be applied to other types of collaborative work. Collaborative workspaces can be broken down into four quadrants as proposed by Johansen (1991): co-located vs. remote by synchronous vs. asynchronous. Co-located workspaces refer to users working in the same physical location while remote workspaces refer to situations when users are distributed. Synchronous work refers to people working at the same time while asynchronous work refers to people working in shifts and thus require some forms of hand off.

Co-located Synchronous (Non-Turn-Based)

The event timeline presented in this dissertation showed a turn-based view and had a fixed structure. In the future, it can be redesigned to incorporate real-time data. It may be applied to multi-device classrooms to provide situation awareness for teachers. By providing aggregated information of students' activities, the timeline could help improve teachers' awareness of students' work progress and their classroom management. The timeline can become a representation closer to an information dashboard, which contains information such as amount of new creations of objects in the workspace for each group, idling time, and visual overview of each group's workspace.

Future work can also consider adapting the timelines to other domains that involve real-time data such as military training. Designers need to consider additional concerns related to handling real-time data. For example, users cannot control the pace of automated events, and new changes may happen while users are exploring the changes. Historical events in the timeline may be related to a moving object on the shared workspace, and the timeline may be moving as time ticks. The visual design needs to investigate how to provide situation awareness for the user to understand the connection between the historical events and the moving objects. The system also needs to consider how to provide workspace awareness of interactions involving moving objects. Although the visual design of the timeline will be quite different to incorporate real-time data, the main features of the interactive event timeline should be preserved, e.g., contain historical information, present meaningful overview data, show detail information upon interaction, highlight events in context, and present meaningful static visualization.

Co-located Asynchronous Work

The interactive event timelines can be applied to asynchronous work to facilitate hand-off in many domains such as emergency response. In the Timeline Study, the animated walkthrough of previous game events, shown at the beginning of the study sessions, was helpful for participants to understand large amounts of historical information. However, it took time for the participants to watch the animation. Similarly, Scott et al. (2006) found that animated interruption assistant required longer task completion time than the bookmark assistant interface, which allowed users to select from a timeline to replay a specific animated sequence of events. Timelines could incorporate controls for animated contents to support the hand-off process during asynchronous work to reduce the viewing time. Attention will also need to be paid to adapt this approach for multi-user environments to ensure the appropriate balance between the power of an individual and their distraction to the entire group. Further research is needed to optimize the design for timeline as an awareness display and a hand-off tool for asynchronous work in a collaborative environment.

Remote Synchronous Collaborative Work

Callout Bubble could also be used for synchronous remote workspace. A student who is sick at home could participate remotely by connecting to the shared canvas, and a group of students could work on their homework in the shared canvas from their respective homes. In a remote scenario, Callout Bubbles are even more important since they provide workspace awareness to help users find out *who* is working on *what* and *where*. Design teams may conduct remote brainstorming sessions that require people to work in parallel in a shared virtual workspace to gather ideas and annotate or modify each other's work. Callout Bubbles can be adapted for this usage scenario. Teams preparing for a presentation in a free-form workspace, such as Prezi[22], will also need Callout bubbles to keep each other aware of new edits and work progress.

Remote Asynchronous Work

The SMART amp™ application has also been used for remote asynchronous work. Informal observations showed that students sometimes misinterpreted the meaning of the Callout Bubble in this context. Schools sometimes organize cross-school collaborative projects. Students would be

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[22] https://prezi.com/

working in the shared canvas at different times since they have different schedules for the particular class. Students entering the workspace might see new changes. Since the system provided no historical information of who conducted which types of edits on which objects at what time, the students attributed the changes to any students who continued to edit the previously modified objects. Students sometimes questioned the current editor about changes made by previous editors of the same object. This created confusion in the collaborative workspace. Thus, students may benefit from similar historical information provided by the timelines for catching up to the changes in this context. However, further research needs to explore how to engage users to use timelines for exploring large amounts of data and how to optimize the visual presentation of events in timelines.

7.3.7 Applications to Other Collaborative Domains

Interactive event timelines and Callout Bubbles can be applied to other collaboration contexts. The interactive event timelines can be applied to other contexts such as debriefing in military trainings. At the end of the session, the timelines may be explored to highlight the progression of the situation and major decisions, and this can be a learning opportunity for the trainees. Furthermore, the timeline may be adapted to other co-located environment where a monitor needs to keep track of the activities happening in the workspace. For example, two teachers co-teaching in a multi-device classroom also need a way to keep track of students' activities.

For example, in the context of an emergency response team, there is often a mix of officers co-located in a command centre and agents in the field. Maintaining situation awareness and workspace awareness is essential. Future research can explore how the timelines and Callout Bubbles may be adapted to fit the needs of such different group contexts. Callout Bubbles can be applied to other collaborative free-form workspaces with touch devices such as remote brainstorming sessions and co-located design critiques. It can also be used for other types of multi-device environments such as intelligent meeting spaces (Beaudouin-Lafon et al., 2012; Fox et al., 2000).

7.3.8 Applications to Other Co-located Collaborative Technologies

Two specific types of co-located technologies were investigated in this research: tabletop systems and multi-device environments. Future research can explore the effectiveness of the timeline and Callout Bubble for different technology setups. For example, how well would the timeline work on a digital whiteboard with people standing around it for a strategizing task? Alternatively, the timeline can be placed on individual devices, and the interactions on the timeline can trigger feedback on the shared display, which can be a digital tabletop or a digital whiteboard. The effectiveness of the timeline and how it can be adapted to different setups can be investigated. It is unclear of the potential effectiveness of Callout Bubbles on large displays, both vertical and horizontal. Further work may explore how Callout Bubbles facilitate the process of situation awareness maintenance to help users gain an understanding of the changes in the workspaces and predict the future work progress.

7.3.9 Investigate Situation Awareness Elements and Automate Timeline Creation

As discussed in Section 6.2, while the literature in workspace awareness suggests specific elements to support, the design of situation awareness displays typically relies on domain-specific task analyses, which are labour intensive and time consuming. The timeline visualization presented in this dissertation was also derived based on an in-depth task analysis. Future work may investigate fundamental situation awareness elements to guide the design of awareness displays seeking to represent automated changes. Furthermore, future work may investigate ways to use visualization algorithms (Humphrey & Adams, 2010) to create more generalizable event timelines that can be applied to other domains.

7.4 Summary

As co-located technologies start to leverage computational power to support complex work, providing appropriate feedback is essential for users to maintain situation awareness of the dynamic data. Moreover, while multiple users are co-located and collaborating in a shared workspace, the system needs to augment users' actions to enable workspace awareness maintenance and subsequent coordination.

The research presented in this dissertation investigated the situation awareness and workspace awareness needs in co-located workspaces, specifically for tabletop systems and multi-device classrooms. The investigations presented opened up further research questions. While the immediate work includes iterations on the interactive event timeline and the Callout Bubble, future work may consider applying them to enhance other types of collaborative domains and technologies. More importantly, this research revealed the importance of awareness support in co-located collaborative environments.

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Appendix A

Iterative Design Process of the Interactive Event Timeline

This section details the design iterations conducted for the interactive event timeline in the Timeline Study.

A.1 Low-Fidelity Sketches

In the sketching phase, we considered both group and personal territories (Scott & Carpendale, 2010) on the tabletop system as candidates for persistent information displays. The storage territory was not considered given that typical automatic interfaces manage the system state. See Figure A-1 for an illustration of group and personal workspaces.

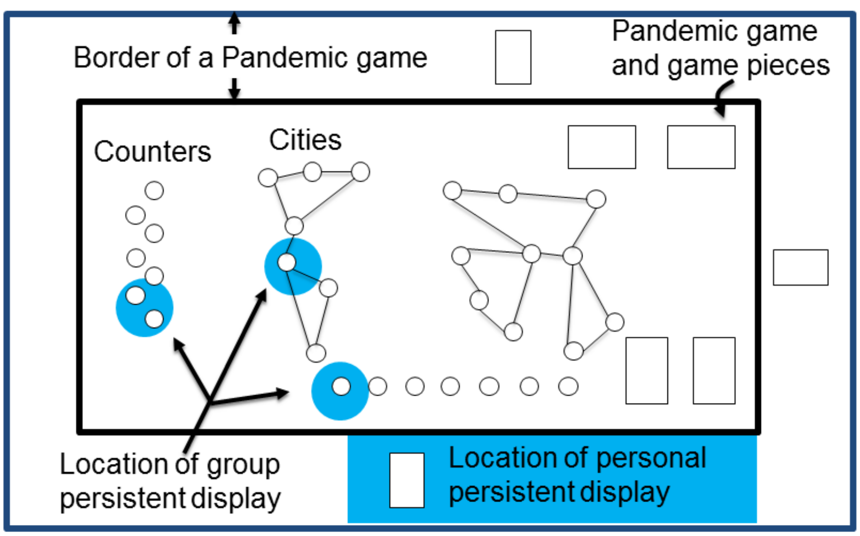
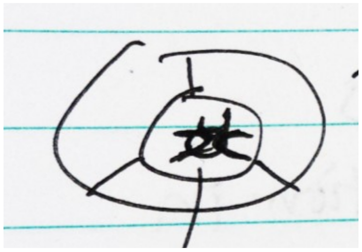


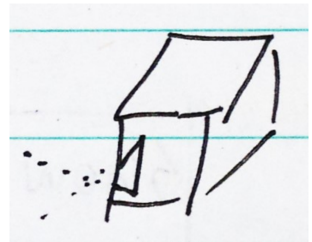
Figure A-1: Illustration of the locations for group and personal persistent displays (highlighted in blue). Group persistent displays are at the shared workspace while personal persistent displays are at the border of the game.

For persistent feedback in the group workspace, we considered several aspects of the design such as the following:

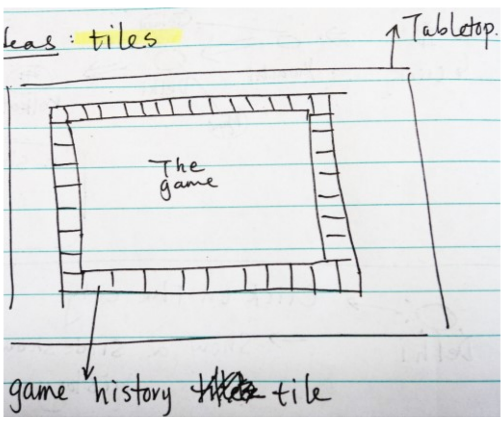
- Static awareness displays (Figure A-2A and Figure A-2B) vs. interactive awareness displays (Figure A-2C to Figure A-2F)
- Different types of historical information such as a city on the map (Figure A-2D), spread of diseases automated by the systems (Figure A-2E), and user actions (Figure A-2F)
- Showing an overview of previous historical system states (Figure A-2C) vs. showing information based on specified parameters (Figure A-2D to Figure A-2F)
- Showing all historical information equally and discounting the older information (Figure A-2F top and bottom)



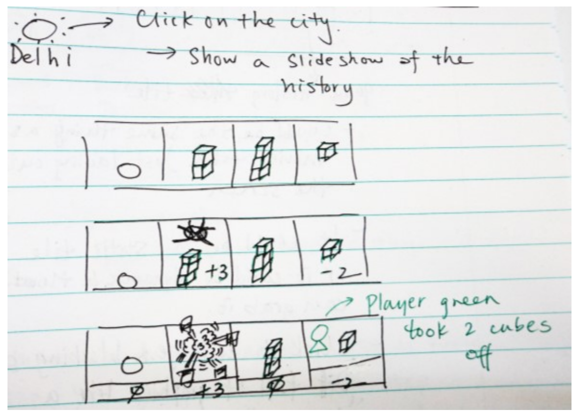
A. Incorporate disease information into city visualization



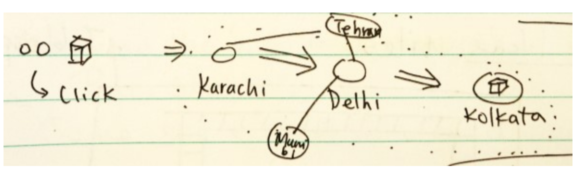
B. Show the source of disease spread on a disease cube using Wedge (Gustafson et al., 2008)



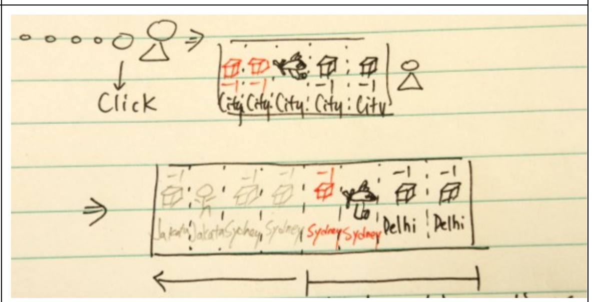
C. Tiles of game history around the game map that can be expanded to see previous game states



D. Tap on a city to see historical events happened there



E. Tap on the trail of a disease cube to see the animated spread of diseases on the map



F. Tap on a player's trail to see their previous actions. Top: Show all information equally. Bottom: Grey out information too long ago

Figure A-2: Some of the design ideas for showing persistent information in the group workspace.

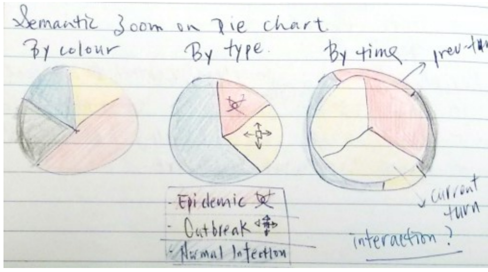
For persistent feedback in a player's personal workspace, we considered several aspects of the design such as the following:

- Showing aggregated information such as stacked graph and pie charts (Figure A-3A) vs. detailed information of the changes such as movie film strips and timelines (Figure A-3B and Figure A-3C) vs. a mix of detail and aggregated information (Figure A-3D)
- Presenting information chronologically (Figure A-3B and Figure A-3C) vs. spatially (Figure A-3E to Figure A-3G)
- Using different mechanisms for highlighting information such as greying out (Figure A-3E), fish eye lenses (Figure A-3F), and folding (Figure A-3G)
- Using individual devices (Figure A-3H)

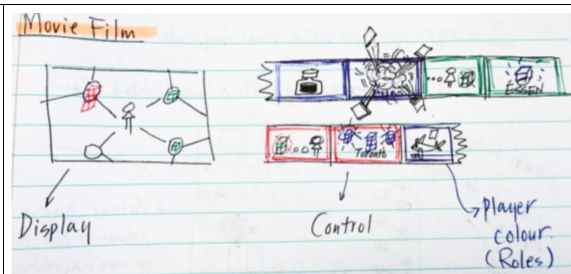
We received feedback on these designs through discussions with other human-computer interaction researchers and expert Pandemic game players. For the group workspace, designs that provided feedback of automated and player actions were chosen as our goal was to enhance situation awareness and workspace awareness. Interactive designs were chosen over static designs to reduce potential clutter in the interface.

For personal workspaces, we decided to focus on historical event logs to facilitate situation awareness maintenance. Moreover, John et al. (2005) and Smallman and John (2003) has shown the benefits of event logs in reducing response time, misses, and errors. We also decided to focus on providing detailed information to address the problem that users sometimes missed automated events. This problem was also previously observed by Wallace et al. (2012).

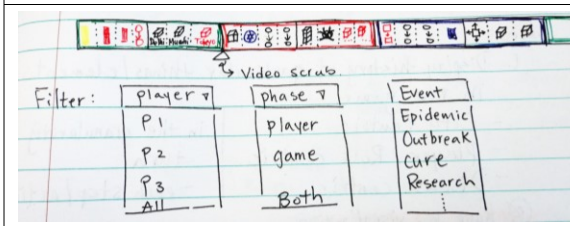
From discussions of the low-fidelity sketches, we had ideas for how to refine the design and were inspired to create new designs. In the next phase, we created digital mock-ups for the selected sketches and new ideas.



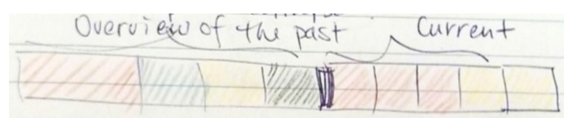
A. Aggregated information of automated changes by region, type, and time



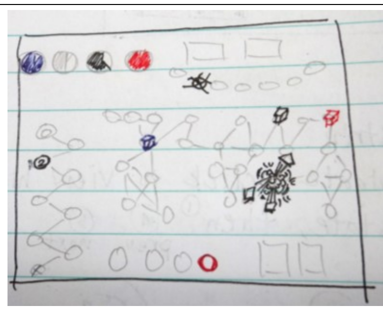
B. Tap on a frame on the strip (right) to see detailed information on the display (left). The film strip shows automated and player actions.



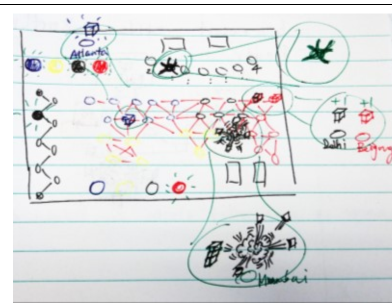
C. Timeline strip showing automated and player actions, with filters for player, game phase, and event type



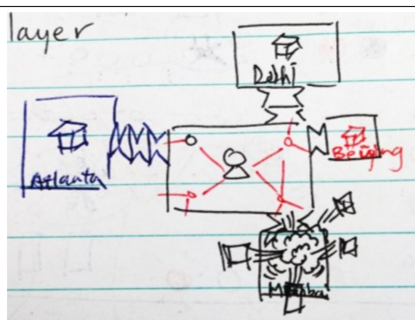
D. Timeline strip with detailed current turn information and overview of previous turns



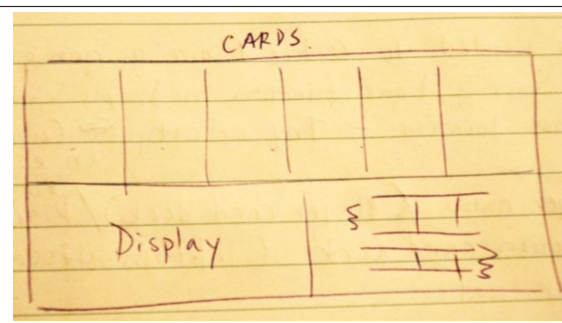
E. Minimap with highlights of recent automated events (the rest is greyed out)



F. Minimap with fish eye lenses highlighting recent automated events



G. Minimap with folded visualizations (Ion et al., 2013) showing automated changes



H. Tablet display incoporating player hand and the movie film sketch in B

Figure A-3: Some of the design ideas for showing persistent information in a player's personal workspace.

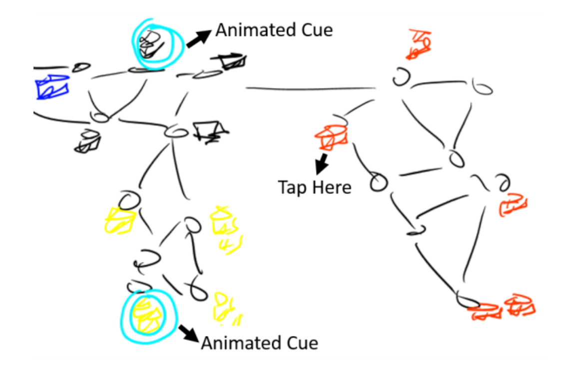
A.2 Medium-Fidelity Mock-Ups

With the goal to iterate on the selected designs and expand on the chosen exploration direction, we created digital mock-ups for the promising ideas from the low-fidelity phase and for new ideas. In this phase, we decided to use a prototyping tool, ProtoActive [23], developed by Tulio et al. (2013). The ProtoActive tool was designed to facilitate rapid prototyping for interactive surfaces. The pen and paper was limited in creating interactive contents. The ProtoActive tool simplified the process by allowing users to define gestural input for interface items and the corresponding changes. During evaluation with users, it recognizes the gestural input and presents the predefined changes.

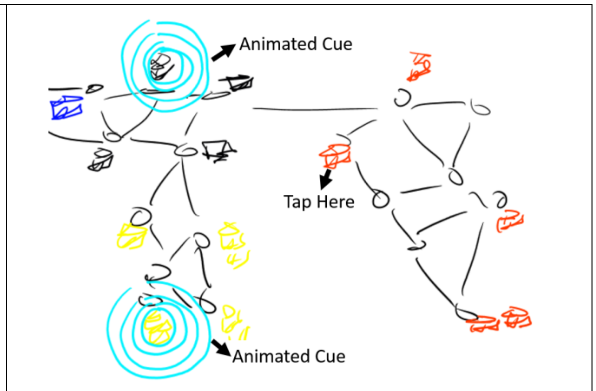
For the persistent feedback in the group workspace, we further explored several aspects of the design such as the following:

- Animating related automated events when tapping on a node (a city in the context of the Pandemic game) to help understand connections between events, see Figure A-4A and Figure A-4B. Different types of animations were prototyped to show different connections.
- Showing a textual log for the history of automated events in-place at a node when users interact with it, see Figure A-4C
- Allowing for navigating through different historical events in- place at a node (Figure A-4D)
- Using global filters and interactive legends (Dykes et al., 2010) as a way to allow for understanding the overall trend of changes and the current system state to facilitate strategizing, see Figure A-4E for global filters and Figure A-4F for interactive legends

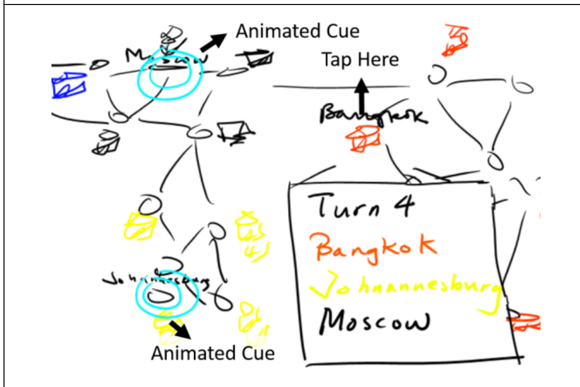
[23] http://pages.cpsc.ucalgary.ca/~tdsalcan/ProtoActive.msi



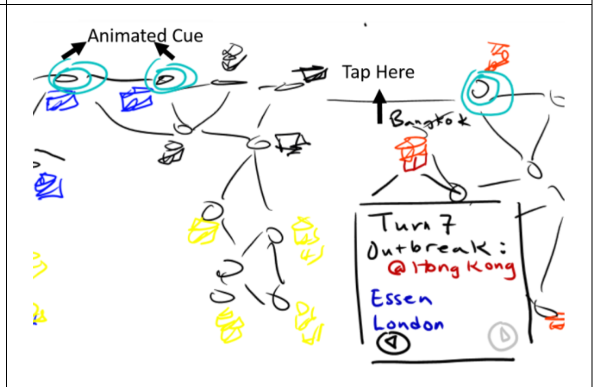
A. Animated cue highlighting relevant events (first frame)



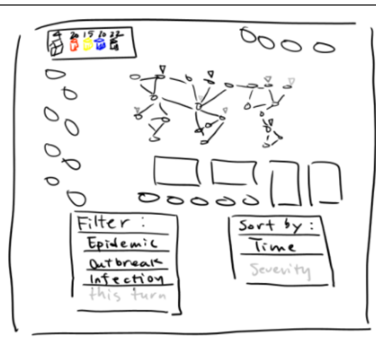
B. Animated cue highlighting relevant events (third frame from A)



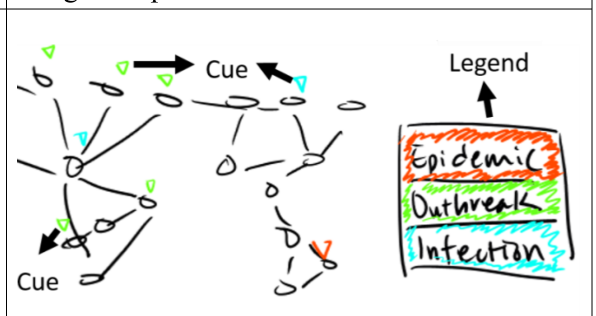
C. Persistent textual history on the city Bangkok with relevant city highlighted



D. Based on C, additional changes took place. Upon tapping the city Bangkok, users can see the new changes happened in the textual log and navigate to previous historical events.



E. Global filters to see triangles on the map indicating types of events happened on particular cities



F. Interactive legend (Dykes et al., 2010) to see triangles on the map indicating types of events happened on particular cities

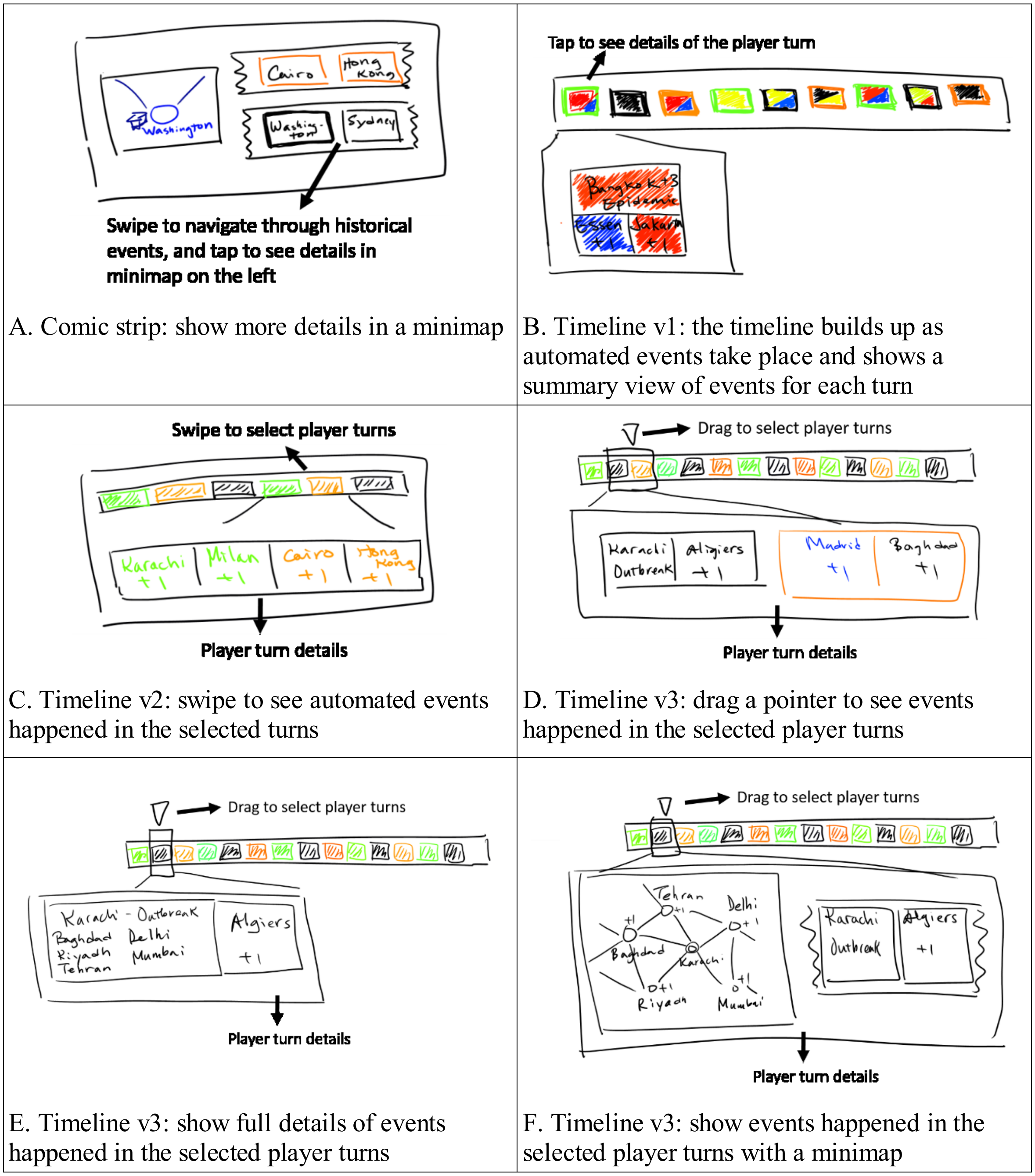
Figure A-4: Some of the design ideas explored for persistent displays in group workspace in the medium-fidelity phase. The black arrows and typed texts are annotations to explain the mock-ups, and they are not part of the mock-ups.

For persistent feedback in a player's personal workspace, we explored several aspects of the design such as the following:

- A comic strip that shows a limited amount of detailed information (Figure A-5A) vs. a timeline that provides an overview that shows the game progression (Figure A-5B to Figure A-5F)
- Textual vs. graphical timelines
- Variable location for detailed information (Figure A-5B) vs. fixed location (Figure A-5C and Figure A-5D)
- Different interactions for navigating through the timelines such as tapping on specific turns (Figure A-5B), swiping gestures (Figure A-5C), and a widget for scrubbing (Figure A-5D)
- Different encodings of the detailed information such as colour (Figure A-5B), size (Figure A-5B), text (Figure A-5A and Figure A-5C), symbols, and a spatial map (Figure A-5F)
- Showing different levels of detail (Figure A-5D to Figure A-5F)

We installed the ProtoActive tool on a tablet device and used it to discuss the designs with human-computer interaction experts and Pandemic game players. For the group workspace, we decided to provide historical information of nodes when players were interacting with them (i.e., Figure A-4C). This design placed the feedback near users' centre of attention in order to minimize the amount of time spent on searching for feedback. The other options required visual search on the map for the feedback, which can be time consuming due to the large size of the tabletop display.

For the personal workspace, we decided to move forward with the graphical event timeline for several reasons. Sasangohar et al. (2014) showed that interactive graphical event timelines are beneficial for interruption recovery in terms of decision accuracy and recovery time. Furthermore, graphical representations allow for quick recognition of crucial information (Sasangohar et al., 2014). A graphical interactive event timeline is also space-efficient as the interactivity allows us to show information on demand rather than showing all historical information at once. Furthermore, a timeline that fits into a user's field of view may allow for quick perception of changes since all the information is in one location. We also decided to use a fixed location for the feedback in order to allow users to brush through several events while fixating on the same spot to reduce the amount of time spent on searching for feedback.



A. Comic strip: show more details in a minimap

B. Timeline v1: the timeline builds up as automated events take place and shows a summary view of events for each turn

C. Timeline v2: swipe to see automated events happened in the selected turns

D. Timeline v3: drag a pointer to see events happened in the selected player turns

E. Timeline v3: show full details of events happened in the selected player turns

F. Timeline v3: show events happened in the selected player turns with a minimap

Figure A-5: Some of the design ideas explored for persistent displays in a player's personal space in the medium-fidelity phase. The black arrows and typed texts are annotations to explain the mock-ups, and they are not part of the mock-ups.

A.3 High-Fidelity Prototypes

Based on the medium-fidelity digital mock-ups, we began implementing persistent feedback in the group and personal workspaces. We used Processing[24] and the Simple Multi-Touch Toolkit[25] as they allow for a relatively rapid prototyping process and the flexibility to create custom interfaces. The prototypes were implemented and piloted on tabletop systems.

For the group workspace, we found that persistent feedback in the group workspace created too much clutter and manual work to manage the opening and closing of the persistent feedback. We thus removed it from the interface.

For the personal workspace, we iterated on the design of the timeline, and the final timeline design was similar to the ideas developed in the previous iteration. We refined the layout of the timeline, colour palette, and input interactions. We also reused many of the symbols and icons in the physical Pandemic games to encode information on the timeline to provide a familiar interface and reduce training time.

[24] https://www.processing.org/
[25] http://vialab.science.uoit.ca/portfolio/smt-toolkit

Appendix B

Timeline Study Materials

This section contains all the study material related to the first study on ways to support situation awareness using interactive event timelines in the context of the digital tabletop Pandemic game.

B.1 Permission to Use the Pandemic Board Game

Pandemic game permission

Matt Leacock <mleacock@mac.com> Sat, Feb 23, 2013 at 11:26 PM
To: Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>

Hi Betty

You're approved given the following are observed:
- the app cannot be made publicly available
- please credit Z-man Games and Matt Leacock
- Z-man won't be able to provide source artwork so you'll need make due with what you can find or scan

Best of luck with the experiments! I'd love to be kept in the loop as things progress.

- Matt

On Feb 22, 2013, at 2:51 PM, Yu-Ling Betty Chang wrote:

Hello Mr. Leacock,

Thanks! Have a great weekend!

Betty
On Fri, Feb 22, 2013 at 4:46 PM, Matthew Leacock <mleacock@mac.com> wrote:
Hi Betty

Apologies—I have not heard back from them. I'll ping them again and get back to you within the next 3-5 days.

- Matt

On Feb 22, 2013, at 10:52 AM, Yu-Ling Betty Chang <betty.chang@uwaterloo.ca> wrote:

Hello Mr. Leacock,

I hope everything is going well for you. Have you heard back from Z-man about the permission to use Pandemic for our research project?

Thanks for your help.

Cheers,
Betty
On Sat, Dec 15, 2012 at 12:45 AM, Yu-Ling Betty Chang <betty.chang@uwaterloo.ca> wrote:
Hello Mr. Leacock,

Thank you so much for your quick reply! Please keep us updated.

It was actually my colleague, Victor, that was standing by the poster. After CSCW, we were circulating the photo of you two by the poster in the lab, and everyone else was sad that we couldn't be there when you passed by.

Thanks for giving us permission to use Pandemic so far! Sometimes, people are attracted by our poster because they recognize the game, which is something they really enjoy!

Hope to hear back from you soon.

Cheers,
Betty
On Thu, Dec 13, 2012 at 11:26 PM, Matt Leacock <mleacock@mac.com> wrote:
Hi Yu-Ling

Thanks for your inquiry. I've forwarded on your message to Z-man (they're currently licensing the game and own the artwork) and will get back to you soon as I hear from them.

Incidentally, I think I may have bumped into Joey at the CSCW Conference last year in Seattle. I think I caught his poster session there.

All the best,

- Matt

On Dec 13, 2012, at 1:18 PM, Yu-Ling Betty Chang wrote:

Dear Mr. Shlasinger, Mr. Leacock, and Mr. Cappel,

My name is Yu-Ling (Betty) Chang. I am a third year PhD candidate in Systems Design Engineering at the University of Waterloo. In my research, I investigate ways to improve face-to-face collaboration through the use of computers, specifically digital tabletop computers. My collaborator, Joey Pape, from Queen's University has been using the *Pandemic* board game as the case study for investigating the impact of automation on collaboration. Joey has recently finished his Master's degree. For my passion in improving people's life through technology and my personal interest in board gaming, I would like to continue with the project.

I'm writing to request your consent to use the *Pandemic* board game in the next phase of my thesis research. In Joey's work, he has implemented a version of the*Pandemic* on digital tabletop computers. As part of a collaborative effort with Joey's research group, we conducted user studies of Joey's system at Queen's University and here at the University of Waterloo, inviting players to play the game and observing their interactions with each other and with the tabletop computer. From this study, we found that while automation could reduce workload (e.g., playing the infector's role), it could also negatively impact their awareness of the game events (e.g., type of events and cities being infected). My thesis will investigate ways to improve players' awareness of the automation. I will run lab studies as well as a field study in a game shop or someone's living room. My thesis will contribute new visualization techniques that improve players' awareness of automation.

It is very important to me to respect Z-Man Games' property. I would like to make clear that this is strictly academic, non-commercial research. If you are interested in supporting us by permitting us to use original *Pandemic* artwork, none of these materials would be transferred, copied, or otherwise redistributed beyond our lab, nor would they be sold or otherwise commercialized. The only exception to this would be, if you consent, the publication of photos of the project in my thesis or other non-commercial academic publication. If you consent, we would hope to share the digital game we develop with other research labs that have digital tabletop systems for strictly research purposes. Furthermore, we would explicitly specify to all participants that our study is not affiliated with Z-Man Games.

If you have any questions about our work, or this request, this please do not hesitate to contact me. Additionally, this project is being overseen by my thesis supervisors Dr. Stacey Scott (Assistant Professor, Systems Design Engineering and English Language and Literature; and Associate Director, University of Waterloo Games Institute) and Dr. Mark Hancock (Assistant Professor, Management Sciences and Associate Director of Research Training, University of Waterloo Games Institute). They may be contacted at stacey.scott@uwaterloo.ca and mark.hancock@uwaterloo.ca, respectively.

Information concerning the current progress of the project with *Pandemic* can be seen at: http://www.nsercsurfnet.org/pmwiki.php?n=SurfNet.ScottGrahamDigitalTabletopBoardGaming

Thank you for considering this request, and I look forward to receiving your response soon.

Sincerely,
Yu-Ling (Betty) Chang

--
Y.-L. Betty Chang
PhD Candidate, Systems Design Engineering
University of Waterloo
http://www.bettychang.net

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Y.-L. Betty Chang
PhD Candidate, Systems Design Engineering
University of Waterloo
http://www.bettychang.net

B.2 Information Letter

Project Title: Awareness Interface for collaborative digital tabletop games

Student Investigator:
Yu-Ling (Betty) Chang Systems Design Engineering betty.chang@uwaterloo.ca

Faculty Supervisors:
Dr. Mark Hancock Management Sciences Engineering mark.hancock@uwaterloo.ca
Dr. Stacey Scott Systems Design Engineering stacey.scott@uwaterloo.ca

You are invited to participate in a research project conducted by Yu-Ling (Betty) Chang, and Drs. Hancock and Scott (Faculty Supervisors) at the University of Waterloo. The researcher will read through this letter of information with you, describe our experimental procedures in detail, and answer any questions you may have. The research is funded by the NSERC SurfNet research network.

Summary of the Project:
The purpose of the project is to investigate design alternatives of an awareness interface for digital tabletops. Digital tabletops provide an opportunity for automating complex tasks in collaborative domains involving planning and decision-making, such as strategic simulation in command and control. It is essential that people using such systems have a high level of awareness of the situation and of the potential consequences of any changes occurring in the environment. This study will evaluate different factors that impact the design of an awareness interface, which aims to improve the participants' situation awareness in tabletop systems that use automation. Participants will be asked to play a digital tabletop board game with different configurations to simulate a complex collaborative environment. They will fill out questionnaires that gather feedback on their workload, gaming experience, and awareness of the game state.

Procedure:
You will be asked to play a digital version of the Pandemic board game in a group of 3 players. The study will take up to 150 minutes (2.5 hours).

At the beginning of the session, you will be asked to complete a questionnaire, including demographic and background information. The study consists of three phases. In the first phase, you will be asked to play the base game and complete a questionnaire. In the second phase, you will play three different game trials. For each condition, you will play a Pandemic challenge where you will see a scenario of the game. As a group, you have to strategize and carry out the strategies. You will fill out questionnaires on your gaming experience, knowledge of the game state, and your preference. In the third phase, you will play a configurable version, and fill in a questionnaire again. Finally, the researcher will debrief you on what aspects of the user interface were specifically tested and ask for any additional feedback. You will be provided with a copy of the official rules of the Pandemic game. If you experience any difficulties during the study and cannot proceed, advise the researcher who may briefly help you. With your permission, the study will be audio and video recorded.
You will be given a $20 honorarium for your participation: 10$ for the first hour of participation and 10 dollars if the study is completed entirely. The amount received is taxable. It is your responsibility to report the amount received for income tax purposes.
Your participation is voluntary. You may decline to answer any questions if you wish. If you wish to withdraw from participation at any time, please advise the researcher and the session will stop. Any data collected up to the point of withdrawal will be destroyed. Should you choose to withdraw, you will still receive the $10 honorarium for your participation.
Risks and Benefits:

Minimal risk is anticipated in the study. The infrared lasers used for the tabletop could damage human eyes if the laser line goes directly into the eye. The laser plane is right above the table surface. Therefore, please do not look at the laser from the height of the table surface directly.

While you may not benefit directly from this study, results from this study may improve the understanding of digital tabletop games. Applications of this work are in the development of collaborative software and interfaces.

Confidentiality and Data Security:
All information provided is considered completely confidential. Your name will not appear in any publication resulting from this study; however, with your permission anonymous quotations from the conversation may be used. In these cases participants will be referred to as Participant 1, Participant 2, … (or P1, P2, …). Data collected during this study will be retained indefinitely in a locked cabinet or on password protected desktop computers in the Collaborative Systems Laboratory at the University of Waterloo.

You will be asked to explicitly consent to the use of video and audio data captured during the study for the purpose of reporting the study's findings. If and only if consent is granted, this data will be used only for the purposes associated with teaching, scientific presentations, publications, and/or sharing with other researchers. Participants will not be identified by name.

Contact Information and Research Ethics Clearance:
We would like to assure you that this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics committee. However, the final decision about participation is yours. Should you have any ethical comments or concerns resulting from you participation in this study, please contact the Director, University of Waterloo Office of Research Ethics (Dr. Maureen Nummelin, maureen.nummelin@uwaterloo.ca, 519-888-4567 ext. 36005).

Please retain a copy of the letter of information and consent form. If you have any questions, concerns or comments about this research, please contact any of the research team: Yu-Ling (Betty) Chang (betty.chang@uwaterloo.ca), Dr. Mark Hancock (mark.hancock@uwaterloo.ca, 519-888-4567 ext. 36587), and Dr. Stacey Scott (stacey.scott@uwaterloo.ca, 519-888-4567 ext. 32236).

Thank you for your assistance in this project.

B.3 Information Consent Form

Project Title: Awareness Interface for collaborative digital tabletop games

I have read the information presented in the information letter about a study being conducted by Yu-Ling (Betty) Chang at the University of Waterloo under the supervision of Dr. Mark Hancock and Dr. Stacey Scott. I understand that I will be participating in a research project in tabletop gaming, and that I will be engaging in a study and the procedures and risks are described in the attached letter of information. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

Sometimes a certain image and/or segment of video recording clearly shows a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific presentation or in a publication.

I am aware that I may allow video and/or digital images in which I appear to be used in teaching, scientific presentations, publications, and/or data sharing with other researchers with the understanding that I will not be identified by name. I am aware that I may allow excerpts from the conversational data from this study to be included in teaching, scientific presentations and/or publications, with the understanding that any quotations will be anonymous.

I am aware that my participation is voluntary and that I may withdraw my consent for any of the above statements or withdraw my study participation at any time without penalty by advising the researcher.

This project has been reviewed and received ethics clearance through a University of Waterloo Research Ethics committee. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Yu-Ling (Betty) Chang (betty.chang@uwaterloo.ca), Dr. Mark Hancock (mark.hancock@uwaterloo.ca, 519-888-4567 ext. 36587), and Dr. Stacey Scott (stacey.scott@uwaterloo.ca, 519-888-4567 ext. 32236), and that if I have any ethical comments or concerns about the study I may contact the Director of University of Waterloo Office of Research Ethics (Dr. Maureen Nummelin, maureen.nummelin@uwaterloo.ca, 519-888-4567 ext. 36005).

	Please Circle One		**Please Initial Your Choice**
With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.	**YES**	**NO**	____
I agree to be audio and video recorded.	**YES**	**NO**	____
I agree to let my conversation during the study be directly quoted, anonymously, in presentation of the research results.	**YES**	**NO**	____
I agree to let the video recordings, digital images, or audio recordings be used for presentation of the research results.	**YES**	**NO**	____

Participant Name: ____ (Please print)

Participant Signature: ____

Date: ____

B.4 Debriefing Letter

Project Title: Awareness Interface for collaborative digital tabletop games

Student Investigator:

Yu-Ling (Betty) Chang	Systems Design Engineering	betty.chang@uwaterloo.ca

Faculty Supervisors:

Dr. Mark Hancock	Management Sciences Engineering	mark.hancock@uwaterloo.ca
Dr. Stacey Scott	Systems Design Engineering	stacey.scott@uwaterloo.ca

Thank you for your participation in this study. Now that you have completed your tasks, the researcher will answer any questions you raised during the performance of the tasks, and any additional questions you have on the process used and the purpose of the study.

Digital tabletops provide an opportunity for automating complex tasks in collaborative domains involving planning and decision-making, such as strategic simulation in command and control. Examples of automation include advancing military units and enforcing rules of engagement and combat in a simulation. It is essential that people using such systems have a high level of awareness of the situation and of the potential consequences of any changes occurring in the environment. When automation leads to modification of the system's state, users may fail to understand how or why the state has changed, resulting in lower situation awareness and incorrect or suboptimal decisions. The purpose of this project is to design information visualization tools to improve people's awareness of automated actions.

We have designed an interactive event timeline that aims to improve situation awareness in tabletop systems that use automation. This project investigates two relevant design factors: the ownership of the timeline in multi-user situations and the location of the detailed visual feedback resulting from interaction with the timeline.

You have played the base version without the timeline, the six configurations that includes different alternatives of the two factors, and a freely configurable version. Through our observation of the game play and the questionnaire data, we hope to better understand the utility of each configuration. The result will help us refine the design of the awareness interface. In the future, we would like to apply the design lessons learned and the refined design to other collaborative collocated domains to help improve situation awareness of automated actions.

Please remember that all information you provide will be considered completely confidential, except where consent has been granted for an image and/or video recording to be used anonymously in the context of teaching, scientific presentations, publications, and/or data sharing with other researchers.

If you have any ethical comments or concerns about this study, please contact at the University of Waterloo:

- The Director, University of Waterloo Office of Research Ethics (Dr. Maureen Nummelin, maureen.nummelin@uwaterloo.ca, 519-888-4567 ext. 36005).

If you have any questions, concerns, or comments about this research, please feel free to contact any of the research team:

- Yu-Ling (Betty) Chang (betty.chang@uwaterloo.ca)
- Dr. Mark Hancock (mark.hancock@uwaterloo.ca, 519-888-4567 ext. 36587)

- Dr. Stacey Scott (stacey.scott@uwaterloo.ca, 519-888-4567 ext. 32236).

Further information on this and related work is available at the Collaborative Systems Lab website, http://csl.uwaterloo.ca.

B.5 Study Script

1. Greet & Consent Form

Hello, my name is Betty. Thank you for coming to the study. There will be three parts to the study. First, you will play some training games to get you familiar with the game interface. Then, you will solve some Pandemic challenges, and finally you will play a full game. That's the basic flow of the stud. I would like to confirm that all three of you have played Pandemic right? You can read more in the information letter, and once you are done, please sign the consent form. There's a paragraph on the laser table, which you can ignore since we are not using a laser table now. Let me know if you have any questions.

There are three roles for the game, medic, scientist, and operation expert. Which one would you guys like to be? Give them the role card and direct them to the right station. If there are any questions that you prefer not to answer on the survey, please let me know.

2. Game Training

Since we are playing Pandemic, we will do a little role playing throughout the study. I will be your mentor of the day and you three are the new officers to the squad. Our new medic, scientist, and operation expert. Before I give you the actual tasks, you need to be trained first. Let's get started.

In the digital game, you will carry out your 4 actions, and the game will draw cards and spread the diseases for you. The tabletop detects a certain height so please try to place your hand vertically and watch out for your sleeve.

Game Interface

1. The game component
    a. Cities
    b. Cubes (1, 2 and 3 cubes)
    c. Research station (always on the top right)
    d. Player pawns (The glowing player is the current player, same relative location)
    e. Player hand (* meaning new, alphabetical order)
    f. Remaining piece panel (research, cubes left, discard piles)
    g. Outbreak counters
    h. Cure counters
    i. Infection rate counters
2. Treat
3. Move (you can only move one by one)
4. Linear menu (show them how to use the linear menu, open and close)
    a. Default vs Special actions
    b. Move

c. Research
d. Cure
e. Exchange
f. Pass
g. Special action

5. There's no undo
6. Need to use special cards during your action phase

Guided Actions

Guide players through the scripted actions.

Orange	Green	White
Move to Santiago	Move to HK	Exchange
Treat	Move to Shanghai	Treat Shanghai
Use menu to move to Atlanta	Build Research Station	Use Government Grant @ Bruno Aires
Drive to Miami using menu	Cure	Use Airlift: orange to Moscow
Discard Lima		Shuttle flight to Baghdad
		Treat Baghdad

Let them play for 10 minutes. Here's the rule book and special cards in case you need to refer to them.
Good job on completing the first training. We will get you to record your experience during the mission.
Now, please go to your station and do the questionnaire.

3. Timeline Training

You have unlocked two new features in the interface.
We have added two new features to them game. The first is the animation of the game state. The system will start by playing an animation of all previous events. A game log will display the history of the game, and it allows you to explore previous actions and game events automated by the computer.
I will first show you the game log
Run in training * mode to show timeline. Run again to show the animation. Give them 10 min to play.

Log Interface

1. Move and rotate
2. Overview bar
    a. The color and symbols
3. Turn view

    a. Three phases
    b. Each action block
    c. Icons and color
4. EventZone
5. Feedback on board
6. Animation: arrows and diseases

4. Condition 1

Now that you are done with the training, you are ready for the challenge. The diseases are so out of control that we have to replace the previous officers. Your job as the new officers is to save the world, keeping it under control again. Also, try to discover as many cures as possible. You will have 2 rounds (6 turns). At the end, you will answer questions about the world state so we can pass that to the officer taking over your job. For example, cities with 3 cubes, what is the top priority city, when did an important event happen, and what is about to happen. Let's how you guys will do
This version is the same as what you have played
At the end: Please fill in the questionnaire. You will find the game map on the desktop. Please do not discuss the answers with others.

5. Condition 2 and 3 & Full Game Phase

Cond 2: You guys did a good job on the previous challenge so you have received another mission. Same objective as previous challenge, and you will be asked to document your mission afterward
Cond 3: congrats on passing the previous 2 challenges. This would be the last challenge before the promotion.
Full Game: Congrats on passing the previous challenges, we are promoting you to direct your own mission rather than having you clean up after others. You will play right from the beginning. We have also leveled up your tool. The set up is different in … (depending on the previous conditions they played)

1. Toggle for feedback location
2. Minimize and expand

Please press start when you are ready

6. Debriefing

Do you have any feedback in terms of what aspects of the log that you find useful?
What aspects of the log are hinder the gameplay or needs improvement?
What do you think about the different set ups? Are there ones that are more useful under certain situation?
Additional feedback?

B.6 Background Questionnaire

Question	Answers
Participant ID:	Open-Ended Response
What is your sex ?	Female
	Male
What is your age ?	Open-Ended Response
What is your occupation ?	Open-Ended Response
If student, what degree/program are you in ?	Open-Ended Response
Which hand do you primarily use when writing ?	Left hand
	Right hand
How often have you been playing board games in the past two years?	Never
	A few times
	Monthly
	Weekly
	Daily
Which board game titles do you play most often?	Open-Ended Response
How often have you been playing video games in the past two years?	Never
	A few times
	Monthly
	Weekly
	Daily
Which video games do you play most often?	Open-Ended Response
How often have you been playing the game Pandemic in the traditional, board game format in the past two years?	Never
	Once or twice
	Between 3-10 times
	Between 10-50 times
	More than 50 times
How often do you use a touch-based device? e.g., iPhone, iPad, Blackberry Storm, Microsoft Surface, digital tabletop computer, etc.	Never in my life
	A few times in my life
	Monthly
	Weekly
	Daily
How well do you know player #1?	Never met
	Some what
	Well
	Very well
	That's me
How well do you know player #2?	Never met

	Some what
	Well
	Very well
	That's me
How well do you know player #3?	Never met
	Some what
	Well
	Very well
	That's me

B.7 Pandemic Challenges: Preference Ranking Questionnaire

1. Usefulness - Please rank how much you agree or disagree with the following statements.
   - Display information only near the game log is useful.
   - Display information only on the game board is useful.
   - Display information both on the game board and near the game log is useful.

   Each question was given the following 7 options (in a horizontal layout):

   - Strongly Disagree
   - Disagree
   - Moderately Disagree
   - Neutral
   - Moderately Agree
   - Agree
   - Strongly Agree
2. Please rank the timeline setup based on your personal preferences.
   - Information displayed near the game log only
   - Information displayed on the game board only
   - Information displayed both on the board and near the game log
3. Please explain your favorite setup. (Open-Ended Response)
4. Please explain your least favorite setup. (Open-Ended Response)

B.8 Gameplay Questionnaire

B.8.1 NASA Task Load Index

Please rank the following questions from very low to very high.

1. Mental Demand: How mentally demanding was the task?
2. Physical Demand: How physically demanding was the task?
3. Temporal Demand: How hurried or rushed was the pace of the task?
4. Performance: How successful were you in accomplishing what you were asked to do?
5. Effort: How hard did you have to work to accomplish your level of performance?
6. Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?

Each question was given the following 7 options (in a horizontal layout):

- Very Low
- Low
- Moderately Low
- Neutral
- Moderately High
- High
- Very High

B.8.2 PENS

Please rank how much you agree or disagree with the following statements.

1. I feel competent at the game.
2. When playing the game, I feel transported to another time and place.
3. The game provides me with interesting options and choices.
4. Exploring the game world feels like taking an actual trip to a new place.
5. I find the relationships I form in this game important.
6. When moving through the game world I feel as if I am actually there.
7. Learning the game controls was easy.
8. I am not impacted emotionally by events in the game.

9. I feel very capable and effective when playing.
10. The game was emotionally engaging.
11. The game lets you do interesting things.
12. I experienced feelings as deeply in the game as I have in real life.
13. I find the relationships in this game important.
14. When playing the game I feel as if I was part of the story.
15. The game controls are intuitive.
16. When I accomplished something in the game I experienced genuine pride.
17. My ability to play the game is well matched with the game's challenges.
18. I had reactions to events and characters in the game as if they were real.
19. I experienced a lot of freedom in the game.
20. I don't feel close to other players.
21. When I wanted to do something in the game, it was easy to remember the corresponding control.

Each question was given the following 7 options (in a horizontal layout):

- Strongly Disagree
- Disagree
- Moderately Disagree
- Neutral
- Moderately Agree
- Agree
- Strongly Agree

B.8.3 Awareness

Please rank how much you agree or disagree with the following statements.

1. I was always aware of the other players' actions.
2. I always understood what was happening in the game.
3. I always understood the system's animation

Each question was given the following 7 options (in a horizontal layout):

- Strongly Disagree
- Disagree
- Moderately Disagree
- Neutral
- Moderately Agree
- Agree
- Strongly Agree

B.9 Pandemic Situation Awareness Knowledge Analysis

Goal of Pandemic:

collect 4 Cures

Sub-goals:

1. Collect enough cards to trade for cure
    1.1. Utilize opportunity to trade
    1.2. Build research station to exchange for cure
    1.3. Utilize special ability
2. Keep game state under control to get more time
    2.1. Easy travelling to cities
        2.1.1. Build research stations
        2.1.2. Utilize cards vs. driving for travelling
    2.2. Treat Diseases in time
        2.2.1. Prevent Outbreaks
        2.2.2. Prevent cubes from running out
3. Balance strategy based on the turns

Decisions:

1. Decisions for goal: Collect enough cards to trade for cure
    1.1. Who and which card to trade? How to get there? Which turn?
    1.2. Where to build, which research station to remove?
    1.3. Is there any applicable special ability that is beneficial to use now?
2. Decisions for goal: Keep game state under control
    2.1.
        2.1.1. Same as 1.2
        2.1.2. What is the cost of each, Should the cards be used for travelling or for other purposes (research station and cure), Which travelling method to use?
    2.2.
        2.2.1. What are the potential outbreak cities? Which are the top priorities? Which to treat now (next turn)?
        2.2.2. Which color is running out of cubes? What are the easy ones that can be treated now (next turn)

Knowledge required for the goal

1.1 Player locations and hands

1.2 Number of research station left, other research station location, special ability that may help, and player location, and player hands
1.3 Know the special abilities that may help

2.1.1 Same as 1.2, the area that would pay off more (knowledge on disease distribution and map connectedness)

2.1.2 Player hands, player location, disease distribution (current & future) to decide how urgent things are

2.2.1 Current disease distribution (3 cubes, adjacent 3 cube area), cards to be drawn soon (based on previous patterns and epidemics), player location& player hand (how to get there to treat)

2.2.2. Number of cubes left for each disease, player location, and player hand

3. The number of turns we are in and number of turns left, disease distribution, number of cures found

For our study, since we are interested in amending the awareness of automated actions, we will focus on testing goal 2.2. Thus, the knowledge required includes the following two items:

- (2.2.1) Current disease distribution (3 cubes, adjacent 3 cube area), cards to be drawn soon (based on previous patterns and epidemics), player location& player hand (how to get there to treat)
- (2.2.2) Number of cubes left for each disease, player location, and player hand

B.10 Initial Situation Awareness Questions

Question Number	Rater 1	Rater 2	Rater 3	Question
1	2	2	3	Which color requires the most urgent attention now?
2	2	1	1	Which player is closest to the last outbreak city?
3	1	1	1	Rank the relative amount of disease that have spread onto the game board for each color.
4	1	1	1	Where is the scientist (white player)?
5	2	3	2	what are the cities that may create chained outbreak?
6	1	1	1	What were the cities just infected in the last turn?
7	1	2	1	what color of cards do the scientist (white player) current has?
8	2	2	2	What are the top priority cities now?
9	1	1	1	During which player's turn, did the last epidemic happen?
10	1	1	1	Whose turn it is now?
11	1	1	1	Where did the epidemic happen last turn?
12	1	2	1	what color of cards do the operation expert (green player) current has?
13	1	1	1	Where did the outbreak happen last turn?
14	1	1	1	Where is the medic (orange player)?
15	2 or 3	3	2	which cities are at the risk outbreak?
16	3	3	3	How likely is it that you get an outbreak next?
17	3	3	1	Which cities may be drawn next?
18	1	1	1	what were the colors(s) of the new disease cubes just added in the last turn?
19	1	1	1	Where is the operation expert (green player)?
20	1	1	1	Which cities have 3 cubes?
21	1	2	1	what color of cards do the medic (orange player) current has?
22	3	3	3	How likely is it that you get an epidemic in the next draw phase?

B.11 Situation Awareness Questionnaire Bank

Category 1: Perception

1. Name one city (if any) with 3 cubes.
2. Name one city that was just infected in the last turn.
3. What were the color(s) of the new disease cubes just added in the last turn?
4. Name the city where the last epidemic happened.
5. Name the city where the last outbreak happened.
6. During which player's turn, did the last epidemic happen?

Category 2: Comprehension

1. Name one city (if any) that may create an outbreak.
2. Name one set of cities (if any) that may create a chained outbreak.
3. Which color requires the most urgent attention now?
4. Which color has the highest number of city infected?
5. Which color has the most cubes on the game board?
6. Which color has the least cubes on the game board?

Category 3: Prediction

1. Name one top priority city for the current game state.
2. Which colour is at the top priority for the current game state?
3. Name one city (if any) that is at the risk of outbreak in the next infection phase.
4. Name one city that is most likely to be drawn in the draw phase.
5. Please estimate how many turns away you are from the next epidemic.
6. Please estimate how many turns away you are from the next outbreak.

B.12 Situation Awareness Questionnaires

B.12.1 Situation Awareness Question Set 1

Question	Answers
Participant ID	Open-Ended Response
Interface Type	Open-Ended Response
Please estimate how many turns away you are from the next outbreak.	1 turn
	2 turns
	3 turns
	4 turns
	5 turns or more
Which colour has the least cubes on the game board?	Blue
	Yellow
	Black
	Red
During which player's turn, did the last epidemic happen?	Medic (orange player, player 1)
	Operation expert (green player, player 2)
	Scientist (white player, player 3)
Which colour has the highest number of city infected (widest spread)?	Blue
	Yellow
	Black
	Red
Name one top priority city for the current game state.	Open-Ended Response
Name the city where the last epidemic happened.	Open-Ended Response
How much do you agree with the team's decision for the previous turn?	Strongly Disagree
	Disagree
	Moderately Disagree
	Neutral
	Moderately Agree
	Agree
	Strongly Agree

B.12.2 Situation Awareness Question Set 2

Question	Answers
Participant ID	Open-Ended Response
Interface Type	Open-Ended Response
Which colour has the most cubes on the game board?	Blue
	Yellow
	Black
	Red
What were the colour(s) of the new disease cubes just added in the last infection phase?	Blue
	Yellow
	Black
	Red
Name one city (if any) that is at the risk of outbreak in the next infection phase.	Open-Ended Response
Name one city (if any) with 3 cubes.	Open-Ended Response
Which colour requires the most urgent attention now?	Blue
	Yellow
	Black
	Red
Please estimate how many turns away you are from the next epidemic.	1 turn
	2 turns
	3 turns
	4 turns
	5 turns or more
How much do you agree with the team's decision for the previous turn?	Strongly Disagree
	Disagree
	Moderately Disagree
	Neutral
	Moderately Agree
	Agree
	Strongly Agree

B.12.3 Situation Awareness Question Set 3

Question	Answers
Participant ID:	Open-Ended Response
Interface Type	Open-Ended Response
Name one set of cities (if any) that may create a chained outbreak.	Open-Ended Response
Name the city where the last outbreak happened.	Open-Ended Response
Which colour is at the top priority for the current game state?	Blue
	Yellow
	Black
	Red
Name one city that is most likely to be drawn in the draw phase.	Open-Ended Response
Name one city that was just infected in the last infection phase.	Open-Ended Response
Name one city (if any) that may create an outbreak.	Open-Ended Response
How much do you agree with the team's decision for the previous turn?	Strongly Disagree
	Disagree
	Moderately Disagree
	Neutral
	Moderately Agree
	Agree
	Strongly Agree

B.13 All Timeline Study Surveys in Printed Forms

See all surveys used for the Timeline Study in the exact order as how participants would see them.

B.13.1 Background

Background Questionnaire

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way.

* 1. Participant ID:

* 2. What is your sex ?

- ◯ Female
- ◯ Male

* 3. What is your age ?

* 4. What is your occupation ?

5. If student, what degree/program are you in ?

* 6. Which hand do you primarily use when writing ?

- ◯ Left hand
- ◯ Right hand

* 7. How often have you been playing board games in the past two years?

Never	A few times	Monthly	Weekly	Daily
◯	◯	◯	◯	◯

* 8. Which board game titles do you play most often?

* 9. How often have you been playing video games in the past two years?

Never	A few times	Monthly	Weekly	Daily
○	○	○	○	○

* 10. Which video games do you play most often?

* 11. How often have you been playing the game Pandemic in the traditional, board game format in the past two years?

Never	Once or twice	Between 3-10 times	Between 10-50 times	More than 50 times
○	○	○	○	○

* 12. How often do you use a touch-based device?
e.g., iPhone, iPad, Blackberry Storm, Microsoft Surface, digital tabletop computer, etc.

Never in my life	A few times in my life	Monthly	Weekly	Daily
○	○	○	○	○

* 13. How well do you know player #1?

Never met	Some what	Well	Very well	That's me
○	○	○	○	○

* 14. How well do you know player #2?

Never met	Some what	Well	Very well	That's me
○	○	○	○	○

* 15. How well do you know player #3?

Never met	Some what	Well	Very well	That's me
○	○	○	○	○

Thanks! Please return to the tabletop.

Thanks for completing the background questionnaire. Welcome aboard! You are now ready for the training sessions. Please return to the tabletop and wait for the next instruction.

B.13.2 Training

Questionnaire (Training)

Please fill out as accurately as possible. None of the information will be personally linked to you in any way.

* 16. NASA Task Load Index
Please rank the following questions from very low to very high.

	Very Low	Low	Moderately Low	Neutral	Moderately High	High	Very High
Mental Demand: How mentally demanding was the task?	○	○	○	○	○	○	○
Physical Demand: How physically demanding was the task?	○	○	○	○	○	○	○
Temporal Demand: How hurried or rushed was the pace of the task?	○	○	○	○	○	○	○
Performance: How successful were you in accomplishing what you were asked to do?	○	○	○	○	○	○	○
Effort: How hard did you have to work to accomplish your level of performance?	○	○	○	○	○	○	○
Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?	○	○	○	○	○	○	○

* 17. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I feel competent at the game.	○	○	○	○	○	○	○
When playing the game, I feel transported to another time and place.	○	○	○	○	○	○	○
The game provides me with interesting options and choices.	○	○	○	○	○	○	○
Exploring the game world feels like taking an actual trip to a new place.	○	○	○	○	○	○	○
I find the relationships I form in this game important.	○	○	○	○	○	○	○
When moving through the game world I feel as if I am actually there.	○	○	○	○	○	○	○
Learning the game controls was easy.	○	○	○	○	○	○	○

* 18. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I am not impacted emotionally by events in the game.	○	○	○	○	○	○	○
I feel very capable and effective when playing.	○	○	○	○	○	○	○
The game was emotionally engaging.	○	○	○	○	○	○	○
The game lets you do interesting things.	○	○	○	○	○	○	○
I experienced feelings as deeply in the game as I have in real life.	○	○	○	○	○	○	○
I find the relationships in this game important.	○	○	○	○	○	○	○
When playing the game I feel as if I was part of the story.	○	○	○	○	○	○	○

* 19. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
The game controls are intuitive.	◯	◯	◯	◯	◯	◯	◯
When I accomplished something in the game I experienced genuine pride.	◯	◯	◯	◯	◯	◯	◯
My ability to play the game is well matched with the game's challenges.	◯	◯	◯	◯	◯	◯	◯
I had reactions to events and characters in the game as if they were real.	◯	◯	◯	◯	◯	◯	◯
I experienced a lot of freedom in the game.	◯	◯	◯	◯	◯	◯	◯
I don't feel close to other players.	◯	◯	◯	◯	◯	◯	◯
When I wanted to do something in the game, it was easy to remember the corresponding control.	◯	◯	◯	◯	◯	◯	◯

* 20. Awareness

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I was always aware of the other players' actions.	◯	◯	◯	◯	◯	◯	◯
I always understood what was happening in the game.	◯	◯	◯	◯	◯	◯	◯
I always understood the system's animation	◯	◯	◯	◯	◯	◯	◯

Thanks! Please return to the tabletop.

Thank you for completing the training questionnaire. We have leveled up your interface.
Please return to the tabletop and wait for the next instruction.

B.13.3 Situation Awareness Survey - Set 1

Post Condition Questionnaire - Set 1

Please fill out as accurately as possible. None of the information will be personally linked to you in any way.

* 1. Participant ID

[ ]

* 2. Interface Type

[ ]

* 3. Please estimate how many turns away you are from the next outbreak.

- ◯ 1 turn
- ◯ 2 turns
- ◯ 3 turns
- ◯ 4 turns
- ◯ 5 turns or more

* 4. Which colour has the least cubes on the game board?

- ☐ Blue
- ☐ Yellow
- ☐ Black
- ☐ Red

* 5. During which player's turn, did the last epidemic happen?

- ◯ Medic (orange player, player 1)
- ◯ Operation expert (green player, player 2)
- ◯ Scientist (white player, player 3)

* 6. Which colour has the highest number of city infected (widest spread)?

- [ ] Blue
- [ ] Yellow
- [ ] Black
- [ ] Red

* 7. Name one top priority city for the current game state.

* 8. Name the city where the last epidemic happened.

* 9. How much do you agree with the team's decision for the previous turn?

Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
○	○	○	○	○	○	○

* 10. NASA Task Load Index

Please rank the following questions from very low to very high.

	Very Low	Low	Moderately Low	Neutral	Moderately High	High	Very High
Mental Demand: How mentally demanding was the task?	○	○	○	○	○	○	○
Physical Demand: How physically demanding was the task?	○	○	○	○	○	○	○
Temporal Demand: How hurried or rushed was the pace of the task?	○	○	○	○	○	○	○
Performance: How successful were you in accomplishing what you were asked to do?	○	○	○	○	○	○	○
Effort: How hard did you have to work to accomplish your level of performance?	○	○	○	○	○	○	○
Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?	○	○	○	○	○	○	○

* 11. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I feel competent at the game.	○	○	○	○	○	○	○
When playing the game, I feel transported to another time and place.	○	○	○	○	○	○	○
The game provides me with interesting options and choices.	○	○	○	○	○	○	○
Exploring the game world feels like taking an actual trip to a new place.	○	○	○	○	○	○	○
I find the relationships I form in this game important.	○	○	○	○	○	○	○
When moving through the game world I feel as if I am actually there.	○	○	○	○	○	○	○
Learning the game controls was easy.	○	○	○	○	○	○	○

* 12. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I am not impacted emotionally by events in the game.	○	○	○	○	○	○	○
I feel very capable and effective when playing.	○	○	○	○	○	○	○
The game was emotionally engaging.	○	○	○	○	○	○	○
The game lets you do interesting things.	○	○	○	○	○	○	○
I experienced feelings as deeply in the game as I have in real life.	○	○	○	○	○	○	○
I find the relationships in this game important.	○	○	○	○	○	○	○
When playing the game I feel as if I was part of the story.	○	○	○	○	○	○	○

* 13. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
The game controls are intuitive.	◯	◯	◯	◯	◯	◯	◯
When I accomplished something in the game I experienced genuine pride.	◯	◯	◯	◯	◯	◯	◯
My ability to play the game is well matched with the game's challenges.	◯	◯	◯	◯	◯	◯	◯
I had reactions to events and characters in the game as if they were real.	◯	◯	◯	◯	◯	◯	◯
I experienced a lot of freedom in the game.	◯	◯	◯	◯	◯	◯	◯
I don't feel close to other players.	◯	◯	◯	◯	◯	◯	◯
When I wanted to do something in the game, it was easy to remember the corresponding control.	◯	◯	◯	◯	◯	◯	◯

* 14. Awareness

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I was always aware of the other players' actions.	◯	◯	◯	◯	◯	◯	◯
I always understood what was happening in the game.	◯	◯	◯	◯	◯	◯	◯
I always understood the system's animation	◯	◯	◯	◯	◯	◯	◯

Thanks! Please return to the tabletop.

Thank you for recording your mission progress. Please return to the tabletop and wait for the next instruction.

B.13.4 Situation Awareness Survey - Set 2

Post Condition Questionnaire - Set 2

Please fill out as accurately as possible. None of the information will be personally linked to you in any way.

* 1. Participant ID

* 2. Interface Type

* 3. Which colour has the most cubes on the game board?

- [ ] Blue
- [ ] Yellow
- [ ] Black
- [ ] Red

* 4. What were the colour(s) of the new disease cubes just added in the last infection phase?

- [ ] Blue
- [ ] Yellow
- [ ] Black
- [ ] Red

* 5. Name one city (if any) that is at the risk of outbreak in the next infection phase.

* 6. Name one city (if any) with 3 cubes.

* 7. Which colour requires the most urgent attention now?

- ○ Blue
- ○ Yellow
- ○ Black
- ○ Red

* 8. Please estimate how many turns away you are from the next epidemic.

- ◯ 1 turn
- ◯ 2 turns
- ◯ 3 turns
- ◯ 4 turns
- ◯ 5 turns or more

* 9. How much do you agree with the team's decision for the previous turn?

Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
◯	◯	◯	◯	◯	◯	◯

* 10. NASA Task Load Index

Please rank the following questions from very low to very high.

	Very Low	Low	Moderately Low	Neutral	Moderately High	High	Very High
Mental Demand: How mentally demanding was the task?	◯	◯	◯	◯	◯	◯	◯
Physical Demand: How physically demanding was the task?	◯	◯	◯	◯	◯	◯	◯
Temporal Demand: How hurried or rushed was the pace of the task?	◯	◯	◯	◯	◯	◯	◯
Performance: How successful were you in accomplishing what you were asked to do?	◯	◯	◯	◯	◯	◯	◯
Effort: How hard did you have to work to accomplish your level of performance?	◯	◯	◯	◯	◯	◯	◯
Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?	◯	◯	◯	◯	◯	◯	◯

* 11. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I feel competent at the game.	○	○	○	○	○	○	○
When playing the game, I feel transported to another time and place.	○	○	○	○	○	○	○
The game provides me with interesting options and choices.	○	○	○	○	○	○	○
Exploring the game world feels like taking an actual trip to a new place.	○	○	○	○	○	○	○
I find the relationships I form in this game important.	○	○	○	○	○	○	○
When moving through the game world I feel as if I am actually there.	○	○	○	○	○	○	○
Learning the game controls was easy.	○	○	○	○	○	○	○

* 12. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I am not impacted emotionally by events in the game.	○	○	○	○	○	○	○
I feel very capable and effective when playing.	○	○	○	○	○	○	○
The game was emotionally engaging.	○	○	○	○	○	○	○
The game lets you do interesting things.	○	○	○	○	○	○	○
I experienced feelings as deeply in the game as I have in real life.	○	○	○	○	○	○	○
I find the relationships in this game important.	○	○	○	○	○	○	○
When playing the game I feel as if I was part of the story.	○	○	○	○	○	○	○

* 13. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
The game controls are intuitive.	○	○	○	○	○	○	○
When I accomplished something in the game I experienced genuine pride.	○	○	○	○	○	○	○
My ability to play the game is well matched with the game's challenges.	○	○	○	○	○	○	○
I had reactions to events and characters in the game as if they were real.	○	○	○	○	○	○	○
I experienced a lot of freedom in the game.	○	○	○	○	○	○	○
I don't feel close to other players.	○	○	○	○	○	○	○
When I wanted to do something in the game, it was easy to remember the corresponding control.	○	○	○	○	○	○	○

* 14. Awareness

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I was always aware of the other players' actions.	○	○	○	○	○	○	○
I always understood what was happening in the game.	○	○	○	○	○	○	○
I always understood the system's animation	○	○	○	○	○	○	○

Thanks! Please return to the tabletop.

Thank you for documenting the world state. Please return to the tabletop and wait for the next instruction.

B.13.5 Situation Awareness Survey - Set 3

Post Condition Questionnaire - 3 (Set 3)

Please fill out as accurately as possible. None of the information will be personally linked to you in any way.

* 1. Participant ID:

* 2. Interface Type

* 3. Name one set of cities (if any) that may create a chained outbreak.

* 4. Name the city where the last outbreak happened.

* 5. Which colour is at the top priority for the current game state?

  - ◯ Blue
  - ◯ Yellow
  - ◯ Black
  - ◯ Red

* 6. Name one city that is most likely to be drawn in the draw phase.

* 7. Name one city that was just infected in the last infection phase.

* 8. Name one city (if any) that may create an outbreak.

* 9. How much do you agree with the team's decision for the previous turn?

Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
○	○	○	○	○	○	○

* 10. NASA Task Load Index

Please rank the following questions from very low to very high.

	Very Low	Low	Moderately Low	Neutral	Moderately High	High	Very High
Mental Demand: How mentally demanding was the task?	○	○	○	○	○	○	○
Physical Demand: How physically demanding was the task?	○	○	○	○	○	○	○
Temporal Demand: How hurried or rushed was the pace of the task?	○	○	○	○	○	○	○
Performance: How successful were you in accomplishing what you were asked to do?	○	○	○	○	○	○	○
Effort: How hard did you have to work to accomplish your level of performance?	○	○	○	○	○	○	○
Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?	○	○	○	○	○	○	○

* 11. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I feel competent at the game.	○	○	○	○	○	○	○
When playing the game, I feel transported to another time and place.	○	○	○	○	○	○	○
The game provides me with interesting options and choices.	○	○	○	○	○	○	○
Exploring the game world feels like taking an actual trip to a new place.	○	○	○	○	○	○	○
I find the relationships I form in this game important.	○	○	○	○	○	○	○
When moving through the game world I feel as if I am actually there.	○	○	○	○	○	○	○
Learning the game controls was easy.	○	○	○	○	○	○	○

* 12. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I am not impacted emotionally by events in the game.	○	○	○	○	○	○	○
I feel very capable and effective when playing.	○	○	○	○	○	○	○
The game was emotionally engaging.	○	○	○	○	○	○	○
The game lets you do interesting things.	○	○	○	○	○	○	○
I experienced feelings as deeply in the game as I have in real life.	○	○	○	○	○	○	○
I find the relationships in this game important.	○	○	○	○	○	○	○
When playing the game I feel as if I was part of the story.	○	○	○	○	○	○	○

* 13. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
The game controls are intuitive.	○	○	○	○	○	○	○
When I accomplished something in the game I experienced genuine pride.	○	○	○	○	○	○	○
My ability to play the game is well matched with the game's challenges.	○	○	○	○	○	○	○
I had reactions to events and characters in the game as if they were real.	○	○	○	○	○	○	○
I experienced a lot of freedom in the game.	○	○	○	○	○	○	○
I don't feel close to other players.	○	○	○	○	○	○	○
When I wanted to do something in the game, it was easy to remember the corresponding control.	○	○	○	○	○	○	○

* 14. Awareness

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I was always aware of the other players' actions.	○	○	○	○	○	○	○
I always understood what was happening in the game.	○	○	○	○	○	○	○
I always understood the system's animation	○	○	○	○	○	○	○

Thanks! Please return to the tabletop.

Thank you for reporting the world state. Please return to the tabletop and wait for the next instruction.

B.13.6 Preference Ranking

Preference Ranking Questionnaire

* 1. Participant ID

* 2. Usefulness

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
Display information only near the game log is useful.	○	○	○	○	○	○	○
Display information only on the game board is useful.	○	○	○	○	○	○	○
Display information both on the game board and near the game log is useful.	○	○	○	○	○	○	○

* 3. Please rank the timeline setup based on your personal preferences.

	1 (My favorite)	2	3 (My least favorite)
Information displayed near the game log only	○	○	○
Information displayed on the game board only	○	○	○
Information displayed both on the board and near the game log	○	○	○

* 4. Please explain your favorite setup.

* 5. Please explain your least favorite setup.

Thanks! Please return to the tabletop.

Thank you for completing the preference questionnaire. You have unlocked a new feature on your interface. Please return to the tabletop and wait for the next instruction.

B.13.7 Configurable Condition

Questionnaire - Configurable

Please fill out as accurately as possible. None of the information will be personally linked to you in any way.

* 6. NASA Task Load Index

Please rank the following questions from very low to very high.

	Very Low	Low	Moderately Low	Neutral	Moderately High	High	Very High
Mental Demand: How mentally demanding was the task?	○	○	○	○	○	○	○
Physical Demand: How physically demanding was the task?	○	○	○	○	○	○	○
Temporal Demand: How hurried or rushed was the pace of the task?	○	○	○	○	○	○	○
Performance: How successful were you in accomplishing what you were asked to do?	○	○	○	○	○	○	○
Effort: How hard did you have to work to accomplish your level of performance?	○	○	○	○	○	○	○
Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?	○	○	○	○	○	○	○

* 7. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I feel competent at the game.	○	○	○	○	○	○	○
When playing the game, I feel transported to another time and place.	○	○	○	○	○	○	○
The game provides me with interesting options and choices.	○	○	○	○	○	○	○
Exploring the game world feels like taking an actual trip to a new place.	○	○	○	○	○	○	○
I find the relationships I form in this game important.	○	○	○	○	○	○	○
When moving through the game world I feel as if I am actually there.	○	○	○	○	○	○	○
Learning the game controls was easy.	○	○	○	○	○	○	○

* 8. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I am not impacted emotionally by events in the game.	○	○	○	○	○	○	○
I feel very capable and effective when playing.	○	○	○	○	○	○	○
The game was emotionally engaging.	○	○	○	○	○	○	○
The game lets you do interesting things.	○	○	○	○	○	○	○
I experienced feelings as deeply in the game as I have in real life.	○	○	○	○	○	○	○
I find the relationships in this game important.	○	○	○	○	○	○	○
When playing the game I feel as if I was part of the story.	○	○	○	○	○	○	○

* 9. PENS

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
The game controls are intuitive.	◯	◯	◯	◯	◯	◯	◯
When I accomplished something in the game I experienced genuine pride.	◯	◯	◯	◯	◯	◯	◯
My ability to play the game is well matched with the game's challenges.	◯	◯	◯	◯	◯	◯	◯
I had reactions to events and characters in the game as if they were real.	◯	◯	◯	◯	◯	◯	◯
I experienced a lot of freedom in the game.	◯	◯	◯	◯	◯	◯	◯
I don't feel close to other players.	◯	◯	◯	◯	◯	◯	◯
When I wanted to do something in the game, it was easy to remember the corresponding control.	◯	◯	◯	◯	◯	◯	◯

* 10. Awareness

Please rank how much you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Moderately Disagree	Neutral	Moderately Agree	Agree	Strongly Agree
I was always aware of the other players' actions.	◯	◯	◯	◯	◯	◯	◯
I always understood what was happening in the game.	◯	◯	◯	◯	◯	◯	◯
I always understood the system's animation	◯	◯	◯	◯	◯	◯	◯

11. What aspects of the configurable game log assisted the gameplay ?

12. What aspects of the configurable game log hindered the gameplay ?

13. Do you have any additional comment for the study?

Thanks! Please return to the study.

Thank you for completing all of the questionnaire. Job well done! We are eternally grateful for your contribution in the force and in science. Please return to the tabletop for the debriefing session.

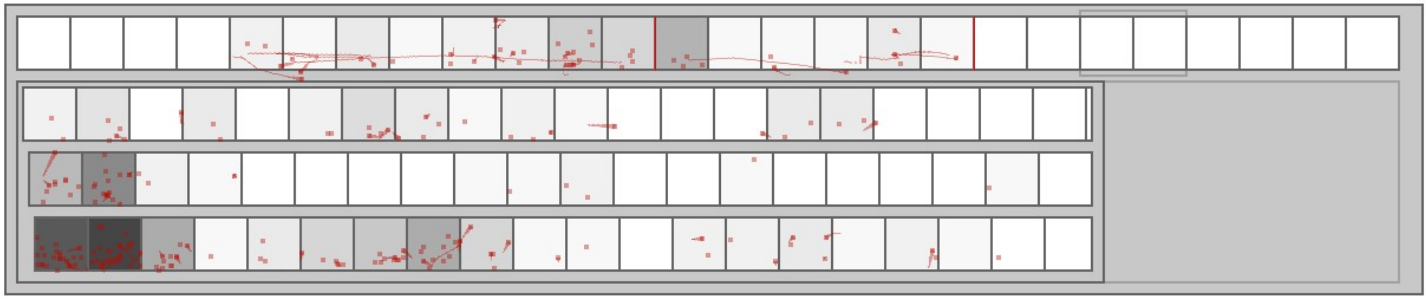
B.14 Video Coding Sheet

Code name	Code description
Timeline	Players checked information in the timelines by looking at timelines or interacting with the cubes in the overview and detailed view. One timeline interaction was considered as the time when players starts interacting till they lift their hands off the table. Players sometimes opened the timeline to just view the information without interacting.
Open timeline	Players opened their timelines.
Minimize timeline	Players closed their timelines.
Timeline - log feedback	Players toggled the log feedback on the timelines (either turn on or off the feedback on the log).
Timeline - board feedback	Players toggled the board feedback on the timelines (either turn on or off the feedback on the shared game map).
Discard pile	Opened discard pile to view cards in the pile
Point	Players used their hands to point at a particular city or area of the map for the purpose of drawing other players' attention to the map. Tracing the cities or proposed/previous actions should also be coded.
Look at board	Looked at the map on the tabletop. Code for specific head movement. If players had no specific physical movement, code only when it could clearly be inferred, e.g., when users explicitly mentioned new changes that they noticed on the map by exclaiming or narrating.
Announce	Announced automation results after watched system animations, watched others' timelines, watched replay animations, or interacted with timelines. Or narrated automation results while watching system animations or replay animations. Automation results could include: 1) called out specific cities that were infected or had a special event, and 2) announced events that happened, e.g., epidemic, outbreak, and winning/losing results.
Deixis	Referred to a location on the board by using deictic expressions that cannot be understood out of context (e.g., go there; treat here). Do not code if players were referring to the situation, not the location. For 'this' and 'that', only code if

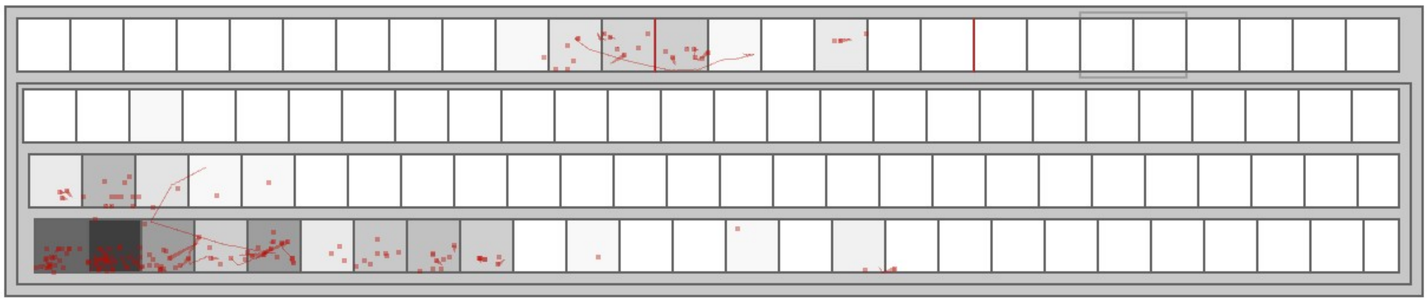
	players were explicitly referring to a location (e.g., they were also pointing at a city).
Explicit reference	Players explicitly mentioned a location's name (e.g., Tokyo). It may occur when commanding other players to carry out actions, comparing strategies, and proposing actions. Also code when players commented on the spread of disease cube by referring to the colour. Do not code for simply reading a list of cities from decks.
Implicit reference	Players did not mention a location's name or use Deixis (here and there) at all, but the team knew the cities being referred to. E.g., narrated the type of actions when a player was controlling the pawn (e.g., move, treat, and build research station); compared different strategies, narrated 1, 2, 3, and 4 while a player was controlling the pawn; and commanded actions.
Discuss automation results	Players asked others for information about automated game actions.
Correct each other	Players corrected each other's knowledge of the automation.
Strategizing	Players proposed a strategy and explained why.

B.15 Interaction Trace Heat Maps

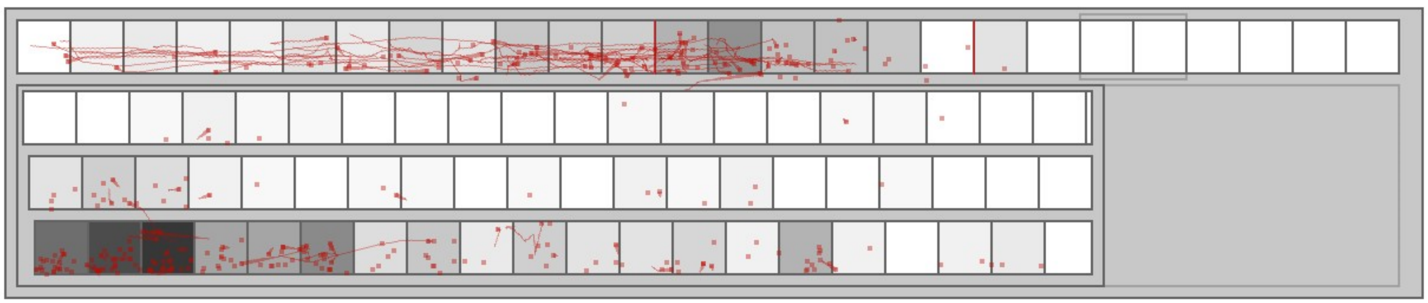
Dedicated log



Dedicated board



Dedicated both



B.16 Statistical Analysis Results

B.16.1 Main Effect of Control Placement on Situation Awareness Score

```
GLM T_SA_All_Clean G_SA_All_Clean B_SA_All_Clean BY Scenario_order
SA_order OW_numerical WITH Group
  /WSFACTOR=FeedbackLocation 3 Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(OW_numerical FeedbackLocation)
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=FeedbackLocation
  /DESIGN=Group Scenario_order SA_order OW_numerical
Scenario_order*SA_order
    Scenario_order*OW_numerical SA_order*OW_numerical
Scenario_order*SA_order*OW_numerical.
```

Note: Control Placement was named as OW_numberical. Situation awareness scores of three conditions were tested (T_SA_All_Clean → timeline condition; G_SA_All_Clean → game board condition; B_SA_All_Clean → both condition).

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
FeedbackLocation	Sphericity Assumed	.007	2	.004	.165	.848
	Greenhouse-Geisser	.007	1.910	.004	.165	.839
	Huynh-Feldt	.007	2.000	.004	.165	.848
	Lower-bound	.007	1.000	.007	.165	.687
FeedbackLocation * Group	Sphericity Assumed	.019	2	.009	.417	.661
	Greenhouse-Geisser	.019	1.910	.010	.417	.652
	Huynh-Feldt	.019	2.000	.009	.417	.661
	Lower-bound	.019	1.000	.019	.417	.523
FeedbackLocation * Scenario_order	Sphericity Assumed	.292	2	.146	6.553	.003
	Greenhouse-Geisser	.292	1.910	.153	6.553	.003
	Huynh-Feldt	.292	2.000	.146	6.553	.003
	Lower-bound	.292	1.000	.292	6.553	.016

FeedbackLocation * SA_order	Sphericity Assumed	.379	4	.095	4.247	.005
	Greenhouse-Geisser	.379	3.821	.099	4.247	.005
	Huynh-Feldt	.379	4.000	.095	4.247	.005
	Lower-bound	.379	2.000	.189	4.247	.024
FeedbackLocation * OW_numerical	Sphericity Assumed	.043	2	.021	.964	.388
	Greenhouse-Geisser	.043	1.910	.022	.964	.384
	Huynh-Feldt	.043	2.000	.021	.964	.388
	Lower-bound	.043	1.000	.043	.964	.335
FeedbackLocation * Scenario_order * SA_order	Sphericity Assumed	.000	0	.	.	.
	Greenhouse-Geisser	.000	.000	.	.	.
	Huynh-Feldt	.000	.000	.	.	.
	Lower-bound	.000	.000	.	.	.
FeedbackLocation * Scenario_order * OW_numerical	Sphericity Assumed	.000	0	.	.	.
	Greenhouse-Geisser	.000	.000	.	.	.
	Huynh-Feldt	.000	.000	.	.	.
	Lower-bound	.000	.000	.	.	.
FeedbackLocation * SA_order * OW_numerical	Sphericity Assumed	.000	0	.	.	.
	Greenhouse-Geisser	.000	.000	.	.	.
	Huynh-Feldt	.000	.000	.	.	.
	Lower-bound	.000	.000	.	.	.
FeedbackLocation * Scenario_order * SA_order * OW_numerical	Sphericity Assumed	.000	0	.	.	.
	Greenhouse-Geisser	.000	.000	.	.	.
	Huynh-Feldt	.000	.000	.	.	.
	Lower-bound	.000	.000	.	.	.
Error(FeedbackLocation)	Sphericity Assumed	1.248	56	.022		
	Greenhouse-Geisser	1.248	53.489	.023		
	Huynh-Feldt	1.248	56.000	.022		
	Lower-bound	1.248	28.000	.045		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	4.649	1	4.649	152.963	.000
Group	.007	1	.007	.223	.640
Scenario_order	.022	1	.022	.717	.404
SA_order	.066	2	.033	1.092	.349
OW_numerical	.144	1	.144	4.727	.038
Scenario_order * SA_order	.000	0	.	.	.
Scenario_order * OW_numerical	.000	0	.	.	.
SA_order * OW_numerical	.000	0	.	.	.
Scenario_order * SA_order * OW_numerical	.000	0	.	.	.
Error	.851	28	.030		

B.16.2 Main Effect of Control Placement on Timeline Interactions

```
GLM T_SumTouchCount B_SumTouchCount G_SumTouchCount BY Ownership
  /WSFACTOR=Feedback 3 Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(Ownership Feedback Ownership*Feedback Feedback*Ownership)
  /PRINT=DESCRIPTIVE ETASQ
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Feedback
  /DESIGN=Ownership.
```

Note: Control Placement was named as Ownership. Interaction counts of the three conditions were the within subject factor (T_SumTouchCount → timeline condition; G_ SumTouchCount → game board condition; B_ SumTouchCount → both condition).

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Feedback	Sphericity Assumed	1551.389	2	775.694	1.590	.229	.137
	Greenhouse-Geisser	1551.389	1.239	1252.303	1.590	.236	.137
	Huynh-Feldt	1551.389	1.469	1056.431	1.590	.235	.137
	Lower-bound	1551.389	1.000	1551.389	1.590	.236	.137
Feedback * Ownership	Sphericity Assumed	1121.167	2	560.583	1.149	.337	.103
	Greenhouse-Geisser	1121.167	1.239	905.022	1.149	.319	.103
	Huynh-Feldt	1121.167	1.469	763.468	1.149	.326	.103
	Lower-bound	1121.167	1.000	1121.167	1.149	.309	.103
Error(Feedback)	Sphericity Assumed	9755.444	20	487.772			
	Greenhouse-Geisser	9755.444	12.388	787.473			
	Huynh-Feldt	9755.444	14.685	664.305			
	Lower-bound	9755.444	10.000	975.544			

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	26786.778	1	26786.778	42.988	.000	.811
Ownership	3844.000	1	3844.000	6.169	.032	.382
Error	6231.222	10	623.122			

B.16.3 Partial Correlation on Timeline Interactions and Situation Awareness

```
PARTIAL CORR
  /VARIABLES=Cube_TouchDown Overview_Tap Viewport_Drag_TouchDown Navigation Total_Interaction_Count
    SA1 SA2 SA3 SA_Avg BY Group
  /SIGNIFICANCE=TWOTAIL
  /STATISTICS=DESCRIPTIVES
  /MISSING=LISTWISE.
```

Correlations

Control Variables			Cube_ TouchDown	Overview_ Tap	Viewport_ Drag_ TouchDown	Navigation	Total_ Interaction_ Count	SA1	SA2	SA3	SA_Avg
Group	Cube_ TouchDown	Correlation	1.000	.432	.530	.518	.939	.164	.138	.026	.163
		Significance (2-tailed)	.	.000	.000	.000	.000	.091	.155	.787	.093
		df	0	105	105	105	105	105	105	105	105
	Overview_ Tap	Correlation	.432	1.000	.791	.921	.686	.121	.100	-.021	.119
		Significance (2-tailed)	.000	.	.000	.000	.000	.215	.307	.829	.224
		df	105	0	105	105	105	105	105	105	105
	Viewport_ Drag_ TouchDown	Correlation	.530	.791	1.000	.967	.776	.164	.145	.125	.226
		Significance (2-tailed)	.000	.000	.	.000	.000	.090	.136	.200	.019
		df	105	105	0	105	105	105	105	105	105
	Navigation	Correlation	.518	.921	.967	1.000	.780	.155	.134	.070	.193
		Significance (2-tailed)	.000	.000	.000	.	.000	.111	.169	.471	.046

	df	105	105	105	0	105	105	105	105	105
Total_ Interaction_ Count	Correlation	.939	.686	.776	.780	1.000	.183	.155	.048	.197
	Significance (2-tailed)	.000	.000	.000	.000	.	.060	.111	.626	.042
	df	105	105	105	105	0	105	105	105	105
SA1	Correlation	.164	.121	.164	.155	.183	1.000	.116	.214	.780
	Significance (2-tailed)	.091	.215	.090	.111	.060	.	.233	.027	.000
	df	105	105	105	105	105	0	105	105	105
SA2	Correlation	.138	.100	.145	.134	.155	.116	1.000	.073	.552
	Significance (2-tailed)	.155	.307	.136	.169	.111	.233	.	.457	.000
	df	105	105	105	105	105	105	0	105	105
SA3	Correlation	.026	-.021	.125	.070	.048	.214	.073	1.000	.556
	Significance (2-tailed)	.787	.829	.200	.471	.626	.027	.457	.	.000
	df	105	105	105	105	105	105	105	0	105
SA_Avg	Correlation	.163	.119	.226	.193	.197	.780	.552	.556	1.000
	Significance (2-tailed)	.093	.224	.019	.046	.042	.000	.000	.000	.
	df	105	105	105	105	105	105	105	105	0

B.16.4 Main Effect of Feedback Location on Time Spent Between Turns

```
GLM T_TimePerTurn G_TimePerTurn B_TimePerTurn BY Ownership
  /WSFACTOR=Feedback 3 Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(Ownership Feedback Ownership*Feedback Feedback*Ownership)
  /PRINT=DESCRIPTIVE ETASQ
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Feedback
  /DESIGN=Ownership.
```

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Feedback	Sphericity Assumed	342084323.574	2	171042161.787	4.196	.030	.296
	Greenhouse-Geisser	342084323.574	1.796	190419467.247	4.196	.035	.296
	Huynh-Feldt	342084323.574	2.000	171042161.787	4.196	.030	.296
	Lower-bound	342084323.574	1.000	342084323.574	4.196	.068	.296
Feedback * Ownership	Sphericity Assumed	90948491.236	2	45474245.618	1.116	.347	.100
	Greenhouse-Geisser	90948491.236	1.796	50626006.674	1.116	.343	.100
	Huynh-Feldt	90948491.236	2.000	45474245.618	1.116	.347	.100
	Lower-bound	90948491.236	1.000	90948491.236	1.116	.316	.100
Error(Feedback)	Sphericity Assumed	815280369.202	20	40764018.460			
	Greenhouse-Geisser	815280369.202	17.965	45382159.562			
	Huynh-Feldt	815280369.202	20.000	40764018.460			
	Lower-bound	815280369.202	10.000	81528036.920			

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	27190237470.416	1	27190237470.416	332.237	.000	.971
Ownership	46903713.975	1	46903713.975	.573	.466	.054
Error	818397677.690	10	81839767.769			

B.16.5 Pairwise Test for Main Effects on Feedback Location on Time Spent Between Turns

```
GLM T_TimePerTurn G_TimePerTurn B_TimePerTurn BY Ownership
  /WSFACTOR=Feedback 3 Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(Feedback Ownership)
  /EMMEANS=TABLES(Feedback) COMPARE ADJ(BONFERRONI)
  /PRINT=DESCRIPTIVE ETASQ OPOWER
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Feedback
  /DESIGN=Ownership.
```

Within-Subjects Factors

Measure: MEASURE_1

Feedback	Dependent Variable
1	T_TimePerTurn
2	G_TimePerTurn
3	B_TimePerTurn

Pairwise Comparisons

Measure: MEASURE_1

(I) Feedback	(J) Feedback	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-1694.180	2601.189	1.000	-9159.782	5771.423
	3	5525.339	2964.483	.276	-2982.941	14033.620
2	1	1694.180	2601.189	1.000	-5771.423	9159.782
	3	7219.519*	2197.195	.025	913.411	13525.627
3	1	-5525.339	2964.483	.276	-14033.620	2982.941
	2	-7219.519*	2197.195	.025	-13525.627	-913.411

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

B.16.6 Group Situation Awareness Test

No main effects of *Control Placement* or *Feedback Location* on group situation awareness

```
GLM Log_Avg Game_Avg Both_Avg BY Ownership
  /WSFACTOR=Feedback 3 Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(Feedback Ownership)
  /PRINT=DESCRIPTIVE ETASQ OPOWER
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Feedback
  /DESIGN=Ownership.
```

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Feedback	Sphericity Assumed	.032	2	.016	1.187	.326	.106	2.375	.230
	Greenhouse-Geisser	.032	1.761	.018	1.187	.323	.106	2.090	.216
	Huynh-Feldt	.032	2.000	.016	1.187	.326	.106	2.375	.230
	Lower-bound	.032	1.000	.032	1.187	.301	.106	1.187	.167
Feedback * Ownership	Sphericity Assumed	.005	2	.003	.195	.824	.019	.390	.076
	Greenhouse-Geisser	.005	1.761	.003	.195	.797	.019	.344	.075
	Huynh-Feldt	.005	2.000	.003	.195	.824	.019	.390	.076
	Lower-bound	.005	1.000	.005	.195	.668	.019	.195	.069
Error(Feedback)	Sphericity Assumed	.266	20	.013					
	Greenhouse-Geisser	.266	17.606	.015					
	Huynh-Feldt	.266	20.000	.013					
	Lower-bound	.266	10.000	.027					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	27.592	1	27.592	2641.366	.000	.996	2641.366	1.000
Ownership	6.944E-5	1	6.944E-5	.007	.937	.001	.007	.051
Error	.104	10	.010					

a. Computed using alpha = .05

B.16.7 Player Type on Situation Awareness

3 *Feedback Location* × 2 *Player Type* RM-ANOVA

```
GLM SA_Log_Driver SA_Log_NonDriver SA_Board_Driver SA_Board_NonDriver SA_Both_Driver SA_Both_NonDriver
  /WSFACTOR=Feedback 3 Polynomial PlayerType 2 Polynomial
  /METHOD=SSTYPE(3)
  /PLOT=PROFILE(PlayerType Feedback)
  /EMMEANS=TABLES(PlayerType)
  /PRINT=DESCRIPTIVE ETASQ OPOWER
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Feedback PlayerType Feedback*PlayerType.
```

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Feedback	Sphericity Assumed	.009	2	.005	.148	.864	.029	.296	.067
	Greenhouse-Geisser	.009	1.855	.005	.148	.850	.029	.274	.066
	Huynh-Feldt	.009	2.000	.005	.148	.864	.029	.296	.067
	Lower-bound	.009	1.000	.009	.148	.716	.029	.148	.062
Error(Feedback)	Sphericity Assumed	.309	10	.031					
	Greenhouse-Geisser	.309	9.276	.033					
	Huynh-Feldt	.309	10.000	.031					
	Lower-bound	.309	5.000	.062					
PlayerType	Sphericity Assumed	.038	1	.038	2.934	.147	.370	2.934	.286

	Greenhouse-Geisser	.038	1.000	.038	2.934	.147	.370	2.934	.286
	Huynh-Feldt	.038	1.000	.038	2.934	.147	.370	2.934	.286
	Lower-bound	.038	1.000	.038	2.934	.147	.370	2.934	.286
Error(PlayerType)	Sphericity Assumed	.065	5	.013					
	Greenhouse-Geisser	.065	5.000	.013					
	Huynh-Feldt	.065	5.000	.013					
	Lower-bound	.065	5.000	.013					
Feedback * PlayerType	Sphericity Assumed	.063	2	.032	.914	.432	.154	1.827	.166
	Greenhouse-Geisser	.063	1.308	.048	.914	.403	.154	1.195	.137
	Huynh-Feldt	.063	1.585	.040	.914	.416	.154	1.448	.149
	Lower-bound	.063	1.000	.063	.914	.383	.154	.914	.123
Error(Feedback*PlayerType)	Sphericity Assumed	.345	10	.035					
	Greenhouse-Geisser	.345	6.542	.053					
	Huynh-Feldt	.345	7.923	.044					
	Lower-bound	.345	5.000	.069					

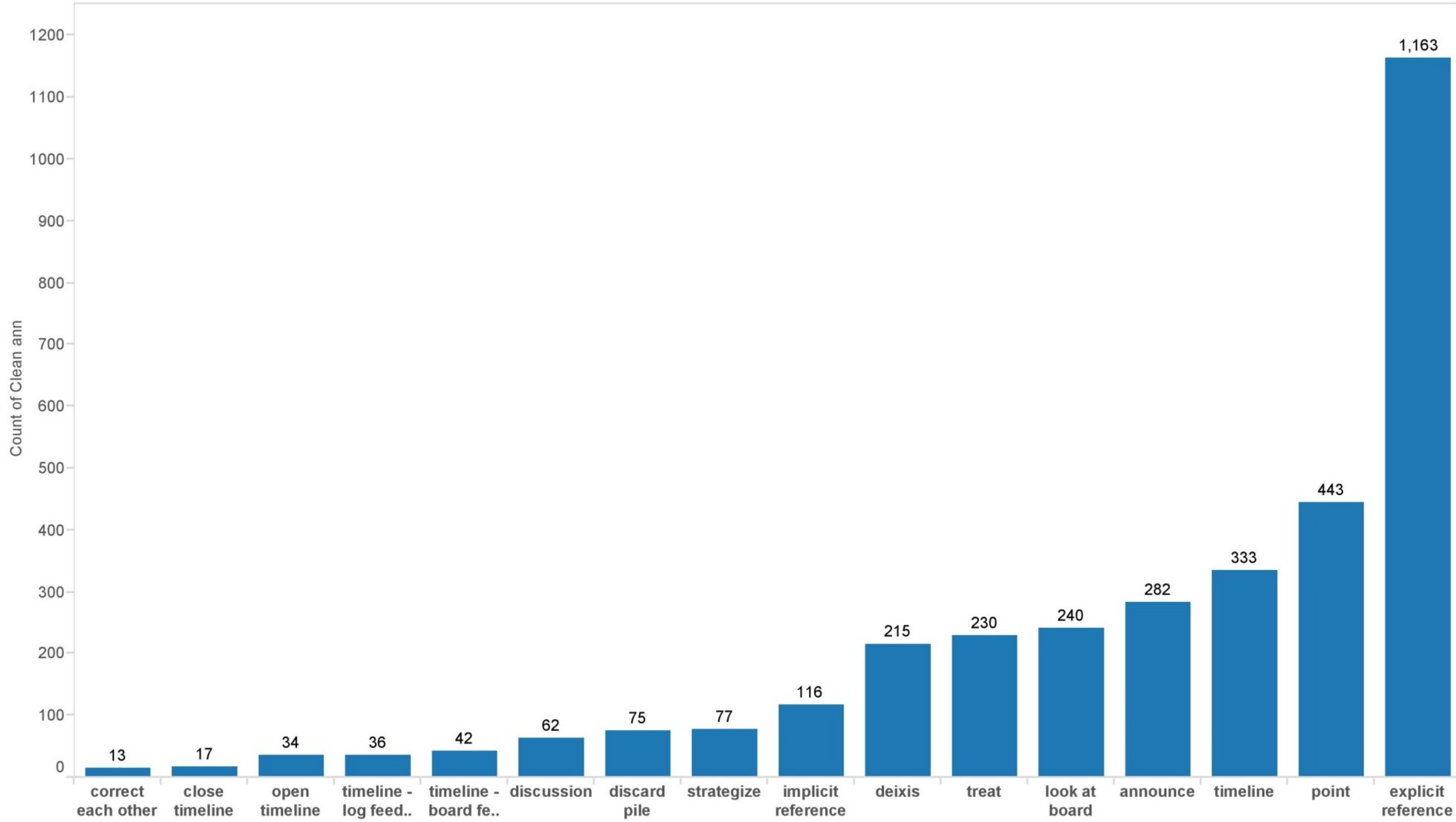
a. Computed using alpha = .05

B.16.8 Player Preference Ranking for Feedback Location

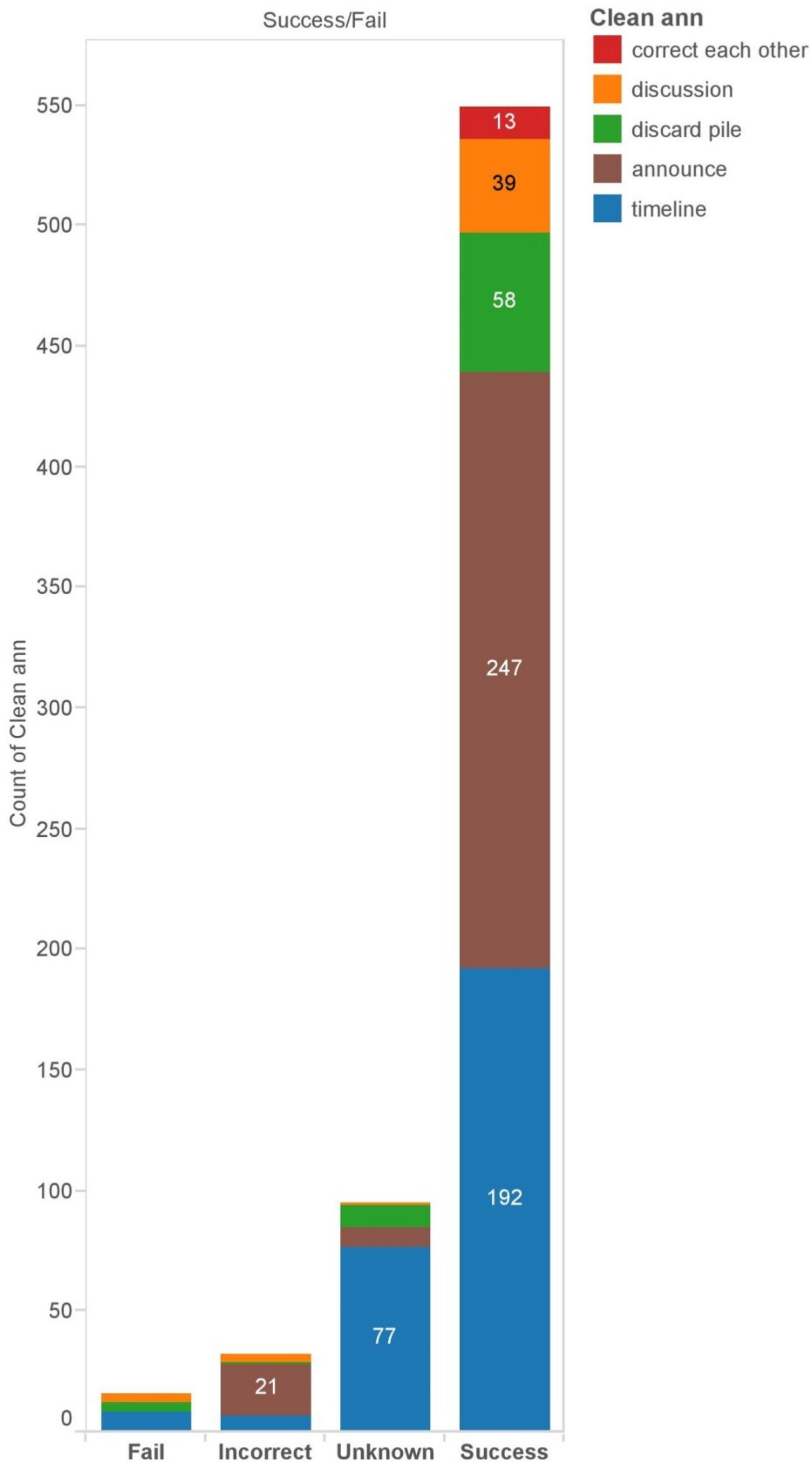
Ranked Position	1			2			3		
Feedback Type	Timeline	Game Board	Both	Timeline	Game Board	Both	Timeline	Game Board	Both
Count of Ranking Position	7	0	29	15	15	6	14	21	1
Percentage	0.19	0	0.81	0.42	0.42	0.17	0.39	0.58	0.03

B.17 Video Coding Results

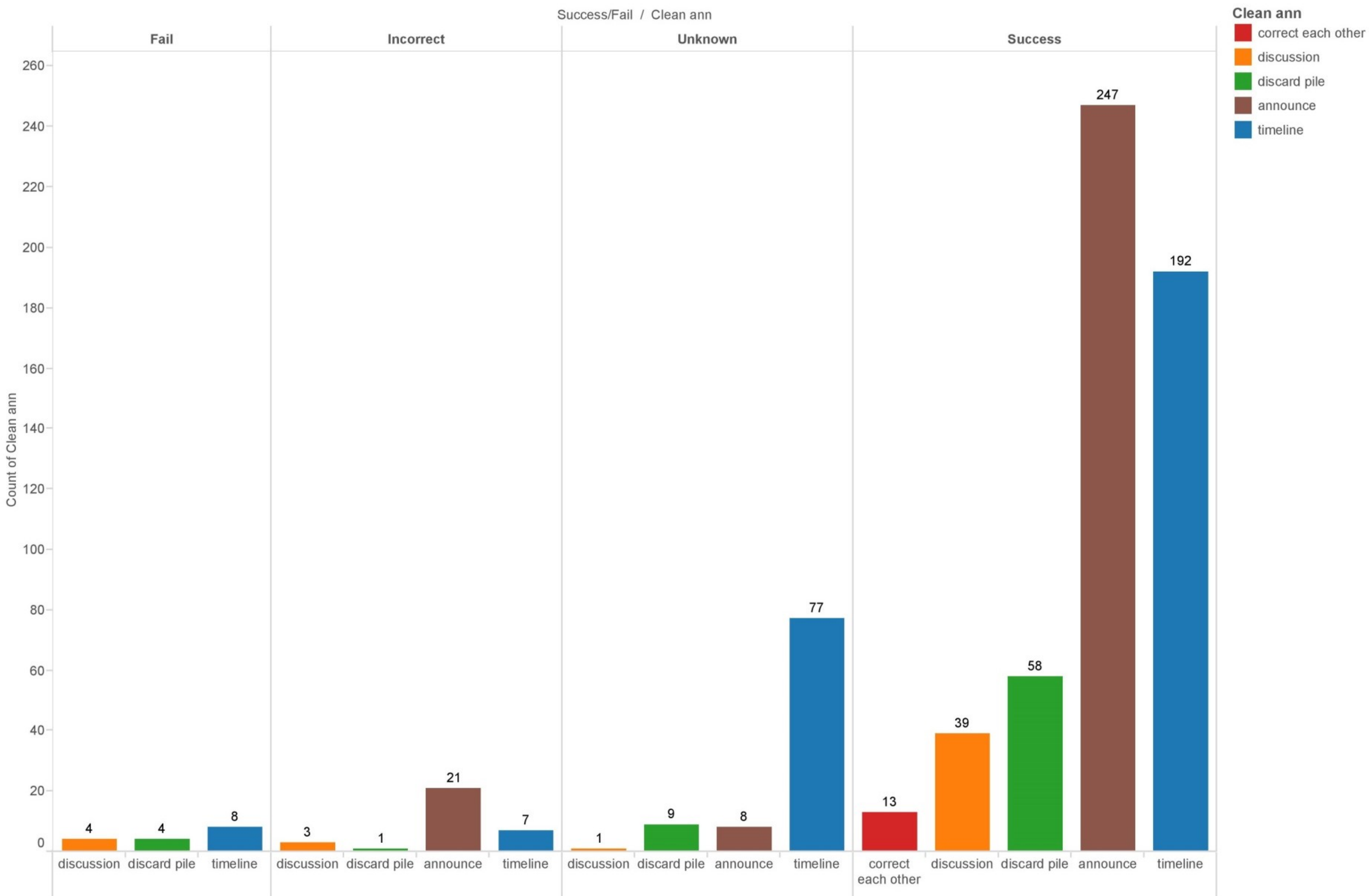
B.17.1 Number of Occurrences for Each Video Code



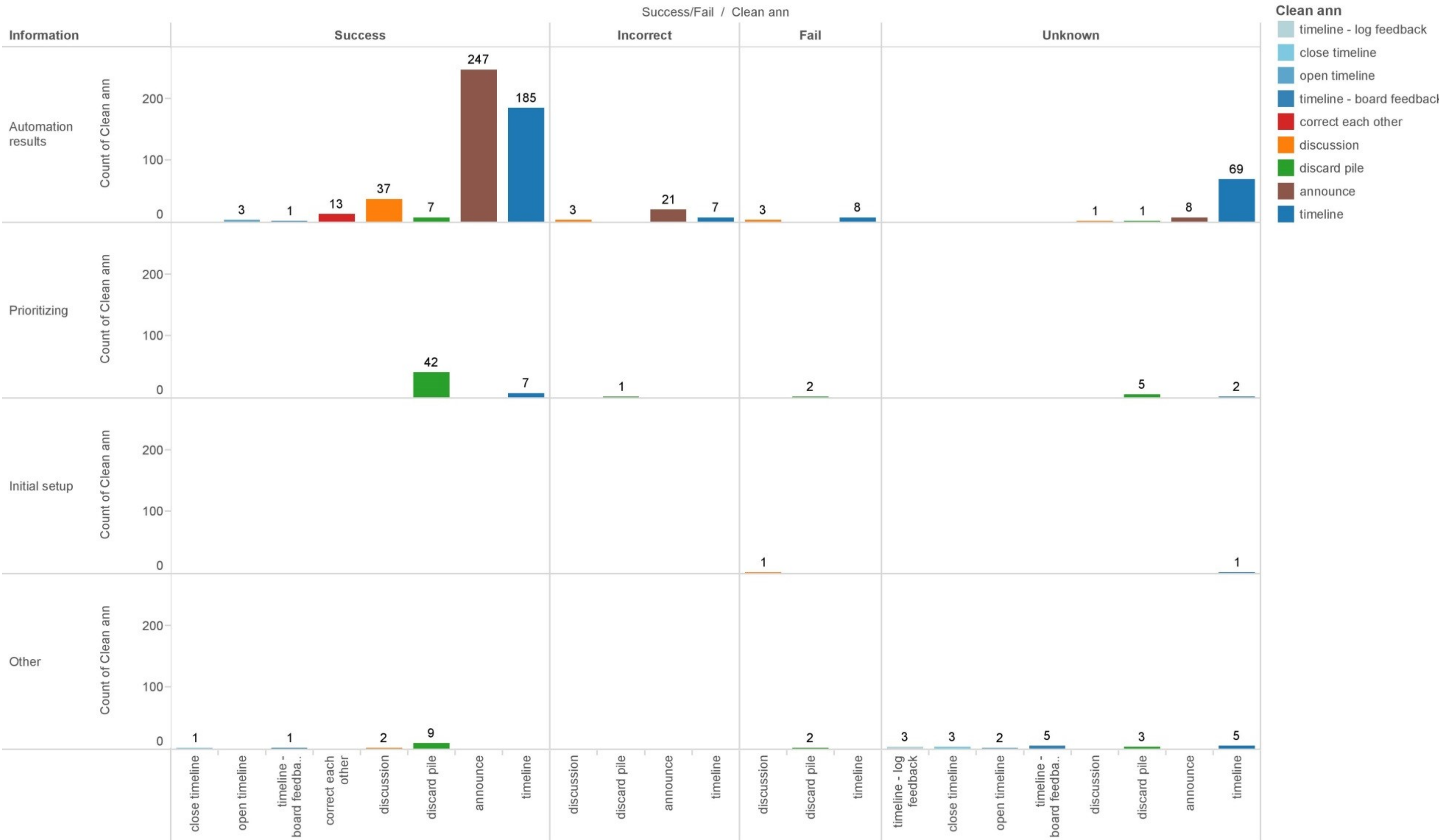
B.17.2 Classification of Video Coding Results by Type of Codes (Stacked Bar Chart)



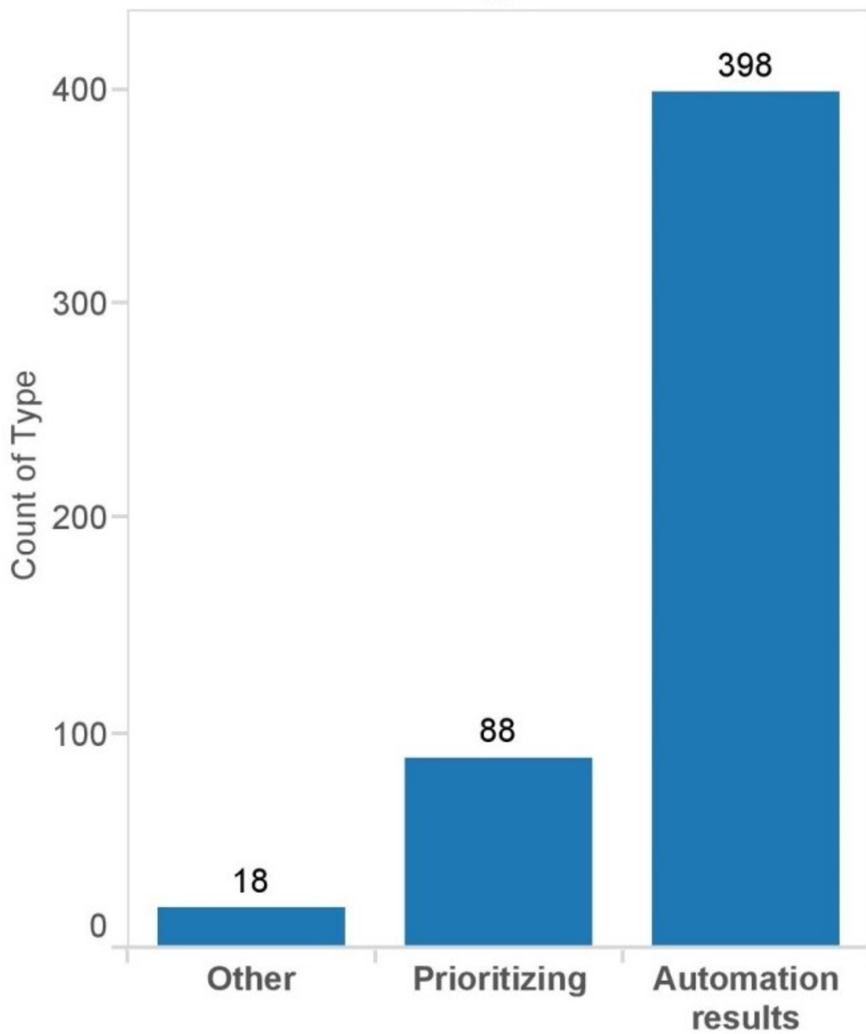
B.17.3 Classification of Video Coding Results by Type of Codes (Full Breakdown)



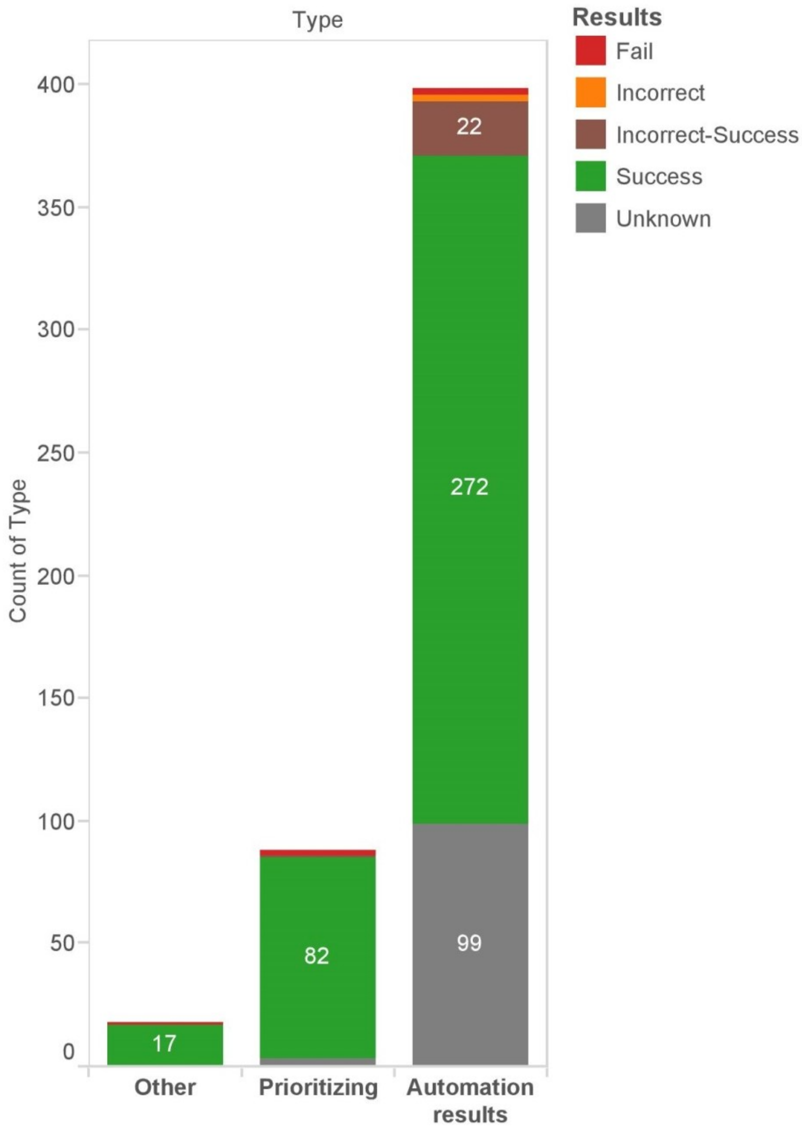
B.17.4 Classification of Video Coding Results by Type of Codes and Information Gathered



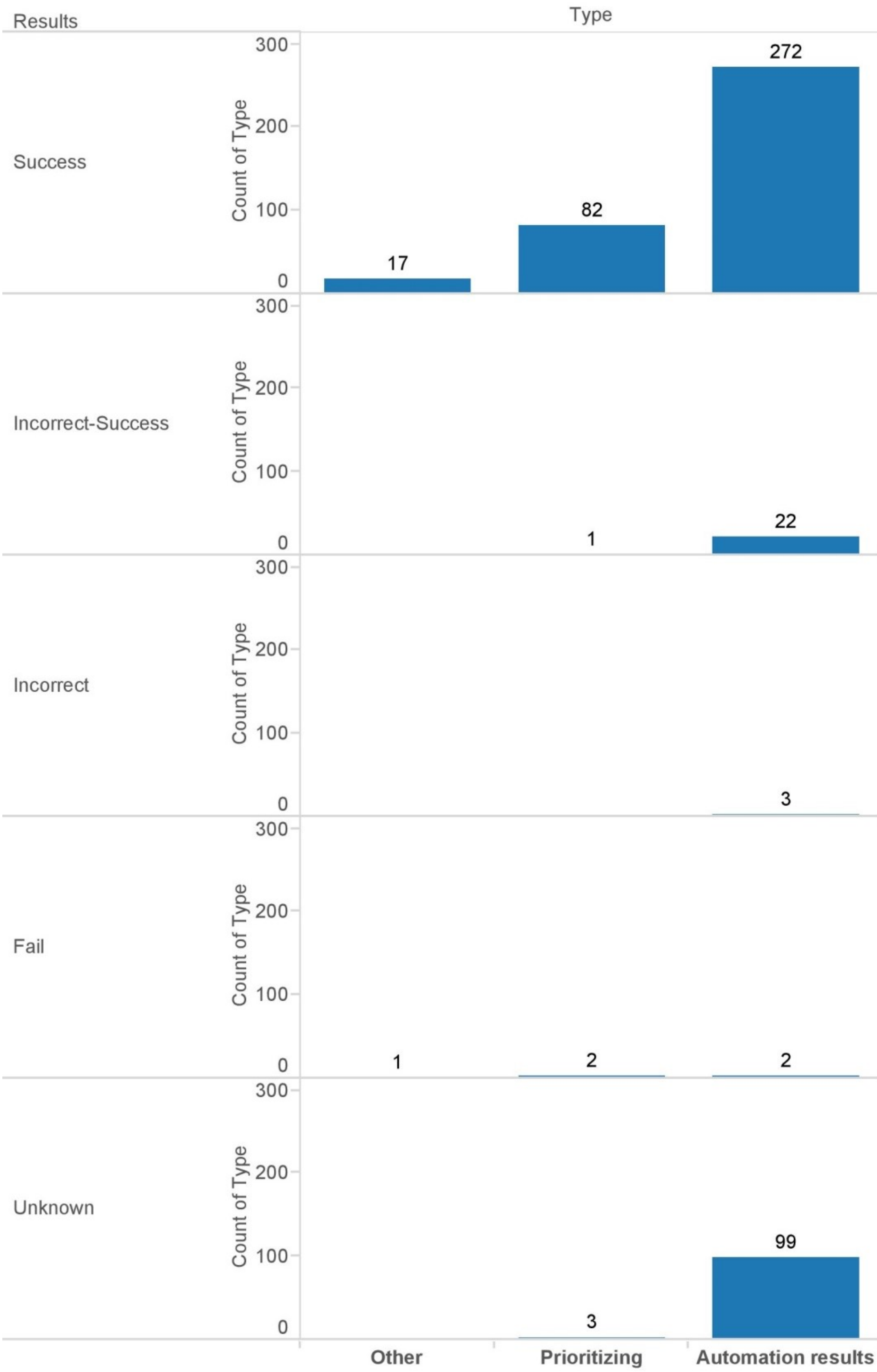
B.17.5 Occurrence Counts of Sequencing Video Codes



B.17.6 Results of Sequencing Video Codes (Stacked Bar Chart)

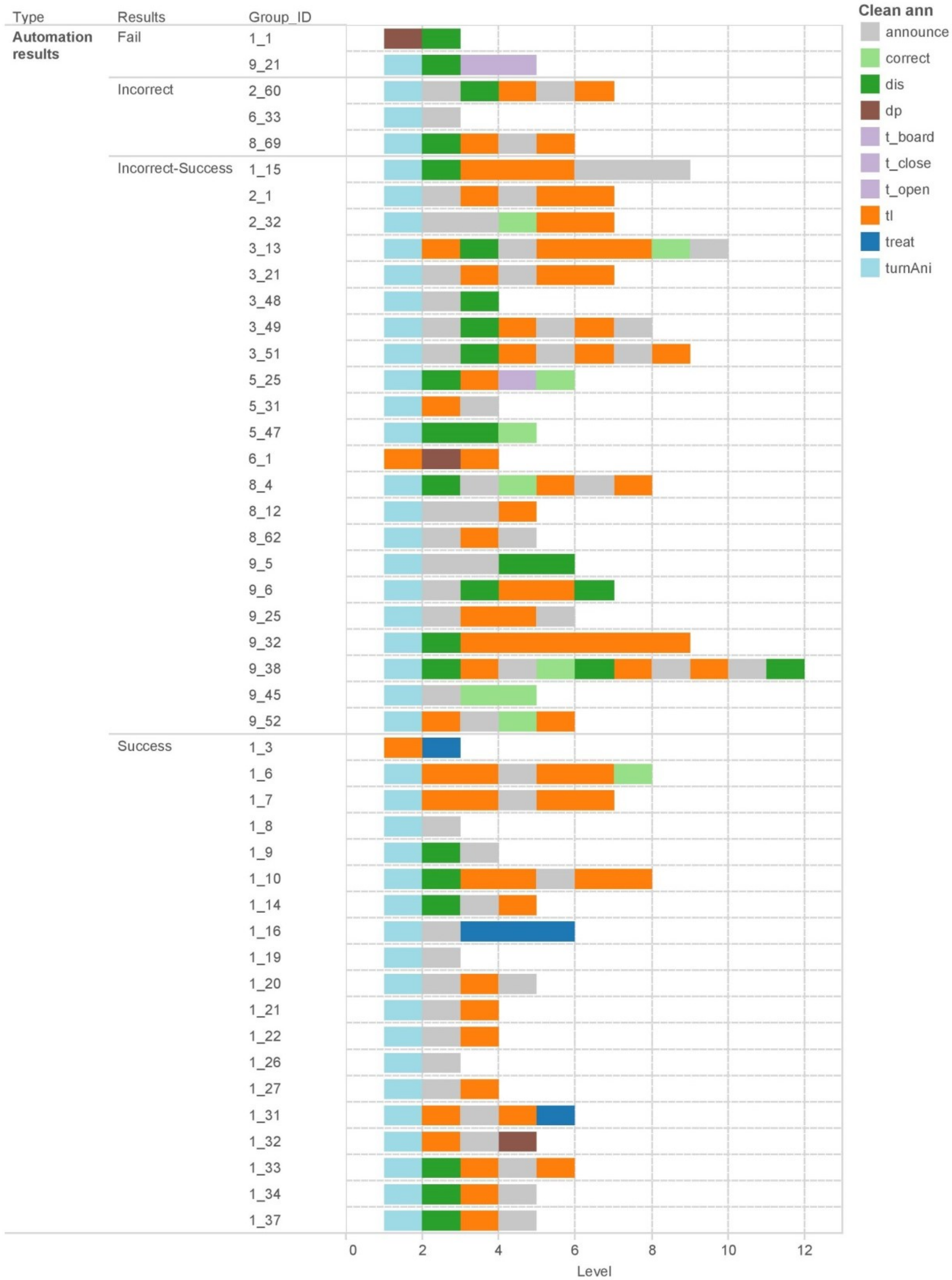


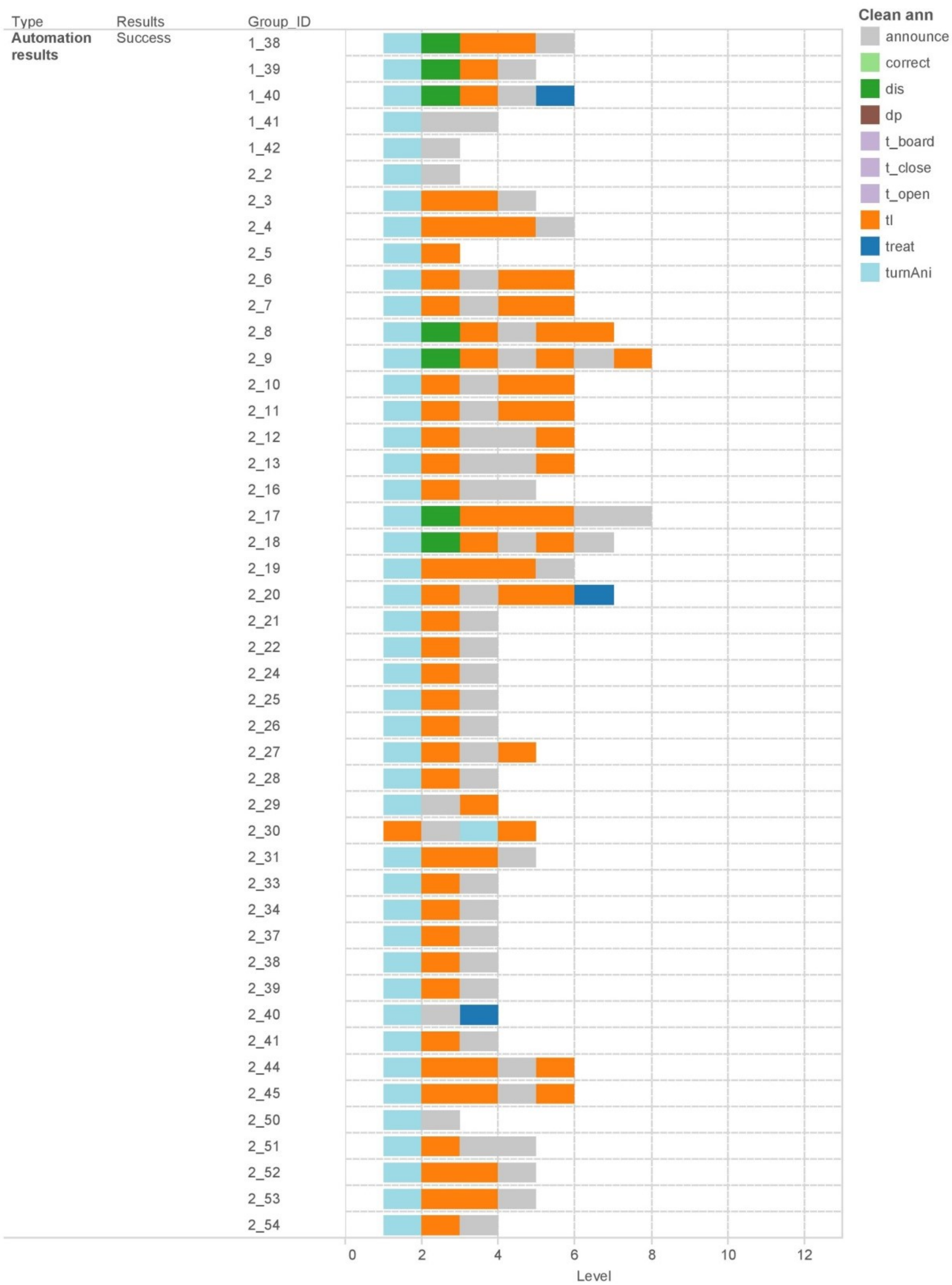
B.17.7 Results of Sequencing Video Codes (Table)

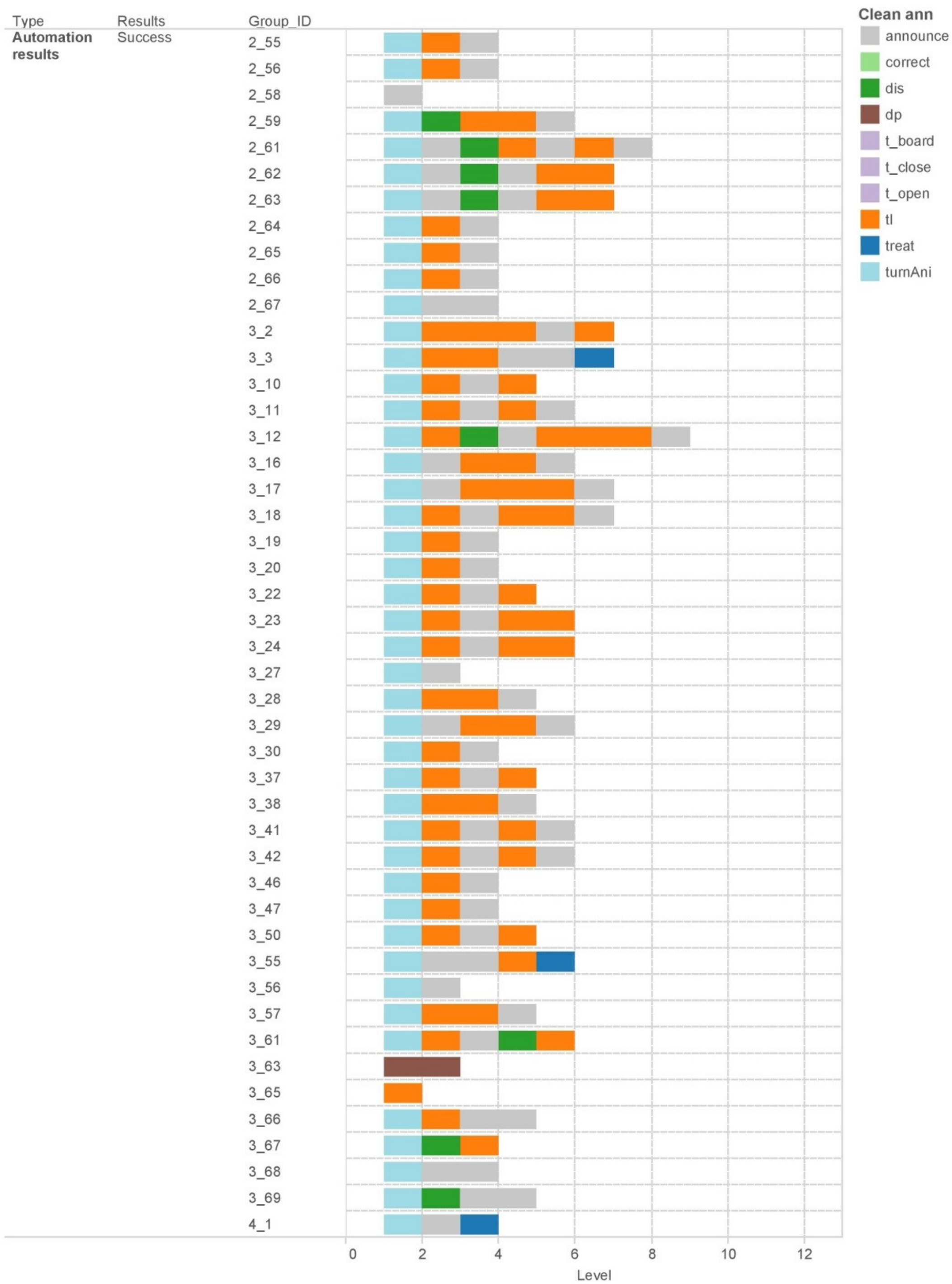


B.17.8 Results of Sequencing Video Codes (Visual blocks)

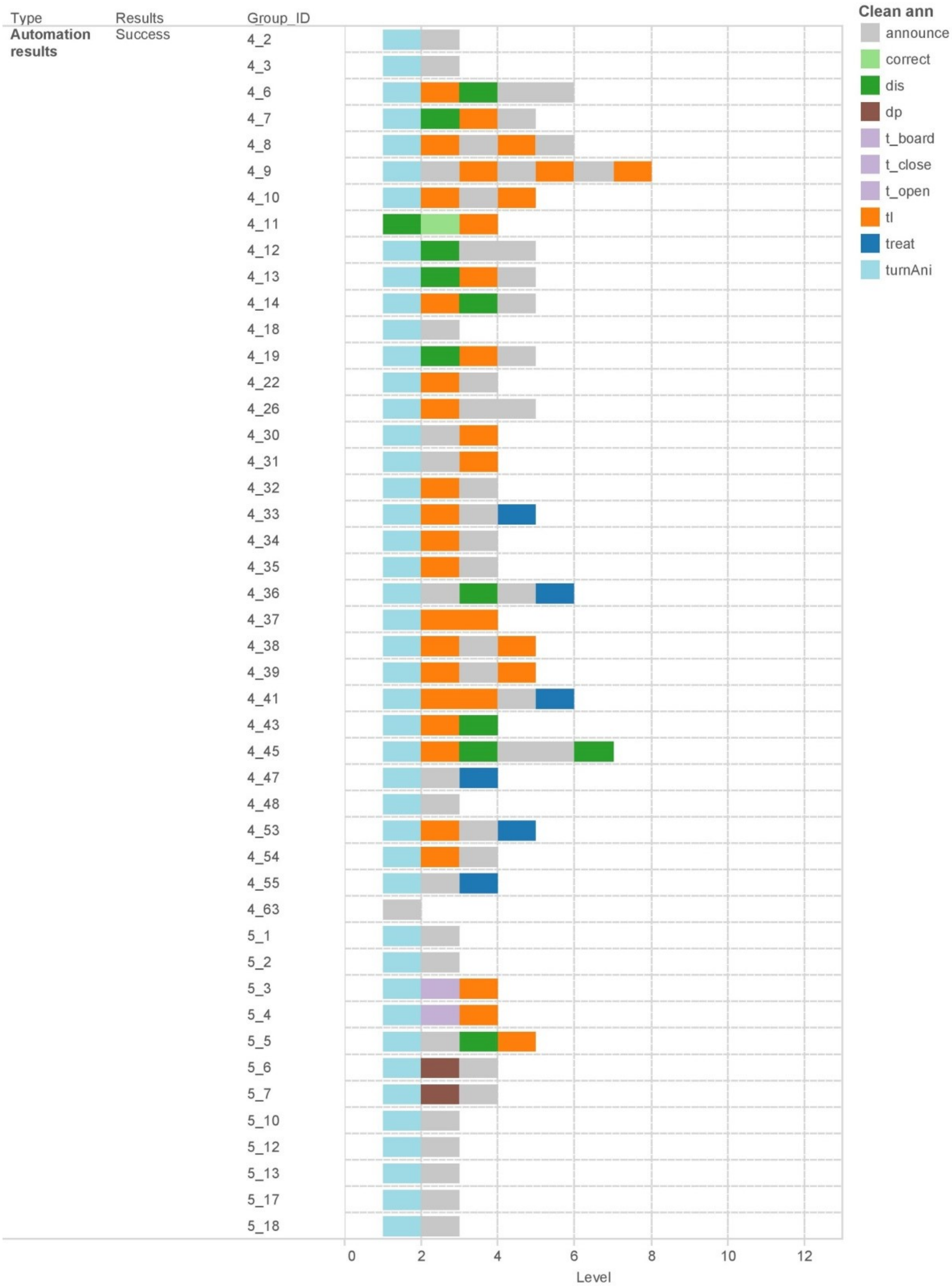
We also printed out a visualization of all the sequenced codes to help searching for interesting usages.

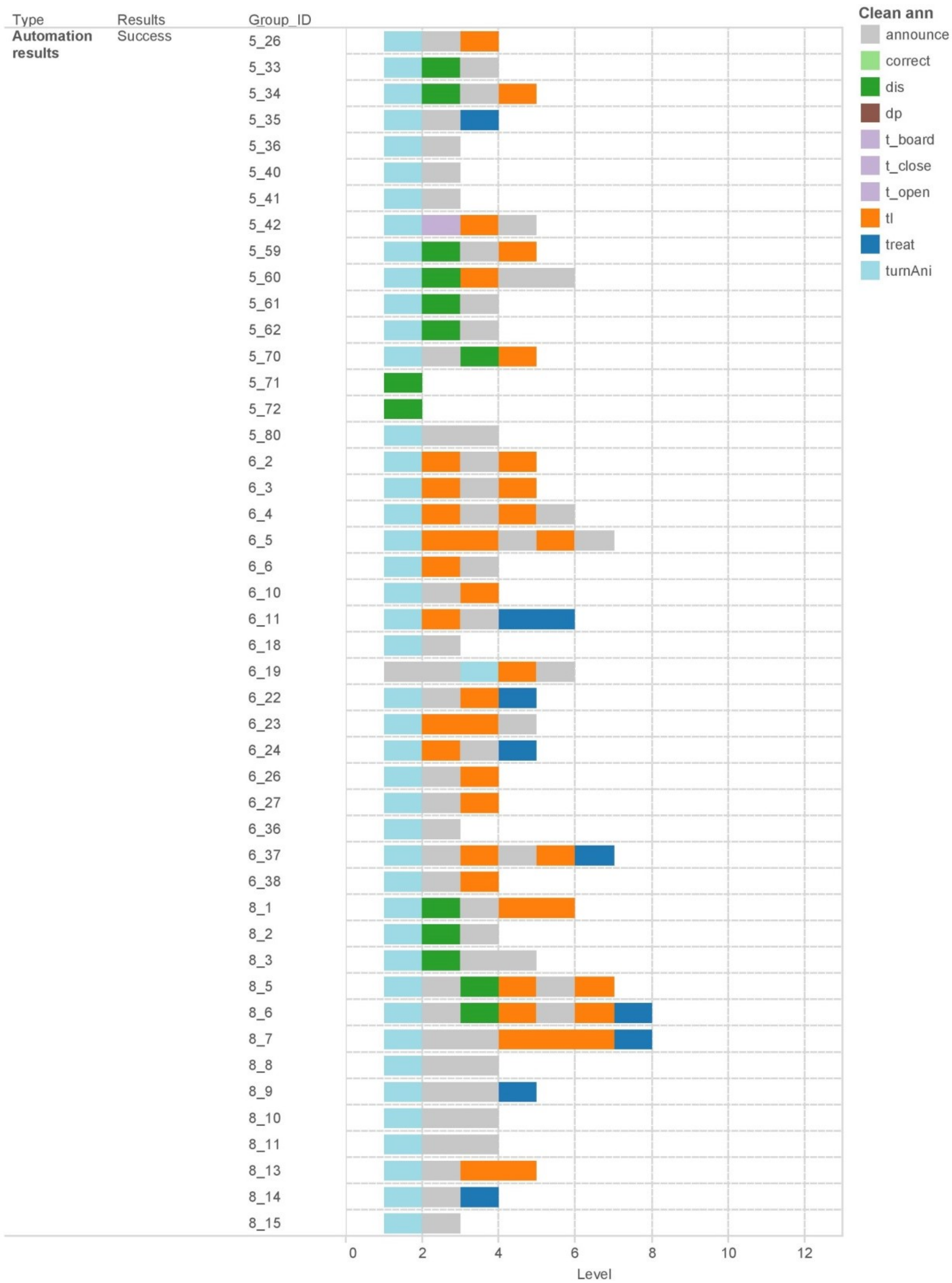


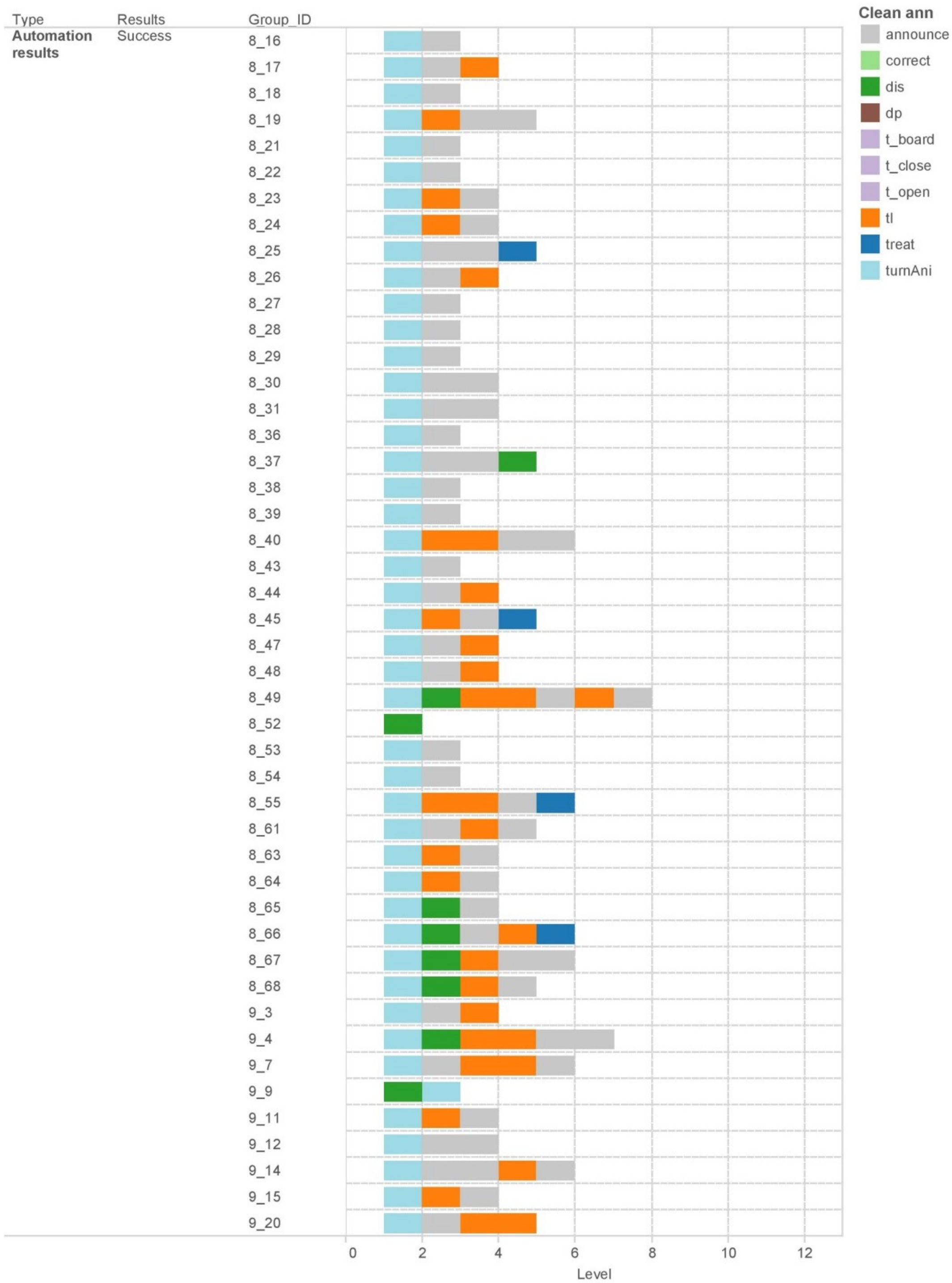

Type
Results
Group_ID
Automation results
Success
1_38
1_39
1_40
1_41
1_42
2_2
2_3
2_4
2_5
2_6
2_7
2_8
2_9
2_10
2_11
2_12
2_13
2_16
2_17
2_18
2_19
2_20
2_21
2_22
2_24
2_25
2_26
2_27
2_28
2_29
2_30
2_31
2_33
2_34
2_37
2_38
2_39
2_40
2_41
2_44
2_45
2_50
2_51
2_52
2_53
2_54
0
2
4
6
8
10
12
Level
Clean ann
announce
correct
dis
dp
t_board
t_close
t_open
tl
treat
turnAni



Type
Results
Group_ID
Automation results
Success
2_55
2_56
2_58
2_59
2_61
2_62
2_63
2_64
2_65
2_66
2_67
3_2
3_3
3_10
3_11
3_12
3_16
3_17
3_18
3_19
3_20
3_22
3_23
3_24
3_27
3_28
3_29
3_30
3_37
3_38
3_41
3_42
3_46
3_47
3_50
3_55
3_56
3_57
3_61
3_63
3_65
3_66
3_67
3_68
3_69
4_1
0
2
4
6
8
10
12
Level
Clean ann
announce
correct
dis
dp
t_board
t_close
t_open
tl
treat
turnAni


Type
Results
Group_ID
Automation results
Success
4_2
4_3
4_6
4_7
4_8
4_9
4_10
4_11
4_12
4_13
4_14
4_18
4_19
4_22
4_26
4_30
4_31
4_32
4_33
4_34
4_35
4_36
4_37
4_38
4_39
4_41
4_43
4_45
4_47
4_48
4_53
4_54
4_55
4_63
5_1
5_2
5_3
5_4
5_5
5_6
5_7
5_10
5_12
5_13
5_17
5_18
0
2
4
6
8
10
12
Level
Clean ann
announce
correct
dis
dp
t_board
t_close
t_open
tl
treat
turnAni


Type
Results
Group_ID
Automation results
Success
5_26
5_33
5_34
5_35
5_36
5_40
5_41
5_42
5_59
5_60
5_61
5_62
5_70
5_71
5_72
5_80
6_2
6_3
6_4
6_5
6_6
6_10
6_11
6_18
6_19
6_22
6_23
6_24
6_26
6_27
6_36
6_37
6_38
8_1
8_2
8_3
8_5
8_6
8_7
8_8
8_9
8_10
8_11
8_13
8_14
8_15
0
2
4
6
8
10
12
Level
Clean ann
announce
correct
dis
dp
t_board
t_close
t_open
tl
treat
turnAni



Type
Results
Group_ID
Automation results
Success
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8_17
8_18
8_19
8_21
8_22
8_23
8_24
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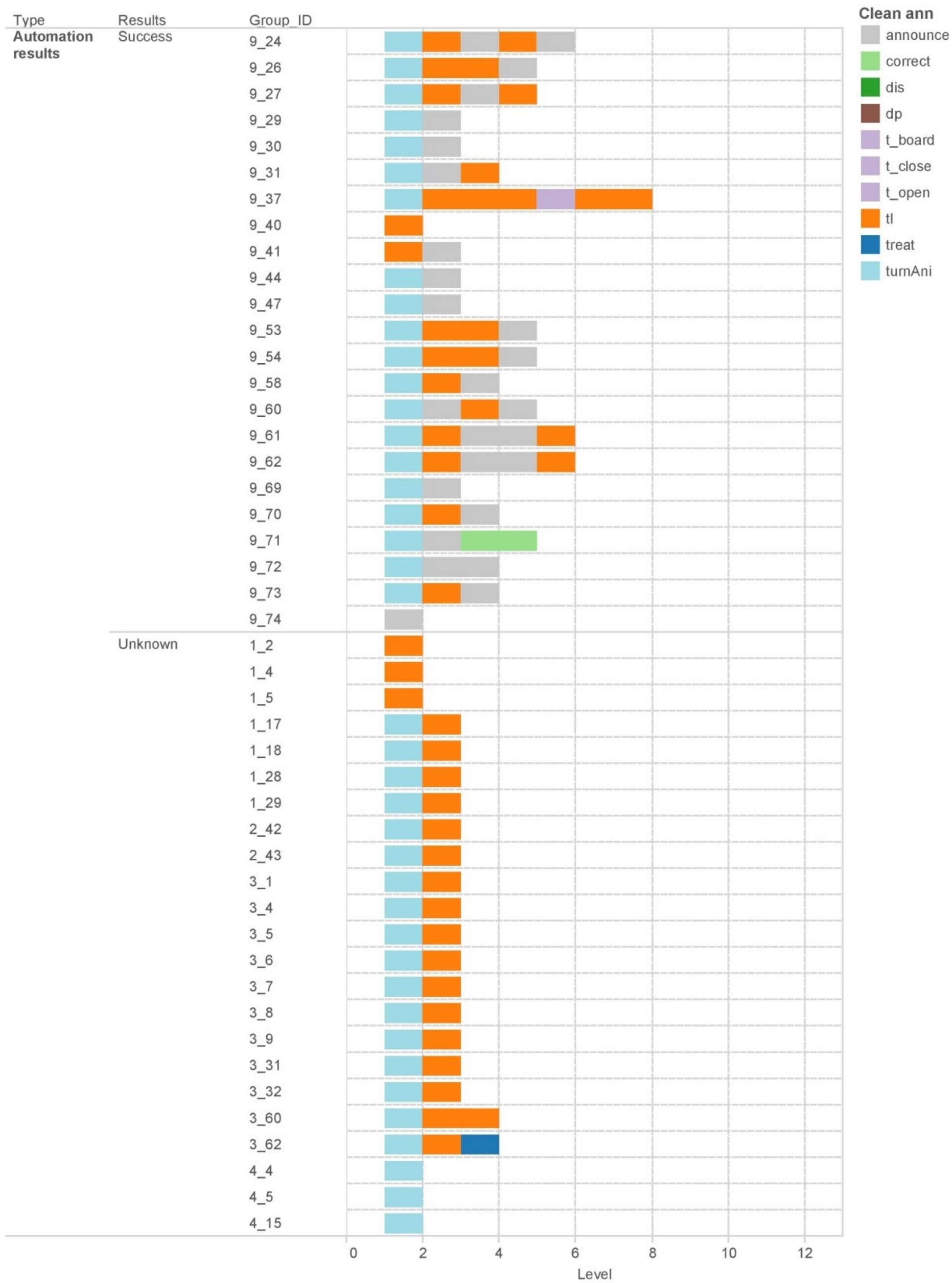
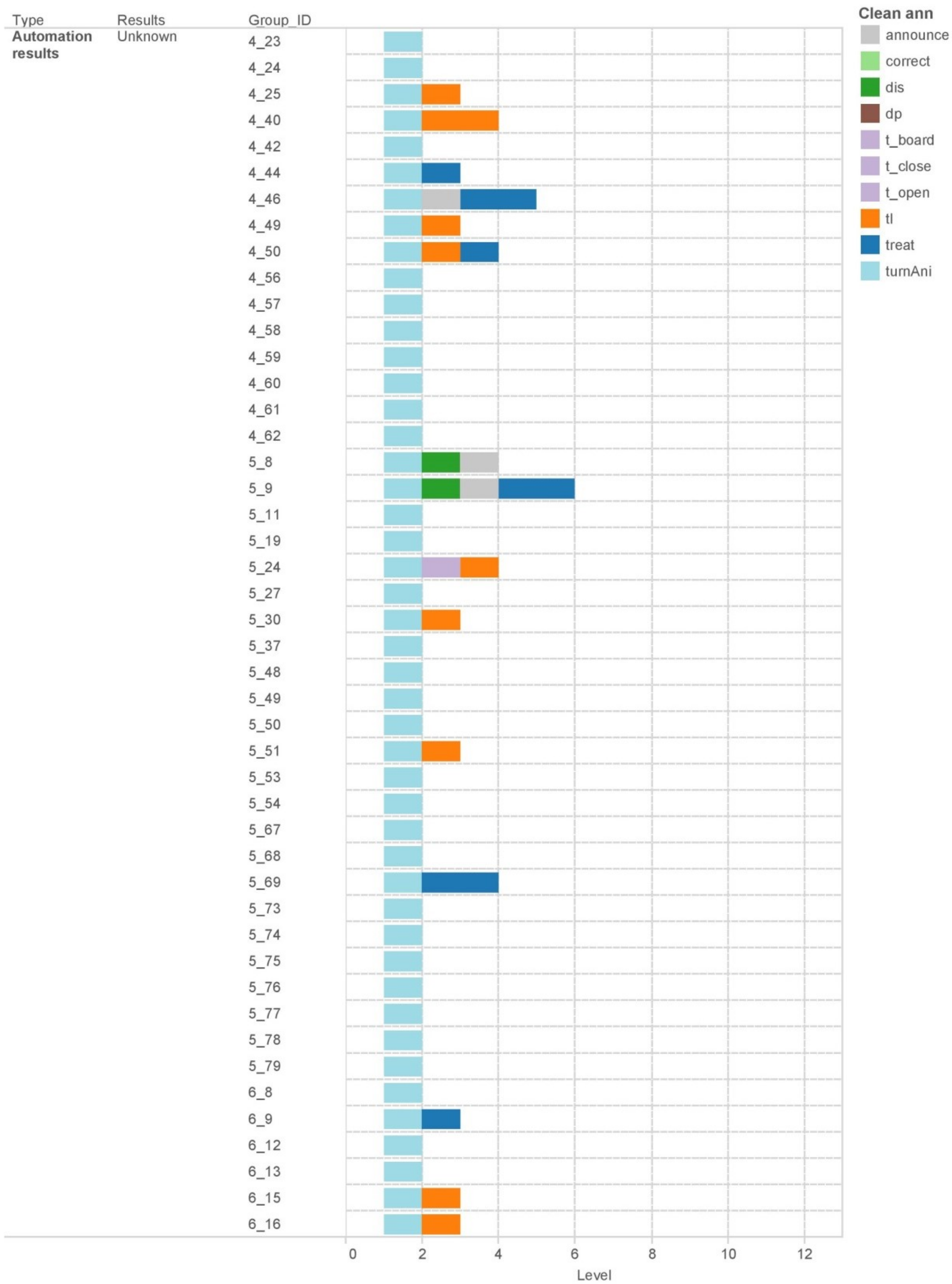
8_26
8_27
8_28
8_29
8_30
8_31
8_36
8_37
8_38
8_39
8_40
8_43
8_44
8_45
8_47
8_48
8_49
8_52
8_53
8_54
8_55
8_61
8_63
8_64
8_65
8_66
8_67
8_68
9_3
9_4
9_7
9_9
9_11
9_12
9_14
9_15
9_20
0
2
4
6
8
10
12
Level
Clean ann
announce
correct
dis
dp
t_board
t_close
t_open
tl
treat
turnAni


Type
Results
Group_ID
Automation results
Success
9_24
9_26
9_27
9_29
9_30
9_31
9_37
9_40
9_41
9_44
9_47
9_53
9_54
9_58
9_60
9_61
9_62
9_69
9_70
9_71
9_72
9_73
9_74
Unknown
1_2
1_4
1_5
1_17
1_18
1_28
1_29
2_42
2_43
3_1
3_4
3_5
3_6
3_7
3_8
3_9
3_31
3_32
3_60
3_62
4_4
4_5
4_15
0
2
4
6
8
10
12
Level
Clean ann
announce
correct
dis
dp
t_board
t_close
t_open
tl
treat
turnAni



Type
Results
Group_ID
Automation results
Unknown
4_23
4_24
4_25
4_40
4_42
4_44
4_46
4_49
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4_56
4_57
4_58
4_59
4_60
4_61
4_62
5_8
5_9
5_11
5_19
5_24
5_27
5_30
5_37
5_48
5_49
5_50
5_51
5_53
5_54
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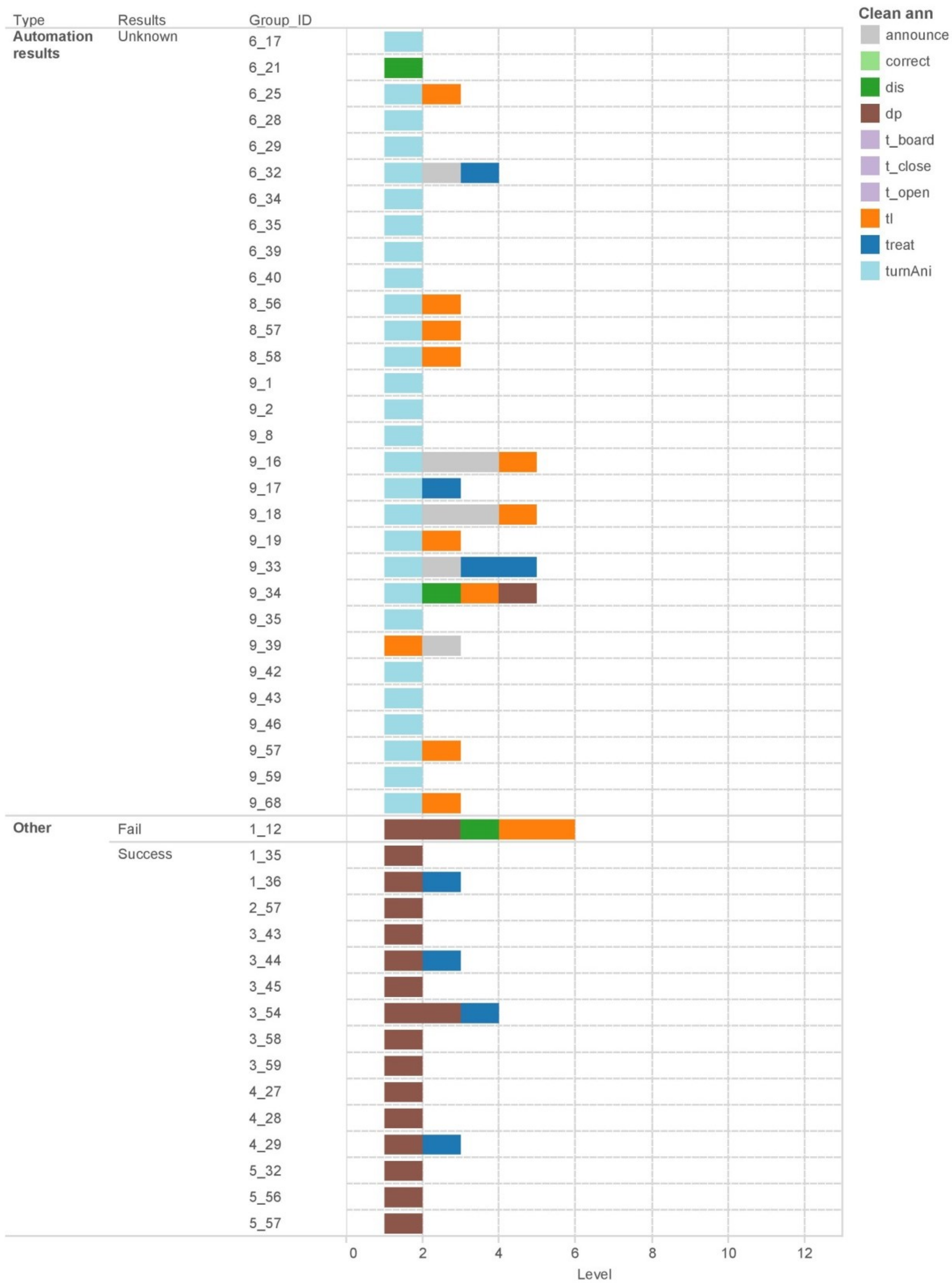
5_68
5_69
5_73
5_74
5_75
5_76
5_77
5_78
5_79
6_8
6_9
6_12
6_13
6_15
6_16
0
2
4
6
8
10
12
Level
Clean ann
announce
correct
dis
dp
t_board
t_close
t_open
tl
treat
turnAni



Type
Results
Group_ID
Automation results
Unknown
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6_21
6_25
6_28
6_29
6_32
6_34
6_35
6_39
6_40
8_56
8_57
8_58
9_1
9_2
9_8
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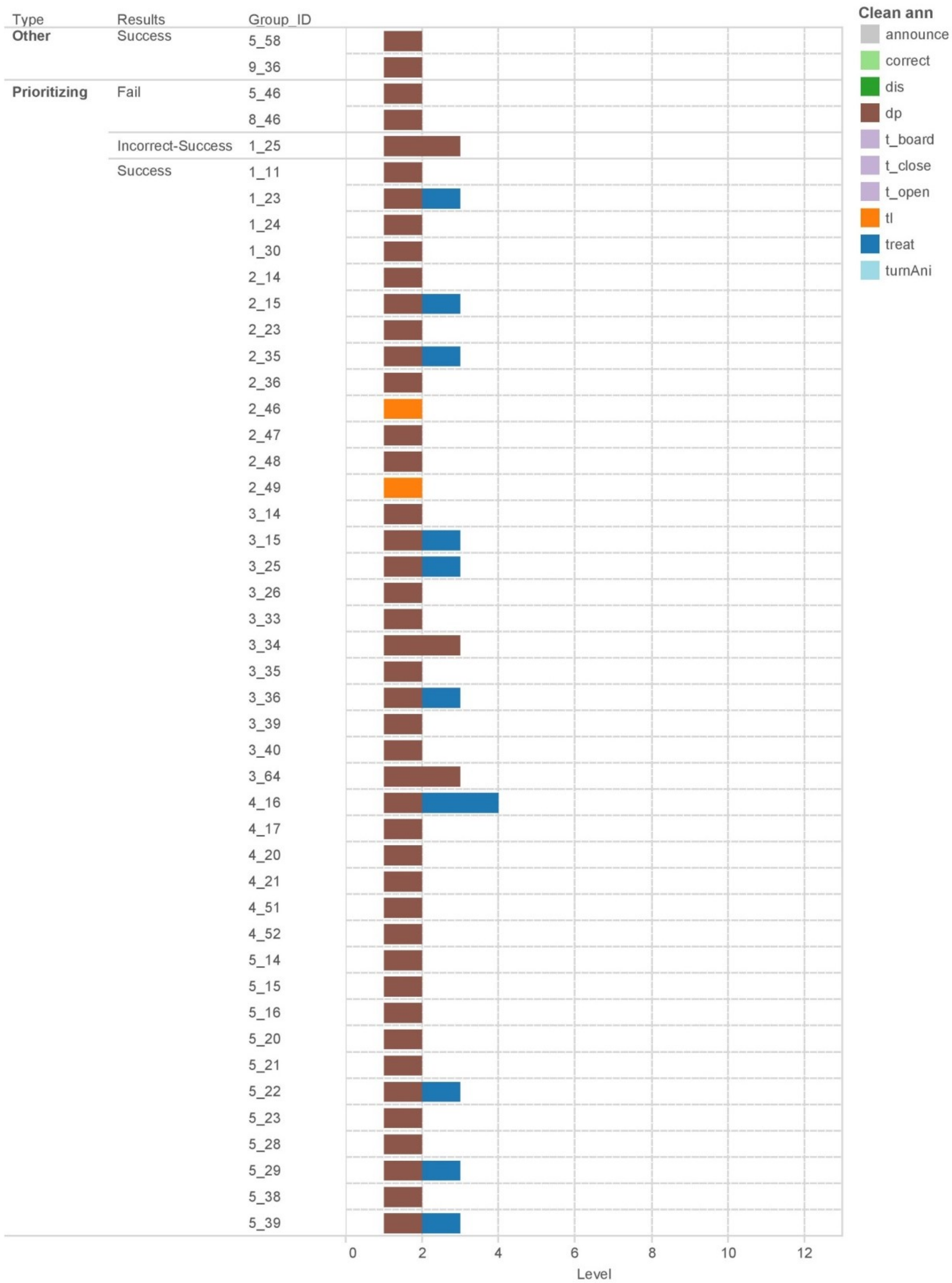
9_17
9_18
9_19
9_33
9_34
9_35
9_39
9_42
9_43
9_46
9_57
9_59
9_68
Other
Fail
1_12
Success
1_35
1_36
2_57
3_43
3_44
3_45
3_54
3_58
3_59
4_27
4_28
4_29
5_32
5_56
5_57
0
2
4
6
8
10
12
Level
Clean ann
announce
correct
dis
dp
t_board
t_close
t_open
tl
treat
turnAni



Type
Results
Group_ID
Other
Success
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9_36
Prioritizing
Fail
5_46
8_46
Incorrect-Success
1_25
Success
1_11
1_23
1_24
1_30
2_14
2_15
2_23
2_35
2_36
2_46
2_47
2_48
2_49
3_14
3_15
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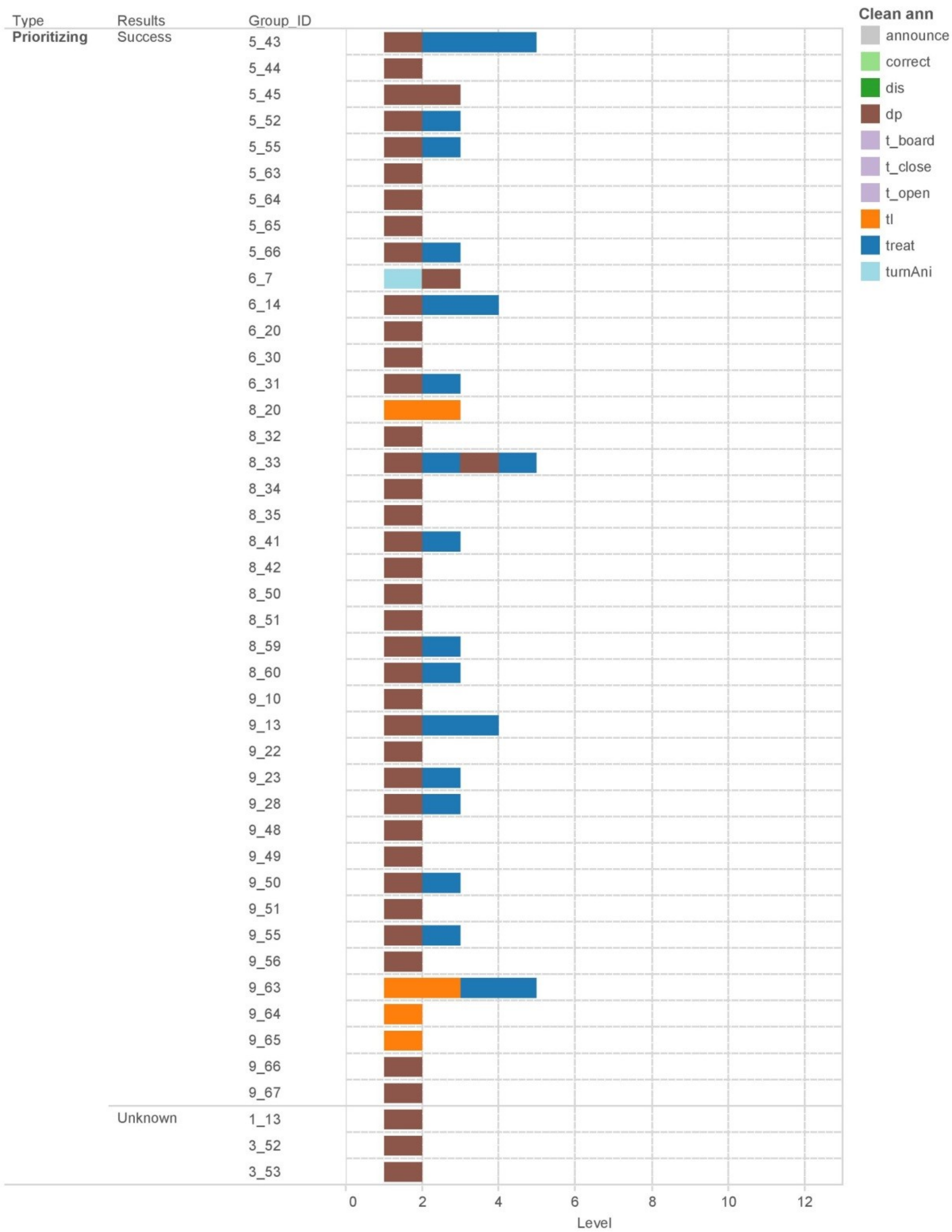
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Appendix C

Callout Bubble Study Materials

C.1 Permission to Use SMART amp^{TM} Photos

Permission to use SMART amp photos

Edward Tse <EdwardTse@smarttech.com> Mon, Feb 22, 2016 at 10:40 AM
To: Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>

Hi Betty,

No problem to use the photos in your thesis, please provide credit.

Edward

From: Kerstin Fischer
Sent: 22 February 2016 05:04 AM
To: Edward Tse <EdwardTse@smarttech.com>
Subject: RE: Permission to use SMART amp photos

Hi Edward,

Yes for certain. She only needs to mention that the screenshots are provided by us.

Best

Kerstin

From: Edward Tse
Sent: Friday, February 19, 2016 6:10 PM
To: Kerstin Fischer <KerstinFischer@smarttech.com>
Subject: FW: Permission to use SMART amp photos

Hello Kerstin,

I'm just wondering if it is ok for Betty Chang to include some screenshots from a SMART YouTube video (this one) in her PhD thesis. She would credit us in her thesis.

Please let me know. Thanks!

Edward

From: Yu-Ling Betty Chang [mailto:betty.chang@uwaterloo.ca]
Sent: 19 February 2016 10:02 AM
To: Edward Tse <EdwardTse@smarttech.com>
Subject: Permission to use SMART amp photos

Hello Ed,

[Quoted text hidden]

C.2 Ethics Materials

The data was collected by SMART Technologies during the project. We thus applied for a secondary use of data to use the data collected for our study.

C.2.1 Ethics Application

ORE OFFICE USE ONLY

ORE #______________

APPLICATION FOR ETHICS REVIEW OF RESEARCH INVOLVING HUMAN PARTICIPANTS

Please remember to PRINT AND SIGN the form and forward with all attachments to the Office of Research Ethics, Needles Hall, Room 1024.

A. GENERAL INFORMATION

1. Title of Project: Providing awareness in large collaborative virtual workspaces (secondary use of data)

2. a) Principal and Co-Investigator(s)

NEW As of May 1, 2013, all UW faculty and staff listed as investigation must complete the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Tutorial, 2nd Ed. (TCPS2) prior to submitting an ethics application. The tutorial takes at least three hours; it has start and stop features.

Name	Department	Ext:	e-mail:

2. b) Collaborator(s)

NEW As of May 1, 2013, all UW faculty and staff listed as investigation must complete the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Tutorial, 2nd Ed. (TCPS2) prior to submitting an ethics application. The tutorial takes at least three hours; it has start and stop features.

Name	Department	Ext:	e-mail:
Cresencia Fong	SMART Technologies		cresenciafong@smarttech.com
Edward Tse	SMART Technologies		edwardtse@smarttech.com

3. Faculty Supervisor(s)

NEW As of May 1, 2013, all UW faculty and staff listed as investigation must complete the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Tutorial, 2nd Ed. (TCPS2) prior to submitting an ethics application. The tutorial takes at least three hours; it has start and stop features.

Name	Department	Ext:	e-mail:
Stacey Scott	Systems Design Engineering	32236	stacey.scott@uwaterloo.ca
Mark Hancock	Management Sciences	36587	mark.hancock@uwaterloo.ca

4. Student Investigator(s)

Name	Department	Ext:	e-mail:	Local Phone #:
Yu-Ling (Betty) Chang	Systems Design Engineering		betty.chang@uwaterloo.ca	519-574-5059

5. Level of Project: PhD **Specify Course:**

Research Project/Course Status: New Project\Course

6. Funding Status (If Industry funded and a clinical trial involving a drug or natural product or is medical device testing, then Appendix B is to be completed):

Is this project currently funded? Yes

- If Yes, provide Name of Sponsor and include the title of the grant/contract: Other : Mitacs Accelerate Program
- If No, is funding being sought OR if Yes, is additional funding being sought? No
- Period of Funding: Oct 15, 2014 - June 14, 2015

7. Does this research involve another institution or site? Yes
If Yes, what other institutions or sites are involved:
SMART Technologies

8. Has this proposal, or a version of it, been submitted to any other Research Ethics Board/Institutional Review Board? Yes
If Yes, provide the name of the REB/IRB, date of ethics review, and the decision or date of submission. Attach a copy of the ethics clearance certificate, if applicable:
University of Toronto - Office of Research Ethics, passed on October 23, 2014

9. For Undergraduate and Graduate Research:

Has this proposal received approval of a Department Committee? Not Dept. Req.

10. a) Indicate the anticipated commencement date for this project: 5/25/2015

b) Indicate the anticipated completion date for this project: 5/25/2016

11. Conflict of interest: Appendix B is attached to the application if there are any potential, perceived, or actual financial or non-financial conflicts of interest by members of the research team in undertaking the proposed research.

B. SUMMARY OF PROPOSED RESEARCH

1. Purpose and Rationale for Proposed Research

a. Describe the purpose (objectives) and rationale of the proposed project and include any hypothesis(es)/research questions to be investigated. For a non-clinical study summarize the proposed research using the headings: Purpose, Aim or Hypothesis, and Justification for the Study. For a clinical trial/medical device testing summarize the research proposal using the following headings: Purpose, Hypothesis, Justification, and Objectives.
Where available, provide a copy of a research proposal. For a clinical trial/medical device testing a research proposal is required:
Problem
Bring-your-own-device classrooms may allow for more engaging learning experience for students than traditional lectures and encourage peer learning through collaborative work. A large digital canvas can act as the shared workspace for students, analogous to the craft paper and chart paper for group work. Even though students can see each other's work in real-time in

the workspace, students may virtually bump into each other or unintentionally distract or interrupt other students' work since they cannot easily tell where others are and what they are working on in the virtual workspace.

Aim
SMART Technologies have developed an awareness feature to show collaborators' actions. The initial feedback was very positive, and we would like to conduct further analysis on the data to understand the teachers' and students' usage and experience of the feature.

Hypothesis
1. Students' awareness ranking is negatively correlates with their ranking of focus level.
2. Students' awareness ranking is negatively correlates with their ranking of frustration level when others got in their way in the virtual workspace.
3. Students who made use of the awareness feature is less frustrated when others got in their way.
4. Students' awareness ranking predicts whether they work differently with other students using the awareness feature.

Justification for the study
The results will help inform further design improvement for supporting awareness in Bring-your-own-device classrooms. Specifically, we would like to gain insights into the balance between distraction and awareness for teacher and students so that we can improve the design and make sure the class function is not interrupted. We also need to understand how users perceive and make use of the awareness cues provided and their effectiveness.

b. In lay language, provide a one paragraph (approximately 100 words) summary of the project including purpose, the anticipated potential benefits, and basic procedures used.
In a bring-your-own-device classroom, students may have low level of awareness of other students' work and their whereabouts since they cannot easily observe their peers to gain awareness. Thus, they may miss the opportunity for collaboration or may unintentionally interrupt other students' work. This project will analyze the existing feedback from teachers and students on the new awareness feature. The analysis will provide insights on teachers' and students' usage and experience of the feature, and the results will help inform further design improvement for supporting awareness in Bring-your-own-device classrooms.

C. DETAILS OF STUDY

1. Methodology/Procedures

a. Indicate all of the procedures that will be used. Append to form 101 a copy of all materials to be used in this study.

Analysis of secondary data set

b. Provide a detailed, sequential description of the procedures to be used in this study. For studies involving multiple procedures or sessions, provide a flow chart. Where applicable, this section also should give the research design (e.g., cross-over design, repeated measures design).
As this is a secondary use of data application, no user studies will be conducted. We have 3 types of data:

- teacher phone interview recordings, see Teacher Interview Questions (Semi-structured) (3 teachers from elementary and middle schools)
- teacher written survey data, see "Collaborator Awareness Teacher Survey" (4 teachers from elementary, middle, and high schools)
- student written survey data, see "Collaborator Awareness Student Survey"

We will contact teachers to gain their consent for allowing us to use their feedback (see teacher information letter and consent form). We will only analyze the data from teachers that have given us consent to use.

For the student written survey, SMART Technologies will only release the anonymized data without identifying information (see "Data fields to be released by SMART Technologies").

We will conduct qualitative and quantitative data analysis on teachers' and students' feedback for the awareness feature.

c. Will this study involve the administration/use of any drug, medical device, biologic, or natural health product? No

d. Will you be using or processing any biological materials such as human blood, tissue, cells or bodily fluids in the proposed research?
No

2. Participants Involved in the Study

a. Indicate who will be recruited as potential participants in this study.
Non-UW Participants:
Adults

b. Describe the potential participants in this study including group affiliation, gender, age range and any other special characteristics. Describe distinct or common characteristics of the potential participants or a group (e.g., a group with a particular health condition) that are relevant to recruitment and/or procedures. Provide justification for exclusion based on culture, language, gender, race, ethnicity, age or disability. For example, if a gender or sub-group (i.e., pregnant and/or breastfeeding women) is to be excluded, provide a justification for the exclusion.

No participants will be recruited. The data that we will receive include teachers and students in elementary, middle, and high schools.

c. How many participants are expected to be involved in this study? For a clinical trial, medical device testing, or study with procedures that pose greater than minimal risk, sample size determination information is to be provided.

No participants will be recruited. The data that we will receive include 6 teachers and 71 students.

3. Recruitment Process and Study Location

a. From what source(s) will the potential participants be recruited?
SMART Technologies has agreed to release the data to us

b. Describe how and by whom the potential participants will be recruited. Provide a copy of any materials to be used for recruitment (e.g. posters(s), flyers, cards, advertisement(s), letter(s), telephone, email, and other verbal scripts).
No participants will be recruited.

c. Where will the study take place? Off campus: No user study will be conducted. The data will be received electronically.

4. Remuneration for Participants
Will participants receive remuneration (financial, in-kind, or otherwise) for participation? No

5. Feedback to Participants

Describe the plans for provision of study feedback and attach a copy of the feedback letter to be used. Wherever possible, written feedback should be provided to study participants including a statement of appreciation, details about the purpose and predictions of the study, restatement of the provisions for confidentiality and security of data, an indication of when a study report will be available and how to obtain a copy, contact information for the researchers, and the ethics review and clearance statement.
Once the data analysis is complete. We will send a written report of the data analysis to the teachers who grant us permission to use their feedback.

D. POTENTIAL BENEFITS FROM THE STUDY

1. Identify and describe any known or anticipated direct benefits to the participants from their involvement in the project.
Participants will receive no direct benefits.

2.Identify and describe any known or anticipated benefits to the scientific community/society from the conduct of this study.
The study result will help us iterate on the awareness cue design and understand teachers and students' perception and usage of the cues. This will help us better support class function and improve teaching and learning experiences.

E. POTENTIAL RISKS TO PARTICIPANTS FROM THE STUDY

1. For each procedure used in this study, describe any known or anticipated risks/stressors to the participants. Consider physiological, psychological, emotional, social, economic risks/stressors. A study–specific current health status form must be included when physiological assessments are used and the associated risk(s) to participants is minimal or greater.
No known or anticipated risks
There is no known or anticipated risk for teachers and students since no user study is being conducted and participants' will never be referred to by their name. SMART Technologies will release anonymized student data.

2. Describe the procedures or safeguards in place to protect the physical and psychological health of the participants in light of the risks/stressors identified in E1.
There is no known or anticipated risk for teachers and students.

F. INFORMED CONSENT PROCESS

1. What process will be used to inform the potential participants about the study details and to obtain their consent for participation?
Information letter with email consent; provide a electronic copy.

2. If written consent cannot be obtained from the potential participants, provide a justification for this.
As the participants locate out of province, we will send them emails with information letter and consent form. The teachers will need to reply us to give us consent for secondary usage of their data.

3. Does this study involve persons who cannot give their own consent (e.g. minors)? No

---

G. ANONYMITY OF PARTICIPANTS AND CONFIDENTIALITY OF DATA

1. Provide a detailed explanation of the procedures to be used to ensure anonymity of participants and confidentiality of data both during the research and in the release of the findings.
All data received from SMART Technologies is considered completely confidential. Participants' names will not appear in any publication resulting from this study; however, anonymous quotations from the conversation may be used. In these cases student volunteers will be referred to as Student 1, Student 2, … (or S1, S2, …), and teacher volunteers will be referred to as Teacher 1, Teacher 2, … (or T1, T2, …). This data will be used only for the purposes associated with teaching, scientific presentations, publications, and/or sharing with other researchers. Participants will not be identified by name.

2. Describe the procedures for securing written records, video/audio tapes, questionnaires and recordings. Identify (i) whether the data collected will be linked with any other dataset and identify the linking dataset and (ii) whether the data will be sent outside of the institution where it is collected or if data will be received from other sites. For the latter, are the data de-identified, anonymized, or anonymous?
Data released by SMART Technologies to us will be retained on password protected computers in a secure location. Data stored on the computer may be transferred between machines using the university or SMART Technologies' secure network or external storage devices. The data will not be shared outside of the university and SMART Technologies.

3. Indicate how long the data will be securely stored and the method to be used for final disposition of the data.
Electronic Data
Erasing of electronic data after 10 year(s).
Location: Games Institue (computers) at the University of Waterloo

4. Are there conditions under which anonymity of participants or confidentiality of data cannot be guaranteed?
No

H. PARTIAL DISCLOSURE AND DECEPTION

1. Will this study involve the use of partial disclosure or deception? Partial disclosure involves withholding or omitting information about the specific purpose or objectives of the research study or other aspects of the research. Deception occurs when an investigator gives false information or intentionally misleads participants about one or more aspects of the research study. No

---

Researchers must ensure that all supporting materials/documentation for their applications are submitted with the signed, hard copies of the ORE form 101/101A. Note, materials shown below in bold are normally required as part of the ORE application package. The inclusion of other materials depends on the specific type of projects.

Protocol Involves a Drug, Medical Device, Biologic, or Natural Health Product
If the study procedures include administering or using a drug, medical device, biologic, or natural health product that has been or has not been approved for marketing in Canada then the researcher is to complete Appendix A. Appendix A is to be attached to each of the one copy of the application that are submitted to the ORE. Information concerning studies involving a drug, biologic, natural health product, or medical devices can be found on the ORE website.

Please **check** below all appendices that are attached as part of your application package:

- Information Letter and Consent Form(s)*. Used in studies involving interaction with participants (e.g. interviews, testing, etc.)

- Data Collection Materials: A copy of all survey(s), questionnaire(s), interview questions, interview themes/sample questions for open-ended interviews, focus group questions, or any standardized tests.
- Other - Information released form from SMART Technologies and data fields to be received from SMART Technologies; Email script for contacting participants

* Refer to sample letters.

NOTE: The submission of incomplete application packages will increase the duration of the ethics review process.

To avoid common errors/omissions, and to minimize the potential for required revisions, applicants should ensure that their application and attachments are consistent with the *Checklist For Ethics Review of Human Research Application*

Please note the submission of incomplete packages may result in delays in receiving full ethics clearance. We suggest reviewing your application with the Checklist For Ethics Review of Human Research Applications to minimize any required revisions and avoid common errors/omissions.

INVESTIGATORS' AGREEMENT

I have read the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans, 2nd Edition (TCPS2) and agree to comply with the principles and articles outlined in the TCPS2. In the case of student research, as Faculty Supervisor, my signature indicates that I have read and approved this application and the thesis proposal, deem the project to be valid and worthwhile, and agree to provide the necessary supervision of the student.

NEW As of May 1, 2013, all UW faculty and staff listed as investigators must complete the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans Tutorial, 2nd Ed. (TCPS2) prior to submitting an ethics application. Each investigator is to indicate they have completed the TCPS2 tutorial. If there are more than two investigators, please attach a page with the names of each additional investigator along with their TCPS2 tutorial completion information.

________________________________	________________________
Print and Signature of Principal Investigator/Supervisor	**Date**

Completed TCPS2 tutorial:
___YES ___NO ___ In progress

________________________________	________________________
Print and Signature of Principal Investigator/Supervisor	**Date**

Completed TCPS2 tutorial:
___YES ___NO ___ In progress

Each student investigator is to indicate if they have completed the Tri-Council Policy Statement, 2nd

Edition Tutorial (http://pre.ethics.gc.ca/eng/education/tutorial-didacticiel/). If there are more than two student investigators, please attach a page with the names of each additional student investigator along with their TCPS2 tutorial completion information.

______________________________________ ___________________________
Signature of Student Investigator **Date**

Completed TCPS2 tutorial:
___YES ___NO ___ In progress

______________________________________ ___________________________
Signature of Student Investigator **Date**

Completed TCPS2 tutorial:
___YES ___NO ___ In progress

FOR OFFICE OF RESEARCH ETHICS USE ONLY:

______________________________ ___________________________
Maureen Nummelin, PhD **Date**
Chief Ethics Officer
OR
Julie Joza, MPH
Senior Manager, Research Ethics
OR
Sacha Geer, PhD
Manager, Research Ethics

ORE 101
Revised August 2003

C.2.2 Data Release from SMART Technologies

SMART Inspired Collaboration™

SMART Technologies ULC
3636 Research Road NW
Calgary, AB T2L 1Y1
CANADA

Phone 403.245.0333
Fax 403.228.2500
info@smarttech.com www.smarttech.com

Data Release Information

To Whom it May Concern,

My name is Edward Tse, I am supervising the research of Yu-Ling (Betty) Chang at SMART Technologies in Calgary. This letter is in regards to the release of collaborator awareness data for the Mitacs research project called IMMSERSe – Supporting Awareness and Encouraging Collaboration in Bring-Your-Own-Device Classroom Environments. SMART Technologies hereby releases the data below to our research collaborators from the University of Waterloo: Stacey Scott, Mark Hancock, and Yu-Ling (Betty) Chang.

1. Written surveys that consist of Likert Scales and Free Form questions from teachers about their experience of teaching with the collaborator awareness feature in classes.
2. Phone interview recordings with teachers after they have used the collaborator awareness feature.
3. Written surveys that consist of Likert Scales and Free Form questions from students about their experience of using the collaborator awareness feature. The identifying information will be removed so that no one can track the identity of any individual student.

Please see the attached questionnaire for more details.

Edward Tse
edwardtse@smarttech.com
External Research Program Manager
403-407-4124

C.2.3 Data Fields to be Released by SMART Technologies

Student Survey

1. Timestamp
2. How often did you know what others were doing in your amp workspace?
3. How easy was it for you to focus on what you were working on (e.g., creating, moving, responding to, etc.)?
4. When you were working in the amp workspace, how often were other people in your way?
5. When someone got in your way in the amp workspace, how did you feel?
6. Did you notice the callout bubbles that showed up (e.g., the grey callout bubble below)?
7. When did you notice the callout bubbles?
8. When someone got in your way in the amp workspace, how did you find out who it was?
9. When someone got in your way in the amp workspace, what did you do to solve the problem?
10. What did you do when you saw a callout bubble on a posting that you wanted to work on?
11. Did callout bubbles change how you work with others in amp? If so, please explain what you have done differently.
12. Any other comments?

Teacher Survey

1. Timestamp
2. What's your name?
3. How many students were in your class?
4. What grade were the students in?
5. How many students were in one group?
6. What were the topic of the lesson and the learning objectives?
7. For this particular lesson, how long was the lesson and how much time did you spend on each activity (in minutes or percentage)?
8. Did the awareness feature (the callout bubbles) change students' collaboration and/or presentation behaviours in amp in any way? Please explain why or why not.
9. Did the awareness feature (the callout bubbles) improve your class management and orchestration load in any way? Please explain why or why not?
10. Any additional comments?
11. Did students have their individual devices? Or were they sharing devices?
12. What device were the students using?
13. Please comment on the balance between distraction level of the awareness cue and the information provided by the cue.
14. Ideally, how much time would you like to spend on each activity for this lesson?
15. If possible, please provide a link to the amp workspace template

C.3 Student Evaluation Surveys

C.3.1 Control – No Awareness Cue

Survey 1

First Name: ____________________________

For each question, choose 1 answer and circle it.

1	How often did you know what others were doing in your amp workspace?	Never	Rarely	Half of the time	Usually	Always	
2	How easy was it for you to focus on what you were creating or sorting?	Very hard	Hard	Okay	Easy	Very easy	
3	When you were working in the amp workspace, how often were other people in your way?	Always	Usually	Half of the time	Rarely	Never	
4	When someone got in your way in the amp workspace, how did you feel?	Very frustrated	Slightly frustrated	I didn't care	Slightly happy	Very happy	Nobody got in my way

Please check off all answers that apply.

5. When someone got in your way in the workspace, how did you find out who it was?
   - ☐ Nobody got in my way
   - ☐ I used amp's chat
   - ☐ I talked to people
   - ☐ I yelled out to the class
   - ☐ I did nothing about it
   - ☐ Other, please explain: ____

     ____

6. When someone got in your way in the amp workspace, what did you do to solve the problem?
   - ☐ Nobody got in my way
   - ☐ I used amp's chat
   - ☐ I spoke with him/her
   - ☐ I did nothing about it
   - ☐ Other, please explain: ____

     ____

7. Any other comments?

   ____

   ____

C.3.2 Balloon Awareness Cue

Survey 2

First Name: ____________________________

For each question, choose 1 answer and circle it.

1	How often did you know what others were doing in your amp workspace?	Never	Rarely	Half of the time	Usually	Always
2	How easy was it for you to focus on what you were creating or sorting?	Very hard	Hard	Okay	Easy	Very easy
3	When you were working in the amp workspace, how often were other people in your way?	Always	Usually	Half of the time	Rarely	Never

4	When someone got in your way in the amp workspace, how did you feel?	Very frustrated	Slightly frustrated	I didn't care	Slightly happy	Very happy	Nobody got in my way

5. Did you notice the balloons that showed up (e.g., the grey balloon below)?

Yes No

Please check off all answers that apply.

6. When did you notice the balloons?
   - ☐ When posting my hobbies
   - ☐ When sorting hobbies
   - ☐ When watching others work
   - ☐ I didn't notice any balloons
   - ☐ Other, please explain: ____

   ____

7. When someone got in your way in the amp workspace, how did you find out who it was?
   - ☐ Nobody got in my way
   - ☐ I used amp's chat
   - ☐ I looked at the balloons
   - ☐ I talked to people
   - ☐ I yelled out to the class
   - ☐ I did nothing about it
   - ☐ Other, please explain: ____

     ____

8. When someone got in your way in the amp workspace, what did you do to solve the problem?
   - ☐ Nobody got in my way
   - ☐ I used amp's chat
   - ☐ I spoke with him/her
   - ☐ I did nothing about it
   - ☐ Other, please specify: ____

     ____

9. Any other comments?

   ____

   ____

C.4 Classroom Evaluation Surveys

C.4.1 Teacher Survey

Edit this form

Collaborator Awareness Teacher Survey

Please complete this form after your classroom test run with the new collaborator awareness feature.

* Required

What's your name? *

[ ]

How many students were in your class? *

[ ]

What grade were the students in? *

[ ]

How many students were in one group? *

- ☐ Students were working individually
- ☐ Groups of 2
- ☐ Groups of 3
- ☐ Groups of 4
- ☐ Groups of 5
- ☐ The entire class was working in one shared amp workspace
- ☐ Other: [ ]

Did students have their individual devices? Or were they sharing devices? *

- ☐ Students used individual devices
- ☐ 2 students were sharing one device
- ☐ Students in the same group were sharing one device
- ☐ Other: [ ]

What device were the students using? *

- ☐ Chromebook
- ☐ iPad
- ☐ iPad mini
- ☐ Android tablets
- ☐ Other: [ ]

What were the topic of the lesson and the learning objectives? *

For this particular lesson, how long was the lesson and how much time did you spend on each activity (in minutes or percentage)? *

e.g., 120 mins in total, 5 minutes on introduction, 10 minutes on technical support, 20 minutes on checking student progress, 10 minutes on discussion, etc.

Ideally, how much time would you like to spend on each activity for this lesson? *

e.g., 5 minutes on introduction, 20 minutes on checking student progress, 20 minutes on providing feedback, etc.

Did the awareness feature (the callout bubbles) change students' collaboration and/or presentation behaviours in amp in any way? Please explain why or why not. *

You may ignore the presentation part if you did not ask students to present their results.

Did the awareness feature (the callout bubbles) improve your class management and orchestration load in any way? Please explain why or why not? *

Please comment on the balance between distraction level of the awareness cue and the information provided by the cue. *

Any additional comments?

If possible, please provide a link to the amp workspace template

To save a workspace as template, please open the workspace in SMART amp -> select the workspace name at the top (next to the class name) -> select "Export Workspace as Template" from the drop down menu -> select "Create Template" in the pop up window -> copy & paste the "Link to share " to here.

Submit

Never submit passwords through Google Forms.

C.4.2 Student Survey

Edit this form

Collaborator Awareness Student Survey

* Required

What's your first name? *

How often did you know what others were doing in your amp workspace? *

	0	1	2	3	4	
Never	◯	◯	◯	◯	◯	Always

How easy was it for you to focus on what you were working on (e.g., creating, moving, responding to, etc.)? *

	0	1	2	3	4	
Impossible	◯	◯	◯	◯	◯	Effortless

When you were working in the amp workspace, how often were other people in your way? *

	0	1	2	3	4	
Never	◯	◯	◯	◯	◯	Always

When someone got in your way in the amp workspace, how did you feel?
Skip this question if nobody got in your way.

	1	2	3	4	5	
Very frustrated	◯	◯	◯	◯	◯	Very happy

Did you notice the callout bubbles that showed up (e.g., the grey callout bubble below)? *

◯ Yes

◯ No

When did you notice the callout bubbles? *

- ☐ When creating new postings
- ☐ When working on a posting (moving, editing, etc.)
- ☐ When watching others work
- ☐ I didn't notice any callout bubbles
- ☐ Other: ______

When someone got in your way in the amp workspace, how did you find out who it was? *

- ☐ Nobody got in my way
- ☐ I used amp's chat to ask who it was
- ☐ I looked at the callout bubble
- ☐ I talked to people around me
- ☐ I yelled out to the class
- ☐ I did nothing about it
- ☐ Other: ______

When someone got in your way in the amp workspace, what did you do to solve the problem? *

- ☐ Nobody got in my way
- ☐ I used amp's chat to work it out with the person who was in my way
- ☐ I spoke with him/her
- ☐ I did nothing about it
- ☐ Other: ______

What did you do when you saw a callout bubble on a posting that you wanted to work on? *

- ☐ I never saw a callout bubble on a posting that I want to work on
- ☐ I waited for the callout bubble to go away then worked on it
- ☐ I did what I wanted to do right away while the callout bubble was still there
- ☐ Other: ______

Did callout bubbles change how you work with others in amp? If so, please explain what you have done differently. *

______

Any other comments?

Submit

Never submit passwords through Google Forms.

C.5 Statistical Analysis Results

C.5.1 Frustration and Conflict

```
COMPUTE filter_$=(Feeling_Q4_Inverted>0).
VARIABLE LABELS filter_$ 'Feeling_Q4_Inverted>0 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
CORRELATIONS
  /VARIABLES=Conflict_Q3 Feeling_Q4_Inverted
  /PRINT=TWOTAIL NOSIG
  /STATISTICS DESCRIPTIVES
  /MISSING=PAIRWISE.
```

Correlations

		Conflict_Q3	Feeling_Q4_Inverted
Conflict_Q3	Pearson Correlation	1	.395**
	Sig. (2-tailed)		.002
	N	58	58
Feeling_Q4_Inverted	Pearson Correlation	.395**	1
	Sig. (2-tailed)	.002	
	N	58	58

**. Correlation is significant at the 0.01 level (2-tailed).

C.5.2 Awareness and Focus

```
CORRELATIONS
  /VARIABLES=Awareness_Q1 Focus_Q2
  /PRINT=TWOTAIL NOSIG
  /STATISTICS DESCRIPTIVES
  /MISSING=PAIRWISE.
```

Correlations

		Awareness_Q1	Focus_Q2
Awareness_Q1	Pearson Correlation	1	.336**
	Sig. (2-tailed)		.004
	N	71	71
Focus_Q2	Pearson Correlation	.336**	1
	Sig. (2-tailed)	.004	
	N	71	71

**. Correlation is significant at the 0.01 level (2-tailed).

C.5.3 Awareness and Frustration

```
CORRELATIONS
  /VARIABLES=Awareness_Q1 Feeling_Q4_Inverted
  /PRINT=TWOTAIL NOSIG
  /STATISTICS DESCRIPTIVES
  /MISSING=PAIRWISE.
```

Correlations

		Awareness_Q1	Feeling_Q4_Inverted
Awareness_Q1	Pearson Correlation	1	-.322*
	Sig. (2-tailed)		.014
	N	58	58
Feeling_Q4_Inverted	Pearson Correlation	-.322*	1
	Sig. (2-tailed)	.014	
	N	58	58

*. Correlation is significant at the 0.05 level (2-tailed).

C.5.4 Focus and Frustration

```
CORRELATIONS
  /VARIABLES=Focus_Q2 Feeling_Q4_Inverted
  /PRINT=TWOTAIL NOSIG
  /STATISTICS DESCRIPTIVES
  /MISSING=PAIRWISE.
```

Correlations

		Focus_Q2	Feeling_Q4_Inverted
Focus_Q2	Pearson Correlation	1	-.032
	Sig. (2-tailed)		.810
	N	58	58
Feeling_Q4_Inverted	Pearson Correlation	-.032	1
	Sig. (2-tailed)	.810	
	N	58	58

C.5.5 Focus and Conflict

```
CORRELATIONS
  /VARIABLES=Focus_Q2 Conflict_Q3
  /PRINT=TWOTAIL NOSIG
  /STATISTICS DESCRIPTIVES
  /MISSING=PAIRWISE.
```

Correlations

		Focus_Q2	Conflict_Q3
Focus_Q2	Pearson Correlation	1	-.191
	Sig. (2-tailed)		.111
	N	71	71
Conflict_Q3	Pearson Correlation	-.191	1
	Sig. (2-tailed)	.111	
	N	71	71

Appendix D

Permission from Co-authors to Use Shared Intellectual Property

Permission to use shared intellectual property

Cresencia Fong <cresencia.fong@gmail.com>
To: Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>

Mon, Feb 22, 2016 at 2:53 PM

Hi Betty,

February 22, 2016

I, Cresencia Fong, give Yu-Ling (Betty) Chang permission to use co-authored work from our paper:

Chang, Y.-L. B., Fong, C., Tse, E., Hancock, M., & Scott, S. D. (2015). "Callout Bubble Saved My Life": Workspace Awareness Support in BYOD Classrooms. In *Proceedings of the 2015 International Conference on Interactive Tabletops and Surfaces*, 73–82.

for Chapter 5 of her Ph.D. dissertation and to have this work archived in the University of Waterloo institutional digital repository.

Sincerely,

Cresencia Fong

PS - Good luck!

[Quoted text hidden]

Permission to use shared intellectual property

Edward Tse <EdwardTse@smarttech.com> Mon, Feb 22, 2016 at 2:59 PM
To: Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>

I, Edward Tse, give Yu-Ling (Betty) Chang permission to use co-authored work from our paper:

- Chang, Y.-L. B., Fong, C., Tse, E., Hancock, M., & Scott, S. D. (2015). "Callout Bubble Saved My Life": Workspace Awareness Support in BYOD Classrooms. In *Proceedings of the 2015 International Conference on Interactive Tabletops and Surfaces*, 73–82.

for Chapter 5 of her Ph.D. dissertation and to have this work archived in the University of Waterloo institutional digital repository.

Sincerely,

Edward Tse

IP Permission

Mark Hancock <mark.hancock@uwaterloo.ca> Mon, Feb 22, 2016 at 5:05 PM
To: Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>

February 22, 2016
I, Mark Hancock, give Yu-Ling (Betty) Chang permission to use co-authored work from our paper:

- Chang, Y.-L. B., Scott, S. D., & Hancock, M. (2014). Supporting situation awareness in collaborative tabletop systems with automation. In *Proceedings of the 2014 International Conference on Interactive Tabletops and Surfaces*, 185–194.
- Chang, Y.-L. B., Fong, C., Tse, E., Hancock, M., & Scott, S. D. (2015). "Callout Bubble Saved My Life": Workspace Awareness Support in BYOD Classrooms. In *Proceedings of the 2015 International Conference on Interactive Tabletops and Surfaces*, 73–82.

for Chapter 3 and 4 of her Ph.D. dissertation and to have this work archived in the University of Waterloo institutional digital repository.
Sincerely,Mark Hancock

Date: Sat, 2 Jul 2016 20:21:03 +0000 [02/07/2016 16:21:03 EDT]
From: Mark Hancock <mark.hancock@uwaterloo.ca>
To: Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>
Subject: Permission for co-authored work

July 2nd, 2016

I, Mark Hancock, give Yu-Ling (Betty) Chang permission to use co-authored work from our paper:

Chang, Y.-L. B., Scott, S. D., & Hancock, M. (2016). Usage of interactive event timelines in collaborative digital tabletops involving automation. To appear in C. Anslow, P. Campos & J. Jorge, (Eds.), Collaboration meets interactive surfaces and spaces (CMISS) - theory and practice. Springer.
for Chapter 3 and Chapter 4 of her PhD dissertation and to have this work archived in the University of Waterloo institutional digital repository.

Sincerely,

Mark Hancock

Permission to use shared intellectual property

Stacey Scott <stacey.scott@uwaterloo.ca> Mon, Feb 22, 2016 at 1:59 PM
To: Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>

February 22, 2016

I, Stacey Scott, give Yu-Ling (Betty) Chang permission to use co-authored work from our paper:

- Chang, Y.-L. B., Scott, S. D., & Hancock, M. (2014). Supporting situation awareness in collaborative tabletop systems with automation. In *Proceedings of the 2014 International Conference on Interactive Tabletops and Surfaces*, 185–194.
- Chang, Y.-L. B., Fong, C., Tse, E., Hancock, M., & Scott, S. D. (2015). "Callout Bubble Saved My Life": Workspace Awareness Support in BYOD Classrooms. In *Proceedings of the 2015 International Conference on Interactive Tabletops and Surfaces*, 73–82.

for Chapter 3 and 4 of her Ph.D. dissertation and to have this work archived in the University of Waterloo institutional digital repository.

Sincerely,

Stacey Scott

Associate Professor, Systems Design Engineering and English Language and Literature
Engineering Faculty Advocate, HeForShe Impact 10x10x10 (http://www.heforshe.org/impact)
Director, Collaborative Systems Lab (http://csl.uwaterloo.ca)
Member, Games Institute (http://uwaterloo.ca/games-institute)
University of Waterloo, Waterloo, ON, Canada

p: 519-888-4567 x32236
e: stacey.scott@uwaterloo.ca
w: www.eng.uwaterloo.ca/~s9scott

Date:	Sat, 2 Jul 2016 21:20:35 +0000 [02/07/2016 17:20:35 EDT]
From:	Stacey Scott <stacey.scott@uwaterloo.ca>
To:	Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>
Subject:	Re: Permission to use CMIS book chapter

July 2nd, 2016

I, Stacey Scott, give Yu-Ling (Betty) Chang permission to use co-authored work from our paper:

- Chang, Y.-L. B., Scott, S. D., & Hancock, M. (2016). Usage of interactive event timelines in collaborative digital tabletops involving automation. To appear in C. Anslow, P. Campos & J. Jorge, (Eds.), *Collaboration meets interactive surfaces and spaces (CMISS) - theory and practice*. Springer.

for Chapter 3 and Chapter 4 of her PhD dissertation and to have this work archived in the University of Waterloo institutional digital repository.

Sincerely,

Stacey Scott

Stacey Scott
Associate Professor, Systems Design Engineering and English Language and Literature
Engineering Faculty Advocate, HeForShe Impact 10x10x10 (http://www.heforshe.org/impact)
Director, Collaborative Systems Lab (http://csl.uwaterloo.ca)
Member, Games Institute (http://uwaterloo.ca/games-institute)
University of Waterloo, Waterloo, ON, Canada

p: 519-888-4567 x32236
e: stacey.scott@uwaterloo.ca
w: www.eng.uwaterloo.ca/~s9scott

Appendix E

Permission to Reuse Materials

Yu-Ling Betty Chang <betty.chang@uwaterloo.ca> Mon, Feb 22, 2016 at 1:14 PM
To: f.sasangohar@mail.utoronto.ca, "fsasango@gmail.com" <fsasango@gmail.com>

Hello Farzan,

My name is Yu-Ling (Betty) Chang. I am a PhD candidate in Stacey Scott's lab, and I am currently writing my thesis.

My work looks into applying interactive event timelines to co-located collaborative environments, specifically tabletop display, and it was inspired by your work on supervisory timeline support:

> Sasangohar, F., Scott, S. D., & Cummings, M. l. (2014). Supervisory-level interruption recovery in time-critical control tasks. *Applied Ergonomics*, *45*(4), 1148–1156.

I would like to show photos of the setup and the timeline to give my readers an idea of the related work. May I have your permission to incorporate Figure 1 and Figure 4 in the paper mentioned above to my thesis? I will be crediting the photos.

Thanks for your help! Please let me know if you need any more information.

Warm Regards,
Yu-Ling (Betty) Chang

Farzan Sasangohar <sasangohar@tamu.edu> Tue, Feb 23, 2016 at 12:15 AM
To: Yu-Ling Betty Chang <betty.chang@uwaterloo.ca>

Dear Betty,

By all means. Good luck with the writing process.

Please say hi to Stacey for me.

Best,

Farzan Sasangohar, Ph.D. | Assistant Professor
Industrial and Systems Engineering | Texas A&M University
p: 979.458.2337 a: 4079 Emerging Technologies Building, 3131 TAMU, College Station, TX 77843

> On Feb 22, 2016, at 12:14 PM, Yu-Ling Betty Chang <betty.chang@uwaterloo.ca> wrote:
>
> My work looks into applying interactive event timelines to co-located collaborative environments, specifically tabletop display, and it was inspired by your work on supervisory timeline support: