The Impact of Shared and Personal Devices on Collaborative Process and Performance

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

On a daily basis humans interact with an increasing variety of personal electronic devices, ranging from laptops, tablets, smartphones, and e-readers to shared devices such as projected displays and interactive, digital tabletops. An emerging area of study focuses on understanding how these devices can be used together to support collaborative work. Where prior research has shown benefits of devices used individually, there is currently a lack of understanding of how devices should be used in conjunction to optimize a group's performance. In particular, the research presented in this dissertation combines qualitative and quantitative analyses of group work in three empirical studies to link the use of shared and personal devices to changes in group performance and process.

In the first study, participants performed an optimization task with either a single, shared projected display or with the shared, projected display and personal laptops. Analyses of study data indicated that when personal displays were present, group performance was improved for the optimization task ($p = 0.025$). However, personal devices also reduced a group's ability to coordinate ($p = 0.016$). Additionally, when personal devices were present, individuals primarily used those devices instead of dividing time between their laptops and the shared display. To further investigate the support that shared displays provide groups, and in particular, how shared displays might support group work in multi-display settings, a follow-up study was conducted.

The second study investigated how two different types of shared displays supported group work. In particular, shared workspaces, which allowed multiple users to simultaneously interact with shared content, and status displays, which provided awareness of the overall problem state to groups, were investigated. While no significant impact on group performance was observed between the two shared display types, qualitative analysis of groups working in these conditions provided insight into how the displays supported collaborative activities. Shared workspace displays provided a visual reference that aided individuals in grounding communication with their collaborators. On the other hand, status displays enabled the monitoring of a group's overall task progress. Regardless of which display was present, an individual's gaze and body position relative to the shared display supported the synchronization of group activities.

Finally, where the previous two studies identified collaborative activities that were supported by the use of shared and personal displays, the experimental task performed by participants did not explore the transfer of task materials between shared and personal devices or alternative personal and shared devices. The third study addressed these limitations through the adoption of a new experimental task that enabled the exploration of how the manipulation of task artefacts supported

collaborative activities, and alternative shared and personal devices in the form of interactive digital tabletops and tablet computers. In particular, the third study compared how personal and shared displays supported sensemaking groups working under three conditions: with shared, digital tables, with shared digital tables plus personal tablets, and with only personal tablets. Quantitative analyses revealed that the presence of the shared, digital tabletop significantly improved a group's ability to perform the sensemaking task ($p = 0.019$). Further, qualitative analyses revealed that the table supported key sensemaking activities: the prioritization of task materials, the ability to compare data, and the formation of group hypotheses.

This dissertation makes four primary contributions to the field of Computer Supported Cooperative Work. First, it identifies cases where the presence of shared and personal displays provide performance benefits to groups, and through qualitative analyses links these performance benefits to group processes. Second, observed uses are grounded in an established process model, and used to identify collaborative activities that are supported by personal and shared devices. Third, equity of participation on shared displays is found to positively correlate ($p = 0.028$), and equity of participation on personal displays is found to negatively correlate ($p = 0.01$) with group performance for sensemaking tasks. Fourth, the method for studying group process and performance based on teamwork and taskwork provides a useful foundation for future studies of collaborative work.

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Chapter 1

Introduction

Today humans live and work within an ecology of devices that surround, interconnect, and enable aspects of their everyday lives like never before. This ecology consists of the growing variety of electronic devices that are encountered and interacted with in any number of contexts. For example, tablet computers have been deployed for a number of professionals, such as United Airlines' flight crews, with the goal of reducing the use of paper and improving the safety and efficiency of commercial passenger flights (United Continental Holdings Inc, 2011). Technologies deployed to the classroom such as tablets, iClickers, and digital tabletops make students' learning experiences more engaging and interactive, with claims of the use of technology leading to a 20% improvement in their test scores (Harcourt, 2012). And in the home, where entertainment and ease of use are favoured over productivity, a wide variety of devices have been introduced including e-readers, such as Amazon Kindle and Barnes and Noble's Nook; smartphones such as Apple's iPhone and Google's Android devices; and digital thermostats such as the Nest Leaf. Most significantly, all of these devices have found widespread adoption within the past five years. Not only are humans living in an ecology of devices, but that ecology is evolving at an increasingly rapid rate. In a recent quarterly results announcement

Tim Cook, Chief Executive of Apple Inc., put this change into perspective when he said, “Just two years after we shipped the initial iPad, we sold 67 million. It took us 24 years to sell that many Macs, and five years for that many iPods, and over three years for that many iPhones” (Chen, 2012).

Yet, even as these new technologies are rapidly adopted, there remains a need to establish best practices to guide their deployment and use. That is, given a set of users, a task, and an environment, guidelines are needed that can help designers understand how to determine technologies that would optimally support a specific usage context. As a society, the attitude of individuals in developed nations towards adopting new technologies is often to deploy novel technologies before understanding their impact on social and cultural interactions (Brende, 2004). One might question whether there are potential side effects to introducing iPads into the cockpits of commercial airlines, and if doing so could potentially put passengers at risk. The analysis presented in Chapter 6 suggests that introducing personal devices to a shared workspace may impact a team’s ability to coordinate their activities. Similarly, when deploying technology to the classroom, what are the potential educational benefits of deploying novel technologies? The work reported in Chapter 8 suggests that providing a shared workspace may improve a group’s ability to explore and understand data. The focus of this dissertation is understanding how these technologies may impact a group of individuals before those technologies are deployed to production environments, with the goal of being able to make conscious decisions about how those technologies will impact their users.

In particular, this dissertation focuses on two types of technology, *shared* and *personal* devices, and aims to develop an understanding of their impact when used to support group work. *Shared devices* are defined as large displays that support co-located, synchronous interaction for multiple users. These devices are designed to support group awareness and facilitate collaborative behaviours such as communication grounding (Clark & Brennan, 1991). On the other hand, *personal devices* are defined as those that are small and primarily used for single-user interactions, such as laptops, tablets, or smartphones. Personal devices are designed to enhance or extend a single users' abilities, but with recent developments in mobile display technologies and connectivity provide opportunities to interconnect and share personal data with co-located collaborators.

Interest in understanding how these technologies can be optimally deployed to support groups has been present in the academic community for some time, for example in the fields of Human-Computer Interaction (HCI) and Computer-Supported Collaborative Work (CSCW) (e.g. Biehl & Lyons, 2008; Inkpen et al., 2004; Terrenghi et al., 2006). To date, a number of guidelines have been proposed (e.g. Elwart-Keys et al., 1990; Scott et al., 2003) for improving software designed for shared and personal devices, however they fall short in two important ways. First, these guidelines fail to provide information to developers about the relative strengths and weaknesses of specific devices. To borrow from Tohidi et al. (2006), developers must get the right design before they get the design right, and current best practices lack the understanding of the relative strengths and weaknesses of devices to appropriately consider alternative designs for supporting collaborative work. Second, once different devices are determined to support a certain group of users and tasks, guidelines do not address how these technologies should be used together. That is, devices have traditionally been designed for use in isolation, yet are increasingly used in contexts where opportunities exist to use them together in a way that improves users' productivity. Guidelines often suggest inter-device connectivity as a requirement (e.g. Elwart-Keys et al., 1990; Scott et al., 2003), however tangible recommendations for how this connectivity should take shape, or activities that should be supported are lacking. As the ecology of personal and shared devices continues to evolve, an understanding of their relative strengths and weaknesses, and how these devices can best support the needs of different usage contexts is required.

1.1 Thesis Statement

The research presented in this dissertation systematically explores the impact of personal and shared devices on co-located collaborative work. A series of experimental studies of collaborative work was conducted that investigated the performance and process of groups working with a variety of personal and shared device configurations. In particular, the data collected throughout these studies supports the thesis statement:

The hardware and software design of a co-located collaborative computing environments warrant careful consideration as personal and shared computing devices each play unique roles in supporting group performance and process.

The work presented in this dissertation provides important insights into the relationship between groups, the technology available to them, and the processes used to perform collaborative work. In particular, it reveals important trade-offs between performance and process, a correlation between equity of participation and performance, and the utility of understanding the teamwork and taskwork aspects of group performance.

1.2 Research Approach and Impact

Evaluations of collaborative technologies are often limited to a single type of device. The research approach utilized in this dissertation contributes to the field by directly comparing how groups use a combination of personal and shared devices in a laboratory setting, and by providing analyses of how these technologies influenced groups' performance and process. A series of three empirical studies was conducted that investigated the use of shared projected and tabletop displays, and personal laptops and tablets. As work in this field is still at an exploratory phase, and the main goal of this research is to understand both collaborative performance and process, a mixed-methods approach is employed. This mixed-methods approach (Cresswell & Clark, 2011) uncovered quantitative evidence that personal and shared devices can impact group performance, as well as qualitative descriptions of how groups utilize provided devices to support their work processes.

Quantitative data is useful for exploring objectively measured phenomena such as performance differences between groups, whereas qualitative measures can aid researchers in understanding *how* and *why* phenomena occur. Maxwell (2005) explains that qualitative research is particularly useful for "[i]dentifying unanticipated phenomena and influences ... [u]nderstanding the meaning, for participants in the study, of the events, situations, experiences, and actions they are involved with or engage in" (p.22). Moreover, qualitative analysis is particularly useful for developing and understanding causal relationships where the process that connects two phenomena is of interest to researchers (Maxwell, 2005). The analyses presented in this dissertation leverage both quantitative and qualitative analyses to identify performance differences between groups, and use qualitative analyses to understand the impact of different personal and shared device configurations on group process. This work provides four primary contributions to the field of CSCW:

1. The identification of conditions where the choice of shared and personal devices impact group performance and process for intellective tasks.

2. The identification of collaborative activities that are supported by shared and personal devices based on an established process model.

3. The identification of a positive correlation between equity of participation on shared devices and group performance, and a negative correlation between equity of participation of personal devices and group performance for sensemaking tasks, a subset of intellective tasks.

4. A critique of the strengths and weaknesses of the methodology utilized during the research program, and a description of how future studies of co-located, synchronous group work can leverage the method to better understand group process and performance.

Many of the personal devices studied over the course of this work such as tablets and smartphones are already deployed on a large scale in production environments, including offices, commercial airline cockpits, and classrooms. The shared devices, many of which may not be mass-produced for commercial applications, are candidates for adoption in the workplace, and are of interest to a broad group of industrial and academic researchers. As technology continues to evolve, and new devices are developed, research methods must maintain an understanding of the relative strengths and weaknesses of an increasingly diverse ecology of devices. This work provides a richer understanding of how personal and shared devices support collaboration, and a methodology that can be used to study their use in collaborative contexts as new devices continue to be developed.

1.3 Overview of Research

The research presented in this dissertation systematically explores the impact of personal and shared displays on the performance and process of groups. In presenting this research, related work is first discussed in Chapters 2 and 3. Following this discussion, the selection and development of analytical methods used to study collaborative technologies are presented in Chapters 4 and 5. After establishing this methodological approach, the research program followed three stages, each with a unique focus:

Study I: The Role of Personal Devices in Collaborative Optimization Tasks To begin the investigation, a controlled experiment was conducted that compared the performance and process of groups during a collaborative optimization task with either a large, shared display or a shared display plus a personal display for each participant. This study is described in detail in Chapter 6. The data analyses indicated that while the use of personal displays facilitated improved task performance, groups working with only a shared display were able to better coordinate their activities. The analyses also revealed that when personal displays were present, individuals tended to focus on their personal device for the majority of the task since it provided a sheltered workspace that enabled users to better utilize their cognitive resources for the optimization task.

Study II: The Role of Shared Devices in Collaborative Optimization Tasks The focus on personal displays observed during the first study raised an important question - if participants spent most of their time looking at personal devices, how do shared displays support group coordination and awareness? To investigate this question, a second empirical study, presented in Chapter 7, was conducted that explored how different types of shared display content influenced collaborative process. Groups worked under two shared display conditions: a shared workspace that allowed all participants to interact in a shared workspace, and a status display that was designed to give an overview of task progress. The data analyses revealed important differences in how the shared displays supported group work. In particular, the shared workspace display supported conversational grounding and improved participants' ability to communicate with one another during the task, whereas the status display supported individuals' ability to monitor group activity while working on their personal display. Moreover, in both display conditions, the presence of the shared display provided transactional space that facilitated the synchronization of group members' activities.

Study III: The Role of Personal and Shared Devices in Collaborative Sensemaking Finally, a third empirical study presented in Chapter 8 was conducted to investigate how participants share information between shared and personal devices. In particular, this study provided an opportunity to investigate the activities identified in Study II in settings where individuals were responsible for moving task artefacts between personal and shared devices. To investigate collaboration in these settings, a new experimental task was adopted that required participants to make sense of a shared data set. Further, novel personal and shared devices were utilized, and an experimental condition without a shared display was introduced into the study's design. Analyses of collected data revealed that the shared display supported the process of prioritizing, comparing, and synthesizing task materials. Further, more equitable interactions with the shared display were positively correlated with performance, while more equitable interaction with personal devices was negatively correlated with performance. After describing the study and its results, the results of all three studies are discussed in Chapter 9, and conclusions are presented in Chapter 10.

Chapter 2

Small Group Work

This chapter establishes definitions for the core concepts of this dissertation. First, definitions for small groups are presented, with a discussion of how related literature influenced the experimental design for the studies presented in this research. Second, a classification scheme for group work developed in McGrath (1984) is described, and the types of group work within this classification scheme are briefly discussed. Finally, *intellective* tasks, a subset of the classification scheme described by McGrath (1984), are presented, in addition to a discussion of why intellective tasks are appropriate for this research.

2.1 Small Groups

For the purposes of this research, a group is defined as a collection of individuals working together towards a shared goal. In particular, this dissertation studies groups of *knowledge workers*, or workers who "think for a living" (Cortada, 1998), such as software engineers, scientists, and lawyers. The work performed by these groups "resists standardization" (Reinhardt et al., 2011, p. 153) and consists of the organization, creation, consideration, and transformation of information artefacts. That is, the knowledge workers are primarily concerned with understanding a problem's parameters, creating and manipulating task materials, and determining a solution to the problem that they are working on. Thus, providing support for knowledge workers is a challenging research problem, as there are no standard tasks that they perform, and they may interact with a wide variety of tools and data over the course of a work day. These workers are important to study because they represent a large, and growing, portion of workers in developed nations. For example, as of 2003 knowledge workers represented over 24% of the workers in Canada, an increase from under 14% in 1971 (Baldwin & Beckstead, 2003). More recently, it has been argued that in the modern economy all workers are knowledge workers (Hagel et al., 2010), and that businesses need to focus on improving the productivity of all workers' problem solving activities. A more in-depth review of the importance, history, and growth of knowledge work is beyond the scope of this dissertation (See Pyöriä (2005) for a comprehensive review).

In practice, groups of knowledge workers may consist of any number of individuals, however CSCW literature typically reports studies of groups of 3 to 6 individuals (e.g. Biehl et al., 2007; Plaue & Stasko, 2009; Ryall et al., 2004), with some studies including groups with as few as two individuals (e.g. Ryall et al., 2004). In order to understand how technologies will impact a group's performance and process, groups studied in this dissertation have 3 or 4 members. Groups of 3 or 4 individuals are particularly useful for the study of group process because they are large enough to enable the observation of groups working both "tightly" and "loosely" coupled (Tang et al., 2006). *"Loosely"* coupled groups are those that work in a largely independent manner. For example, two group members might look up two related statistics separately before sharing them, or might write separate portions of a document before merging the two versions into a single document. On the other hand, *"tightly"* coupled groups work very closely together, and might write an entire document or look up two statistics together on a single computer.

Previous studies of collaborative work have found that group size can impact group process. For example, Ryall et al. (2004) found that groups of two composing poetry worked in tightly coupled configurations, whereas their counterpart groups of three and four worked in more loosely coupled configurations. These studies also found that performance can be influenced by group size, for example Ryall et al. (2004) found that larger groups tended to complete a poetry composition task faster than smaller groups, and Forlines et al. (2006) found that groups committed fewer errors, but sometimes took longer than individuals when completing visual search tasks. The use of groups of 3 and 4 in studies conducted as a part of this dissertation allowed for the observation of both tightly and closely coupled work, and for groups to be large enough for both types of work to occur in parallel. For example, a group of three may have worked together for some time before two participants paired up and worked separately, while the third worked independently for a period. Observing transitions from loosely to tightly coupled work, and vice versa, provided an opportunity to understand the roles that technologies played in supporting these transitions, as well as the work that was performed by groups throughout their task.

2.2 Group Work

The work performed by groups, or the *task* that they perform, may account for up to half of the variance in their performance (Poole et al., 1985). As the task plays such an important role in determining a group's performance, taxonomies have been developed to describe the types of work performed by groups, and to facilitate comparisons of studies of different tasks. In particular, a task circumplex described by McGrath (1984) is widely used by the CSCW community when describing tasks performed by groups (Figure 2.1). The circumplex described by McGrath (1984) consists of four quadrants: generate, execute, negotiate, and choose. These quadrants are organized along two dimensions: the degree to which a task is cognitive or behavioural, and the degree to which a task requires interdependence of group members. Generate tasks are subdivided into creativity and planning tasks, and typically involve creative processes. For example, the collaborative poetry composition task studied in (Ryall et al., 2004) would be classified as a "Generate" task. Execute tasks are largely behavioural, and examples of such tasks are dance performances or team sports. Negotiate tasks are characterized as being cognitive tasks where participants may be adversaries, but require a high degree of coordination, for example in games such as Checkers or Chess where each player's turn is dependent on the other's. And finally, Choose tasks are characterized as being both highly cognitive and requiring a degree of collaboration between participants. For example, collaborative decision-making tasks such as determining which candidate to hire from a pool of applicants would fall under this category.

While each of these types of tasks are representative of work performed in practice, Choose tasks most closely match the work performed by knowledge workers. Between the two types of Choose tasks, intellective tasks have a number of advantages in the context of the research questions addressed by this dissertation. First, the characteristic difference between intellective and decision-making tasks is whether they have a demonstrably correct solution. Intellective tasks have demonstrably correct solutions, and thus provide an opportunity to objectively assess a group's task performance, the benefits of which are discussed in more detail in Chapter 5. Second, these tasks have been noted as being particularly useful for

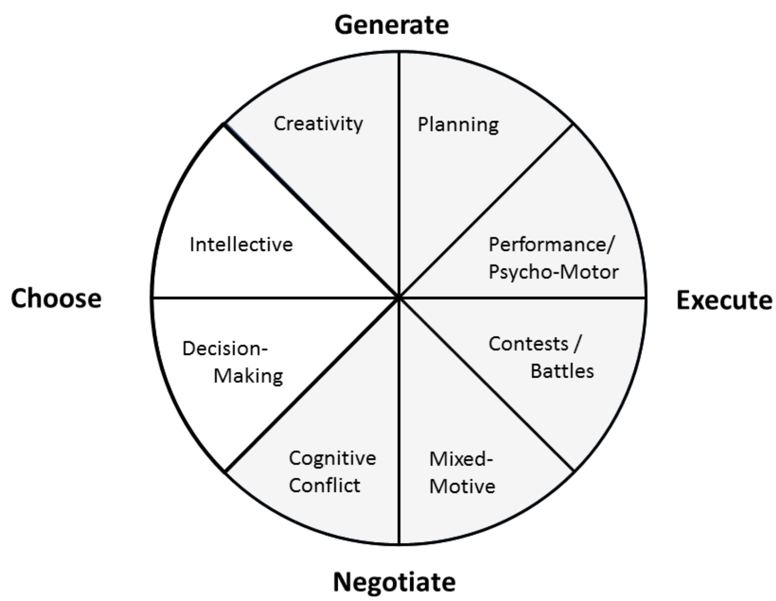


Figure 2.1: A classification of collaborative tasks, proposed by McGrath (1984). Under this classification scheme, tasks fall into one of four quadrants: Generate, Execute, Negotiate, and Choose. This dissertation focuses on groups who perform *intellective* tasks, which fall under the 'Choose' quadrant.

eliciting group discussion and negotiation (Tan et al., 2008), and allow for both interdependent and independent work by group members, thus representing a variety of working behaviours. For example, group members may work independently for some of the task, but might also work collaboratively during other times. Thus, these tasks provide opportunities to study how groups divide work, and shift between periods of individual and group work (e.g. Begole et al., 1999; Tang et al., 2006). Finally, CSCW has relied heavily on studies of decision-making tasks (Fjermestad & Hiltz, 1997; Plaue, 2009), and there are relatively few studies of intellective tasks in the literature (Tan et al., 2008). For example, Fjermestad & Hiltz (1997) noted in a survey of Group Decision Support Systems (GDSS) research that 41% of experimental tasks were classified as decision-making tasks, and 21% were classified as creativity tasks. Given the lack of intellective tasks studied in the literature, there is an opportunity to contribute to the CSCW literature by extending existing work to a classification of tasks that is potentially understudied.

In this dissertation, two intellective tasks are studied. First, in Studies I and II, the Job Shop Scheduling task (Tan et al., 2008) is used as an experimental task. This task requires groups to collaboratively optimize the scheduling of shared task resources, and was specifically adapted by Tan et al. (2008) for the study of collaborative technologies. As the task was recently adapted for this purpose, there is relatively little related literature to draw upon in informing the studies presented in this dissertation. However, in Study III, a more widely used intellective task, the Bonanza Paper Forms task (Gallupe & DeSanctis, 1988; Jarvenpaa & Dickson, 1988; Plaue & Stasko, 2009) is used as an experimental task. This task requires groups identify the cause of declining revenue for a hypothetical company based on provided financial, advertising, and marketing information. The analysis of this task, presented in Chapter 8, draws significantly upon the sensemaking literature, which provides a substantial background in which to ground analyses of group performance and process. In particular, a sensemaking process model by Yi et al. (2008) describes a model of sensemaking activities which can be used to inform investigations of group work. Moreover, observational analysis of groups in Study I and II suggested that similarities existed between the process used by groups to solve the Job Shop Scheduling task and this process model. Thus, the model is used to interpret analyses of data in all three studies presented in this dissertation. Related literature is now discussed, and the sensemaking process model is described.

2.3 Sensemaking and a Sensemaking Process Model

Sensemaking can be defined as understanding information (Whittaker, 2008), or gaining insight (Card et al., 1999); and involves a user, or group of users, who 'make sense' of a data set in order to make better decisions. That is, they must explore data provided to them, gain an understanding of underlying trends, and make some determination of how those trends should influence future decisions. As sensemaking is so broadly defined it can be a challenging activity to support. Dervin (2003) describes sensemakers as using ideas, emotions, and memories to bridge a 'gap' in understanding. Klein et al. (2006) discuss how creativity, curiosity, mental modelling, and situation awareness all play roles in sensemaking. Sensemaking also represents a significant portion of the work conducted in the workplace today, yet is poorly supported by current software (Plaue & Stasko, 2009). This poor support has led to research in single-user domains such as education (Duffy, 1995), in IT adoption (Seligman, 2000), and in HCI (Russell et al., 1993). Similarly, support for collaborative sensemaking has investigated web search (e.g. Morris et al., 2010; Paul & Morris, 2009), healthcare (e.g. Albolino et al., 2007; Billman & Bier, 2007; Sharoda & Madhu, 2010), firefighting and rescue (e.g. Landgren & Nulden, 2007), and analytics (e.g. Isenberg et al., 2010). While sensemaking has been extensively researched in these contexts, an important question remains regarding what role personal and shared devices can play in providing support to sensemaking groups.

Building on work by Pirolli & Card (2005), Yi et al. (2008) identified four fundamental activities that sensemaking groups perform: overview, adjust, detect pattern, and match mental model (Figure 2.2). In the overview step, users look at the "big picture", survey the information available, and prioritize that information for future explorations. During the adjust step, users filter and explore the data at different levels of abstraction, with the goal of setting themselves up for the detect pattern step where trends are identified. Finally, once trends have been identified, sensemakers work to reconcile newly identified information with their own mental models, thus making sense of the data. Vogt et al. (2011) describe a similar series of five basic activities: extract, cluster, record, connect, review. This model closely resembles the one reported by Yi et al. (2008), where cluster and record would both be considered aspects of the adjust steps. For the remainder of this dissertation, this four stage model proposed by Yi et al. (2008) is adopted.

While these stages may be well defined, a group's progress through them may not be. Sensemaking, especially in collaborative settings, is an ongoing activity. When groups are making sense of available data, work is done in an iterative fashion. Furthermore, individuals within a group may not all perform the same types of work while sensemaking. Vogt et al. (2011) reports that in study of pairs performing a sensemaking task, individuals tended to take on one of two distinct roles as their task progressed: *sensemakers* and *foragers*. The sensemaker was the dominant participant, who stood at a provided whiteboard to direct the group effort and take notes, and often asked the forager to find documents. On the other hand,

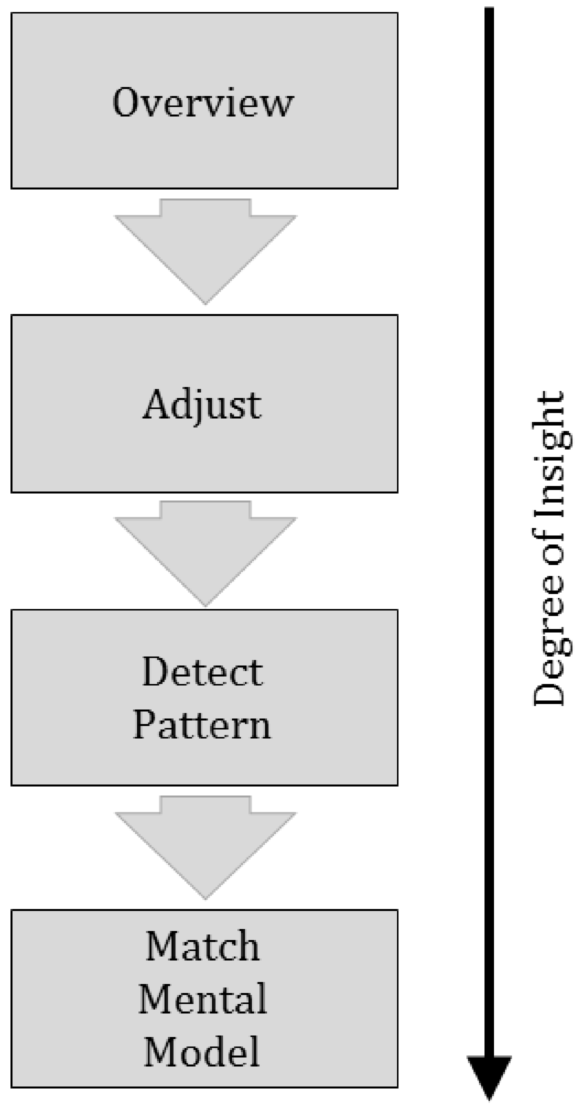


Figure 2.2: The sensemaking process model by Yi et al. (2008). Groups perform four sensemaking activities: provide overview, adjust, detect pattern, and match mental model. In the provide overview step, users look at the ‘big picture’. During the adjust step, users filter and explore a data set at different levels of abstraction, with the goal of setting themselves up for the detect pattern step where trends are identified. Finally, once trends have been identified, the sensemakers work to reconcile newly identified information with their own mental models.

the forager questioned the sensemaker's active hypothesis, found information, and maintained an overall awareness of the task information. This dichotomy of the work performed by pairs is illustrative of the active and evolving process that groups undertake when making sense of data. Hypotheses are formed and tested, and must evolve as new data is discovered by the group.

There is a growing consensus in the literature that closely coupled collaboration is also a key factor to success in collaborative sensemaking. Isenberg et al. (2010) noted that the amount of time that groups spent working together was positively correlated with their performance at the task. In a subsequent study, Vogt et al. (2011) report that their results supported these findings. The authors of these studies argue that in supporting sensemaking, designers must design for transient behaviour and encourage closely coupled work. That is, sensemaking environments should facilitate transitions between individual and group work, and provide tools to allow individuals to easy share information with their collaborators. Jetter et al. (2011) make a similar claim; that sensemaking environments should support *low viscosity interaction* (Blackwell & Green, 2003), or interaction that can evolve with minimal effort as groups progress. There is a need to elucidate what it is about closely coupled collaboration that is so valuable, and if possible, to determine how to support this work at the hardware and software levels of design.

Finally, Sharoda & Madhu (2010) identified three key characteristics of successful groups while transitioning between the four sensemaking activities: *prioritization*, *activity awareness*, and *sensemaking trajectories*. First, groups must be able to prioritize information as they work through the task, and this prioritization often shapes what information is shared, and when. That is, individuals are most likely to work with information that has previously been identified as important, and less likely to share information that has not. Thus, the ability to effectively prioritize information at hand is crucial to the sensemaking process. Second, activity awareness is important when sensemaking tasks are handed off between group members. For example, in order for a forager to effectively question a sensemakers' active hypothesis, they must try to understand the reasoning behind that hypothesis. Third, as groups progress through the task, the sense that they have previously made of information will influence the sense that they make as they continue. Sharoda & Madhu (2010) describe the sensemaking process as a path, and as groups progress through the task the persistence of previously used materials along that path will influence future sensemaking.

2.4 Why Study Intellective Tasks?

In this chapter definitions were provided for both small groups, and the work that they perform. In particular, the scope of research in this dissertation was described as being for small groups of knowledge workers, consisting of 3 or 4 individuals, and intellective tasks as defined by McGrath (1984). In addition to being representative of the work that knowledge workers perform, intellective tasks were described as being an appropriate choice for the study of group performance and process because they have well defined and objective measures of performance (McGrath, 1991), elicit group discussion and communication (Tan et al., 2008), and provide an opportunity to extend existing research which largely focuses on decision-making tasks (Plaue & Stasko, 2009; Tan et al., 2008) to a new class of collaborative task. Finally, a model for sensemaking tasks, a type of intellective task, was described, which provides a background for the types of activities that have previously been identified by researchers as contributing to collaborative performance and process. This process model is used to interpret empirical findings in Chapters 6, 7, and 8 and as a basis for the discussion of these results in Chapter 9.

With the scope and focus of the research clarified, Chapter 3 provides further background on how groups work and how to provide tools that can enhance and extend a group's abilities.

Chapter 3

Support for Small Group Work

This chapter overviews existing approaches to understanding collaborative work by the research community. As the evolution of research is discussed, one notes an important shift in research focus; where early researchers were predominantly interested in the performance and process of groups, later research has focused on how to develop technology to support those groups. This chapter concludes with a discussion of where existing research falls short, and identifies opportunities to further the field's understanding of how technology can support work performed by small groups.

3.1 Group Process and Performance

Early research into small group work, conducted in the 1960s and 1970s, was primarily concerned with understanding how to improve work performed by small groups. This work includes a range of activities such as negotiations between two groups of business executives, collaborative analysis of scientific data, brainstorming design ideas for a new product, or a hiring committee tasked with interviewing and hiring the most appropriate candidate from a pool of applicants (Hackman et al., 1976; Wittenbaum & Bowman, 2004). These are activities that are carried out every day by potentially billions of individuals worldwide, and therefore improving such activities can significantly improve society's productivity as a whole. Regardless of the task performed by groups, this research focused on understanding two aspects of collaborative work: a group's performance, and the process they utilized to perform the task. A group's performance is defined as how well they do, and can encompass both the quality of their solution as well as factors such as how long it took to produce. On the other hand, a group's process is defined as the series of steps taken to solve a collaborative problem, and can be more complicated to investigate. In Chapter 5 the measures of performance and process used in this dissertation are defined more specifically. In this chapter the relationship between process and performance is described, in addition to how that relationship has shaped the development of collaborative technologies over time.

The importance of group process is perhaps best demonstrated by a seminal study by Hackman et al. (1976), which, when analysing group performance for an assembly task, found that groups who were instructed to discuss strategy, or who were instructed "not to waste time" and to work immediately without discussion, were more productive than control groups who received no instructions regarding group strategy. That is, groups who gave thought to the process they would use to solve the problem were significantly better performers than those groups who immediately started working. In addition to the noted performance benefits, Hackman et al. (1976) note that groups who were asked to strategize tended to be more flexible in the face of difficulties, less strictly obedient to task instructions, communicated more clearly, and that individual participants rated the group atmosphere as more effective and comfortable, and rated themselves higher on leadership and influence questionnaires.

Yet, despite this demonstrated benefit to group performance, the selection of group strategy is rarely a conscious decision made by groups in practice (Gersick, 1989; Hackman et al., 1976). Wittenbaum et al. (1998) note that group strategy is often driven by tacit coordination, or the non-verbal coordination techniques that influence how and when group members may interact. For example, individuals may share common interests or backgrounds and may therefore be more likely to share ideas with one another. Conversely, differences in opinion, social norms, or culture may deter group members from interacting with one another to the detriment of the group's performance. Thus, while the process that a group employs to work together can drastically impact their performance at a shared task, it is rarely a conscious decision made by groups. This lack of conscious control or consistency of group process has motivated research that explores how technology, called Group Decision Support Systems (GDSS), can be used to augment, improve, or enhance a group's ability to work together.

GDSS research has focused on the development of technologies that can influence group process to improve their performance. This research has explored multiple levels of influencing process (DeSanctis & Gallupe, 1987; Fjermestad & Hiltz, 1997; Nunamaker et al., 1996), ranging in scope from "Level 1" support that merely facilitates information exchange by providing a medium such as a projected display in a meeting room, to "Level 2" support that might influence a group's communication process by providing analytical aids to the group to interpret shared information, to "Level 3" support that would more forcefully monitor and induce communication between group members, such as by enforcing Robert's Rules of Order. For example, for a group tasked with hiring a new employee, a Level 1 system might simply provide a large, shared display to facilitate the discussion of an applicant's resume, a Level 2 system might provide tools to contrast and compare alternative candidates' strengths and weaknesses, whereas a Level 3 system might structure the conversation to ensure that each member of the group contributes to the discussion, and that each candidates' strengths and weaknesses are considered.

One of the most significant limitations to GDSS research is the underlying assumption that tools are tailored to the specific tasks that groups are performing. While in theory this approach can yield more optimal group performance, in practice the costs associated with developing special-purpose software for each and every task that a group should perform may be prohibitive. Thus, Level 1 GDSSs are more common than Level 2; Level 2 GDSSs are more common than Level 3; and environments where Level 3 GDSSs are deployed are rare. Modern technologies have built upon the work of GDSS researchers, and in particular tend to provide a shared workspace for groups (i.e. Level 1 support). Recent trends in providing shared workspaces, and means of augmenting shared space space with devices that may support individual work will now be discussed.

3.2 Shared Devices

As computing and display capabilities have progressed, the ability to create large displays that supported work by multiple users simultaneously became a feasible design space. Stewart et al. (1999) coined the term Single Display Groupware (SDG) to encompass computing platforms that support multiple users simultaneously via a single, shared display, and identified potential application domains such as education, sales, and collaboratively created works. In the literature, SDG has typically been implemented in the form of a nearby wall display (e.g. Biehl & Bailey, 2004; Hailpern et al., 2007; Johanson et al., 2002) or an interactive digital table (e.g. Morris et al., 2006; Ryall et al., 2004; Sugimoto et al., 2004), and multiple input devices, for example mice and keyboards (Inkpen et al., 1999; Izadi et al., 2003) or pens, styli and users' hands (Dietz & Leigh, 2001; Liu & Kao, 2005). These displays are often used as Level 1 support, and such shared, physical workspaces can provide benefits such as improved activity awareness and coordination (e.g. Gutwin et al., 1996; Ha et al., 2006; Tang, 1991), improved communication efficiency by enabling non-verbal communication such as gestures (Baker et al., 2002; Gutwin et al., 1996), and enhanced conversational grounding via a shared visual reference (Clark & Brennan, 1991; Gergle et al., 2004b). SDG applications developed for shared, public displays (e.g. Guimbretière et al., 2001; Izadi et al., 2003; Piper et al., 2006; Shen et al., 2006; Tse & Greenberg, 2004) have been shown to support group work activities, such as coordination, communication and awareness maintenance (Pinelle et al., 2003).

This investigation is focused on two types of shared displays, each with an intended role in aiding collaboration; status displays and shared workspaces. Status displays tend to consist of non-interactive data, or task metadata, and are used to help monitor group activity. This functionality has been referred to as "at-a-glance awareness" (Plaue et al., 2009), and may support awareness of projects, challenges facing a group, or group progress in the form of status update information (Carroll et al., 2003). For example, large status displays are often seen in war room configurations where users are assigned specialized subtasks, and provide a mechanism by which users can monitor the progress of the group. In research, projects such as Notification Collage (Greenberg & Rounding, 2001), group participation displays by DiMicco et al. (2004), and FASTDash (Biehl et al., 2007) have deployed status displays in office settings to successfully support awareness of presence, participation, and activity with shared task resources. Projects such as MERBoard (Huang et al., 2006) have explored providing status displays in the support of more specialized groups, such as NASA's space operations.

On the other hand, shared workspaces support synchronous, tightly-coupled communication and coordination. In a study of collaborative puzzle solving, Gergle (2006) showed that shared workspaces support collaboration by improving the efficiency with which groups collaborate. Other research findings help explain how this efficiency is gained, for example, shared displays enable non-verbal communication such as gestures (Baker et al., 2002; Gutwin et al., 1996), and provide a shared visual reference that facilitates communication grounding (Clark & Brennan, 1991). Projects such as Caretta (Sugimoto et al., 2004) have previously explored the use of shared workspaces to provide synchronous access to task resources, to facilitate sharing of personal artifacts, and as a space to share personal task work. Sugimoto et al. (2004) found that groups tasked with planning the layout of a city were able to successfully utilize a shared tabletop display space to share, discuss, and negotiate using an interactive, digital tabletop.

In spite of their collaborative advantages, SDG systems also possess several key limitations for collaborative work. For example, prolonged interaction with large, touch-based systems can lead to fatigue and physical discomfort (Parker et al., 2006; Pinelle et al., 2008), and working around interactive surfaces can lead to social discomfort as interpersonal comfort levels may vary according to age and culture (Hall, 1966). These issues can impact the ability of a group to complete the taskwork aspects of collaboration, that is, the activities required to complete the task itself (Pinelle et al., 2003) such as note-taking and concept organization. An open question for groupware designers is whether a single system can leverage a public display to take advantage of the benefits to coordination, communication and awareness while simultaneously mitigating the hindrances to an individual's performance.

3.3 Shared and Personal Devices

In tandem to advances in large display technology, the proliferation of wirelessly networked and mobile personal displays such as laptops, smart phones, and tablets has also impacted the modern computing landscape. To leverage the availability of these devices, systems that consist of multiple personal devices in addition to a shared device have been explored (Biehl & Bailey, 2004; Booth et al., 2002; Johanson et al., 2002; Wallace et al., 2006). These configurations will be referred to as Multi-Display Groupware (MDG) in this dissertation, however in the literature they may also be known as Multi-Display Environments (MDEs). The combination of personal and public workspaces in these systems offers the potential to support each team member's individual needs, as well as the awareness, communication, and coordination needs of the group. For example, personal devices might reduce the fatigue of individuals when interacting with a shared display by enabling users to utilize more efficient and ergonomic input techniques on a personal device (Gutwin & Greenberg, 1998). In particular, three ways in which personal devices can support individuals' interactions are identified: personal devices can a) be used to provide tailored output to individuals, b) enable individuals to interact with a shared display remotely, or c) act as a portal between a user's personal and shared workspaces.

One of the most significant drawbacks of large, shared devices is that users must share a single display, thereby limiting the amount of parallel work that can be accomplished by a group. For example, a group of individuals searching a shared map can only focus on a single region at a time, which limits their ability to divide their work into parallel searches. Thus, one advantage of introducing personal devices is to enable participants to work with shared materials via a personal device that provides a personalized view of that data. In the example above, individuals might be able to divide their search up and individually search the map, viewing separate regions independently, and thus speeding up the group's overall progress with the task. Similarly, research has also explored using personal devices as a 'lens' which enhances an individual's view of the shared workspace (e.g. Bier et al., 1993; Brown & Hua, 2006; Spindler et al., 2009; Yee, 2003). In conducting this research, lenses have been applied to a number of collaborative domains, such as graphical and text editors (e.g. Bier et al., 1993; Roberts et al., 2012) and 3-dimensional visualization (e.g. Looser et al., 2007; Spindler et al., 2009), to extend the traditional Windows metaphor on desktop computers (Holman et al., 2005), and have found widespread adoption in personal applications such as Google Sky Map (Google Inc., 2012) which annotates the night sky via a user's cell phone display, allowing them to explore the constellations, planets, and other visible night sky objects.

Similarly, personal devices can be used to provide access to or to enhance an individual's interactions with a shared workspace. For example, numerous projects have explored methods of using a laptop's external mouse to enable interaction with other nearby devices (Booth et al., 2002; Johanson et al., 2002; Wallace et al., 2006). Workers might utilize the mouse and keyboard input afforded by personal laptops to collaboratively edit a shared Word document on a nearby projected display. Special purpose software allows multiple users to interact with a nearby shared display using their personal devices, facilitating collaborative work in cases where it may otherwise be infeasible. Enabling users to interact with shared devices has a number of potential advantages. First, it may enable users to interact via a more appropriate paradigm than is available natively on the shared workspace. For example, typing with the keyboard on a nearby laptop may be more appropriate than typing with a virtual keyboard on a tabletop display. Second, physical characteristics of the shared display may prohibit users from interacting simultaneously. Providing an input mechanism via personal devices may help to overcome these limitations. Finally, the provision of a personal input device may allow for socially safe interactions that would otherwise be made public when conducted on a shared device (Wallace & Scott, 2009); for example, password entry.

Finally, as personal devices can typically be considered to carry personal information, such as contacts, documents, or other personal settings, they can also serve as a bridge between personal and shared workspaces. Where early research enabled users to interact with shared workspaces via a Personal Digital Assistant (PDA) (Myers, 2000), recent commercial products such as Apple's iPhone and Apple TV have enabled end users to seamlessly bridge personal and shared workspaces to share content such as videos or photographs. While commercial products tend to have limited fine-grained control over privacy settings, research is addressing that need as well. For example, Berry et al. (2004) enabled users to share personal documents stored on a laptop via a connected projector; and while doing so, private components of the documents could be filtered out or blurred to ensure that privacy was maintained. Researchers are also exploring how proxemics, or the relative positioning of devices in physical space (e.g. Marquardt, 2011; Marquardt & Greenberg, 2012), may also provide opportunities to support and simplify inter-device connectivity by utilizing data such as their relative position and orientation. For example, as a mobile device approaches a shared display, its contents may automatically become visible and available for sharing on that shared display.

3.4 Where Current Research Falls Short

Both personal and shared devices have been developed to enhance and extend individual and group ability to perform shared work. Yet, based on research by Hackman et al. (1976) and Wittenbaum et al. (1998), one might ask whether or not the technology provided to a group may influence its' process. If group process is seldom consciously determined and is influenced by a number of tacit factors that can significantly impact a group's performance, could the technology used by collaborators also tacitly impact their process and performance?

Comparative studies suggest that the technology provided to groups can have a subtle yet important influence over their behaviour. For example, Birnholtz et al. (2007) found that for a mixed-motive negotiation task, participants' behaviour was influenced by the number of mouse inputs available to the group. In particular, when participants were provided with their own mouse, they were more likely to act in their own self-interest. Piper & Hollan (2009) compared students' learning processes between paper and shared digital tabletops. They found that each medium had a unique set of strengths and weaknesses, but that digital tabletops encouraged children to attempt problems on their own before looking at answer keys, and allowed for repetition of practice problems. Nguyen & Canny (2007) found that groups who are meeting via teleconferencing software may form trust more quickly when that software can more faithfully reproduce a three dimensional environment. Streitz et al. (1997) found that groups working with both personal and shared workspaces were more creative, and that the presence of shared displays led to groups working together more often. These results provide an indication that the current understanding of how technologies influence a group's collaborative behaviour is still in development.

The research conducted throughout this dissertation aims to build on contemporary work, and address a gap in the current research. In the words of Fjermestad & Hiltz (1997, pp.4) "The tools and procedures used are the fundamental cause of the expected changes in process and outcome; yet, most experiments seem to (falsely) assume that all GDSS's are a standard "package" that will have the same effect." The examples above suggest that technology may subtly shape the way that individuals interact with one another. As the personal and shared devices that are available to collaborators continues to evolve and is deployed to working environments at an increasing rate, there is a timely opportunity to understand how that technology influences a group's interactions. Moreover, while theoretical advantages and disadvantages of personal and shared devices have been established in the literature, there is an opportunity to build upon existing research to elucidate the strengths and weaknesses of these devices when used together to support collaborative work. This dissertation's primary goal is to contribute to the field through the development of an appropriate methodology, and systematic exploration of these design issues. In particular, the research presented in this dissertation contributes a more detailed understanding of the role of personal and shared devices in supporting collaboration through a description of their impact on collaborative performance and process.

To set the context for this dissertation, this chapter discussed previous research related to studying collaboration and collaborative technologies. In particular, previous work on the collaborative use of personal and shared devices was described. It also identified important gaps in this research that will be addressed by this dissertation. To complete the background for this dissertation, Chapter 4 discusses alternative experimental strategies for approaching this question are described. In particular, the chapter describes alternative experimental strategies for evaluating collaborative technologies, with a focus on their respective strengths and weaknesses for evaluating group performance and process.

Chapter 4

Evaluating Collaborative Technologies

Collaborative technologies are used in a variety of real-world contexts, by many users, and for a number of different tasks. Unlike single-user systems, where interactions are contained to those between the user and computing system, the introduction of multiple users to an evaluation brings significant challenges including the need to understand interactions between technology and the complex social, political, and motivational dynamics of a group. Understanding the impact of technology on these dynamics has been described as an "almost insurmountable [obstacle] to meaningful, generalizable analysis and evaluation of groupware" (Grudin, 1994, p. 97).

In response to this challenge, the research community has utilized a diverse range of techniques when evaluating collaborative systems, including heuristic guidelines that are useful early in the design process (e.g. Elwart-Keys et al., 1990; Hancock & Carpendale, 2006; Scott et al., 2003; Tang et al., 2006; Wallace & Scott, 2009), experimental evaluations of prototypes in the lab (Biehl et al., 2007; Haller et al.,

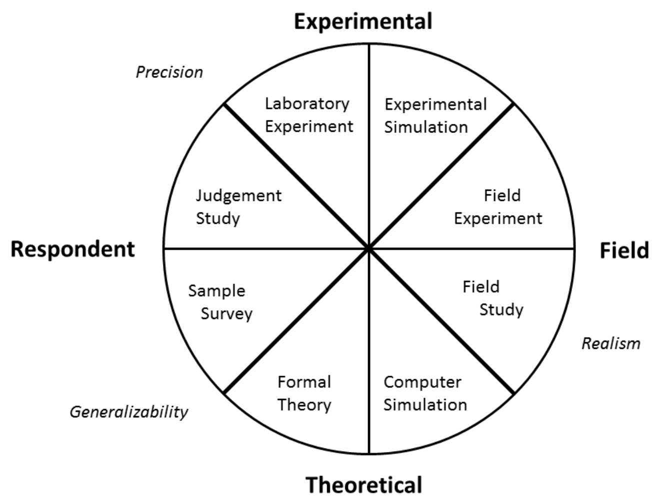


Figure 4.1: McGrath's research strategy circumplex (McGrath, 1984). Research strategies are divided into four quadrants based on their data collection methods: Theoretical, Field, Respondent, and Experimental. Strategies within each quadrant make tradeoffs between precision, realism and generalizability.

2010; Sugimoto et al., 2004; Tan et al., 2008, e.g.), and field and ethnographic studies of complete systems in their intended context of use (e.g. Huang et al., 2006; Hutchins, 1990; Plaue et al., 2009). Each of these research methods can be characterized by trade-offs between the information it provides about group performance and process and how faithfully it represents real world use. These tradeoffs are characterized by McGrath (1984) as belonging to one of four quadrants of a circumplex, with each strategy representing a different set of compromises between *generalizability*, *realism*, or *precision* (See Figure 4.1).

Realism is defined as how much the real-world context is represented in the study design. Field studies exemplify realism by conducting research in a realistic setting; however they do so often at the expense of generalizability and precision. Generalizability is defined as the ability to interpret results obtained from a sample population and extend those findings to a larger group. That is, data analysis that is applicable to the population at large would be considered generalizable, whereas results obtained from a study that may not be reflective of the population at large would not be. Respondent strategies such as polls and surveys can exemplify generalizability by collecting data from a large number of participants, for example a web-based survey can reach out to a large and varied sample population in order to capture data that is representative of the the general public. Finally, precision is defined as the ability of researchers to focus on specific behaviours or measures, for example studies conducted in the laboratory tend to have control over variables such as who participates in the study, what tasks they perform, and what tools they are given. An investigation of a novel interaction technique for left-handed users would be able to selectively recruit left-handed users, improving the researcher's ability to focus on their primary research question.

The four different research strategies presented in McGrath's model are described below, in addition to how they have been employed when researching collaborative technologies. A discussion is then presented of their strengths and weaknesses for this program of research. Finally, the specific experimental strategies determined to be most appropriate for this research are discussed.

4.1 Field Strategies

Field strategies emphasize context, and are valuable tools when trying to understand how collaborative systems are used in practice. Typically, these studies involve observational measures of either a functional prototype deployed into its intended context of use, or of an existing system from which researchers hope to utilize to inform the design of their next project. Field strategies are useful in understanding how a developed system may be used in practice, or if used early in the design process, may help researchers identify research questions before developing technologies in the laboratory. For example, studies of tabletop systems deployed as museum exhibits have been instrumental in revealing many of the shortcomings of current tabletop interfaces and interaction techniques. Hornecker (2008) reported that most users in a museum setting engaged with a shared, digital tabletop via single-finger interaction despite the table's support for multi-finger input. The results of such studies identified "visibility of gestures" as an important design consideration, and prompted designers to develop self-revealing gestures that are more likely to be discovered by novice users (e.g. Ryall et al., 2006; Wu et al., 2006).

Similarly, the "Magic Window" project (Kim et al., 2007) explored the use of shared displays in augmenting the awareness provided by office doors in a shared office space. In this work, researchers wished to enhance the awareness information conveyed through closed office doors, and augmented existing offices with computer displays that conveyed information about the office-owners state. After a 15 month field study, Kim et al. (2007) found that the designed system worked as expected, however a number of contextual issues were also identified. Among these issues were confusion with existing social norms such as using office door state (e.g. closed, open or partially ajar) to convey presence information, and the additional effort involved in using the developed system above and beyond such existing practices.

While field strategies are incredibly valuable to researchers in revealing these contextual design considerations, in practice, logistical constraints can make them difficult to conduct. When conducting studies in the field, partnerships must be established with a group representative of the desired end users. Workers must be interrupted; if even minimally, and a working relationship must be maintained with the end users. It may be costly and technically challenging to deploy and instrument collaborative environments in the field, and once complete, participants may require training to fully function during the study. Once deployed, the ability to accurately measure behaviours of interest may not be possible or feasible in the field, and the apparatus or presence of observers may influence the results. For example, it may not be possible to fully instrument a user's workplace to obtain detailed interaction data with experimental software; as the placement of cameras or observers in the workplace may be disruptive to workers.

Further, field studies have some specific weaknesses that limit their usefulness for the research proposed in this dissertation. First, as discussed in Chapter 4, group process can be influenced by many subtle factors that are not fully understood, and the presence of observers within a working environment may influence their process, a phenomenon known as the Hawthorne Effect (Landsberger, 1958). Second, it may be challenging to test technology that has the potential to compromise performance in mission critical environments, limiting the ability of researchers to fully explore alternative technologies for supporting group work. Finally, and most significantly, in order to fully understand how deployed technologies will be used in the field, they must integrate with existing systems. Developing prototypes that integrate with existing work environments is a significant investment of time and resources, and this cost is multiplied by the number of prototypes that need to be developed. In order to explore the impact of different technologies on group performance and process, a prohibitive number of prototypes would need to be developed to the point that they could be used in the field. This is not a practical level of commitment for this stage of research.

4.2 Respondent Strategies

Respondent strategies strike a balance between precision and generalizability by directly querying users through polls and surveys. The most significant strength of these strategies is that they can collect data about specific questions from a large group of individuals, often with minimal effort by the researcher, thus lending themselves well to correlational analyses. These research strategies are particularly useful early in the design process, as they can be quickly and efficiently used to understand current user behaviour and to gather requirements for prototype systems (Preece et al., 2004). For the research program presented in this dissertation, there are two significant disadvantages to respondent strategies. First, as established in Chapter 4, group process can very subtly change and users may not be immediately self-aware of the decisions that are made during collaborative work that may impact their process. As respondent strategies remove the experimenter from the users being studied, there is no opportunity to observe users and collect behavioural data in a reliable fashion. Second, users may be unable to provide useful feedback about technologies that they have little or no experience using. In the case of this dissertation, very few users have experience regularly using integrated groupware applications, and thus feedback on such systems may have limited utility to inform future work.

4.3 Theoretical Strategies

Theoretical research strategies rely on the synthesis of empirical data obtained from previous work. As this research strategy relies on data that has been previously collected, it is available throughout the design of a system, and is typically used early in the design process. Furthermore, as the data has already been collected, there is little to no cost associated with obtaining and utilizing theoretical knowledge, in terms of both time and money.

Existing theory for the design or evaluation of collaborative environments is predominantly derived from studies of Single Display Groupware (SDG) (Stewart, 1997); collaborative environments consisting of a single, shared display. SDG research has produced many theories that are helpful in describing synchronous, tightly coupled collaboration. Notably, the *mechanics of collaboration* (Gutwin & Greenberg, 2000; Pinelle & Gutwin, 2008) are often cited as fundamental operations of collaborative work, and suggest that actions taken during collaboration contribute to *awareness*, *communication* or *coordination* between collaborators. For example, group members working on a storyboarding activity often place images in a central location to promote awareness of each others' activities. Similarly, theory has been developed to describe collaborative phenomenon such as social loafing and social facilitation (Zajonc, 1965), that can help designers understand potential behaviours of users.

While studies of SDG systems may yield important findings for collaborative environments in general, the presence of both shared and personal workspaces presents new challenges for the application of this existing theory. That is, the application of existing theory when studying group performance and process may not always be appropriate. Researchers have acknowledged this shortcoming, and have identified design considerations for collaborative technologies (e.g. Elwart-Keys et al., 1990; Hailpern et al., 2007; Scott et al., 2003). For example, Elwart-Keys et al. (1990) report that transitions between individual and group work were important considerations for the design of groupware. When discussing limitations of existing tabletop groupware, Scott et al. (2003) list transitions between group and personal work and transitions between the table and external work as important design considerations. Hailpern et al. (2007), in a subsequent investigation of groupware for supporting brainstorming, noted that designers should provide clearly delineated personal and group workspaces, and should provide rapid access to personal and shared designs.

In this dissertation, existing theory is leveraged where possible, and in particular when establishing the framework that is used to study group process in Chapter 5. However, in order to overcome the limited scope of previous work, empirical data is collected in controlled studies, described in Chapters 6, 7, and 8.

4.4 Experimental Strategies

Experimental strategies, which exemplify precision have been the most commonly employed strategies by the CSCW community in recent work (Wainer et al., 2009). Experimental studies typically involve inviting a participant, or group of participants, into a controlled, laboratory setting and requiring them to perform a task or set of tasks. Participants may be selected based on characteristics related to certain research questions such as in the example above where left handed participants would be recruited to test left-handed interaction techniques. As participants complete the experimental task, the experimental apparatus is typically instrumented to collect data that can be used to assess task performance, which is typically quantitative in nature.

The primary strength of experimental studies is that they allow researchers to investigate the use of collaborative technologies in a setting where their participants can be instructed on the use of the prototype system, and the circumstances surrounding its use can be controlled. Further, as experimenters have a significant degree of control over the apparatus that participants interact with during experimental studies, it can be instrumented to collect detailed quantitative data regarding participant interactions with technology throughout the task. Data collection can also be extended to include automated measures of participant behaviours, such as audio or video recordings, and subsequent computer-aided analyses of the collected data. Finally, replication of studies enables researchers to more easily compare data between different groups and conduct statistical analyses that are not typically feasible during observational field studies.

In early HCI research, experimental strategies were instrumental in establishing interaction models such as Fitts's Law (Soukoreff & Mackenzie, 2004) that describe expected performance for virtually any human interaction with a computing system. However, for group studies experimental strategies have seen a reduced role, primarily because of the significant challenges posed by individual and group differences (Biehl & Lyons, 2008; Inkpen et al., 2004; Terrenghi et al., 2006). That is, the precision that is so useful when conducting single-user studies is less useful in the context of group work, since variances are amplified and between-groups comparisons are more difficult to conduct. When taken into consideration with the significant logistical challenges of conducting group studies, and developing experimental software, there are significant disincentives to researchers to conduct such evaluations. Finally, the quantitative data collected during traditional experimental studies is not necessarily useful for understanding complex interactions such as group process, limiting the utility of such studies in understanding the interactions between group members as they utilize collaborative technologies.

4.5 A Mixed-Methods Research Strategy

Each of the research strategies presented in this chapter have strengths and weaknesses for investigating collaborative technologies' impact on performance and process. In particular, the research question addressed by this dissertation has two characteristics that influence the choice of an appropriate research strategy. First, the impact of alternative devices on group performance and process requires that a degree of control be maintained over how participants work given the influence of contextual factors on group performance and process. To address this requirement, a controlled, experimental strategy is appropriate since it enables the comparison of groups working with alternative personal and shared devices. Second, as this work aims to explore the impact of devices on group process, the qualitative research methods typically employed in field research are also valuable in explaining how a group's process changes as they work with different devices. Thus, the methodology utilized throughout this dissertation leverages a mixed-methods approach (Cresswell & Clark, 2011) that combines both the quantitative data typically collected during controlled experiments with the qualitative data typically collected during observational field studies.

One method of combining both quantitative and qualitative data is to conduct complementary experimental and field studies. For example, experimenters might identify key group process behaviours in the field before more carefully understanding how personal and shared devices influence those behaviours in a controlled laboratory setting. However, a significant drawback to this approach is the variability in group work. Behaviours and working conditions identified in the field may be difficult to reliably reproduce in the laboratory. The approach utilized in this dissertation allows for observational data to be collected at the same time as experimental quantitative data, facilitating comparisons of behaviour based on the personal and shared devices provided to groups. A limitation of this approach is that the observational data are collected in the laboratory, diminishing the role that context plays in shaping user interactions and the most significant strength of qualitative field research. This limitation is discussed in more detail in Chapter 10, and in particular, the need to conduct future work that investigates behaviours identified by this dissertation in the field. Further, this approach enables research to be conducted more rapidly in a laboratory environment, as production-ready technologies do not need to be developed and deployed to field settings.

Having now described target users and tasks, discussing previous research into supporting collaborative work and identifying opportunities for new research, and describing appropriate methodologies for approaching those opportunities, Chapter 5 will now introduce the methodology utilized throughout this dissertation to investigate performance and process during collaborative work. In particular, Chapter 5 will discuss how this work builds on existing experimental methodologies to investigate collaborative process, and will set the stage for the three empirical studies conducted as a part of this dissertation.

Chapter 5

Teamwork and Taskwork

In Chapter 3, the importance of group process, the development of technologies to support group work, and technology's potential impact on group process were discussed. This chapter describes an approach for evaluating group process and performance that is designed to aid in understanding the impact of technology on group work. The methodology models collaboration as a combination of *teamwork* and *taskwork*, where taskwork is the work performed by a group that contributes to the completion of the task itself, and teamwork is the effort expended by group members while coordinating individuals' activities. For example, a high school executive council tasked with organizing a dance might perform taskwork while purchasing supplies, selling tickets, and decorating the gymnasium, whereas teamwork would be performed while communicating budget information from ticket sales to those purchasing supplies, the delegation of tasks at council meetings, or in keeping council members aware of each other's activities in day-to-day conversations.

A distinction is made between the teamwork and taskwork dichotomy and the performance and process dichotomy presented in Chapter 3. Where performance and process break down collaborative work into the steps performed to complete

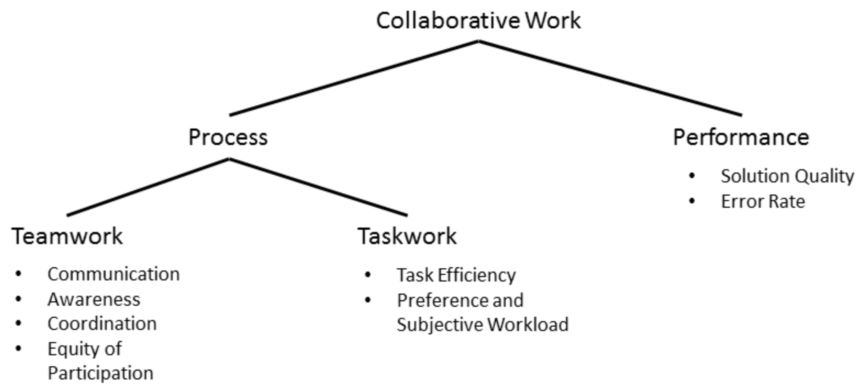


Figure 5.1: This dissertation approaches the study of collaborative work as a combination of performance and process. Process is viewed as a combination of teamwork and taskwork, as proposed by a number of researchers (e.g. Baker et al., 2002; Pinelle et al., 2003; Steves et al., 2001).

that work and its outcome, teamwork and taskwork focus purely on the work performed by groups, and are subsets of process. This dichotomy of group work has been suggested in the literature by a number of researchers (e.g. Baker et al., 2002; Pinelle et al., 2003; Steves et al., 2001). This chapter describes how teamwork and taskwork, in addition to performance, can guide the appropriate choice of experimental measures, analysis of collected data, and the conclusions that can be reached in the studies presented in Chapters 6, 7, and 8. An overview of these measures is illustrated in Figure 5.1

5.1 Performance

Measures of performance reflect the outcome, or end product, of a collaborative effort. These measures are useful because they suggest whether or not a group was able to effectively work together, and ultimately are useful measures for justifying that systems are effectively supporting their users. For example, if a business was to invest in developing a tool to support its workers, measures of performance would likely be useful in assessing whether or not that tool is providing effective support, and that it is ultimately worth the company's invested time and money. Consider now two types of performance measures: solution quality and error rate.

Measures of solution quality will vary based on the type of task performed by groups, and thus may not be easily defined in the general case. However, regardless of the task performed, solution quality should be representative of a 'good' solution, or provide a means to compare two solutions and rate one as 'better' than another. For example, consider solution quality for an optimization task such as the Job Shop Scheduling task (Tan et al., 2008) described in Chapters 6 and 7; one solution can be objectively compared to another based on their distance to an optimal solution. For sensemaking and hidden profile tasks such as the Bonanza Paper Forms Task (Jarvenpaa & Dickson, 1988; Plaue & Stasko, 2009) described in Chapter 8, solution quality may be measured by the degree to which the solution space is explored or by using an expert-generated rubric to rate a given solution for completeness.

Error rate has also been used as a measure of performance, particularly in cases where errors have been identied as degrading the quality of solutions. For example in visual search tasks the number of false positives and missed targets should be reduced (Forlines et al., 2006; Wigdor et al., 2006). One drawback of this measure is that like solution quality, errors may not easily be defined for some tasks and thus may not be applicable to the tasks being studied. For example, errors were easily defined in the Job Shop Scheduling Task used in Studies I and II, and therefore these measures were incorporated into those studies. However error rate measures were not used in Study III, since no objective error definitions were available for the Bonanza Paper Forms task.

5.2 Measures of Taskwork

As taskwork is the work that is performed by individuals contributing to the task itself, it is often measured through quantifiable properties such as task time, the number of interactions required to complete the task, or the individual's perceived effort or satisfaction. These measures are particularly useful when assessing the amount of effort put into obtaining a result, or the end-user's perceived effort or satisfaction while doing so. As these measures are quantitative in nature they are often used when evaluating a prototype, and are used to determine whether a system is appropriately designed for a given task. If solutions take too long to emerge, incorrect solutions are consistently produced, or errors frequently occur, then the system does not offer effective task support.

Since measures of taskwork are typically quantitative, comparing different designs is a straightforward process. This utility has led to the frequent adoption of taskwork measures when evaluating groupware systems. Differences in measures such as task time (Dix et al., 2003) can often be used to illustrate how one system design outperforms another, or supports activities or behaviours that another does not. Two types of taskwork measures are used in this research to reflect performance differences between alternative groupware configurations: task efficiency and subjective workload.

5.2.1 Task Efficiency

Task efficiency refers to the amount of effort exerted by a group while completing the task, relative to the minimal required amount of effort. For example, a task efficiency measure for writing a paper might be the number of keystrokes required to input the paper into a document editor. As with other measures, care must be taken when interpreting task efficiency data, as there may be tradeoffs between efficiency and quality. In the example above, one student may write a paper with half as many keystrokes as another, but that paper may also receive a failing grade.

Task time is often used in groupware evaluation as a measure of efficiency, and is defined as the time taken for a group to complete a collaborative task. As tasks performed in the "real world" may not have easily defined start and end times, these measures may be approximated in the field. However in experimental studies, these times are more easily controlled and task time is used in most studies involving a collaborative task that has a defined outcome. For example, task time has been used in evaluations of groupware systems where groups perform simple telepointer navigation (Nacenta et al., 2007b) to more cognitively involved tasks such as composing poetry (Ryall et al., 2004).

While task time may be a nearly ubiquitous measure in HCI and CSCW research, interpreting differences in task time alone can be dubious without other measures to explain why differences exist. For example, if one group takes longer than another to compose a poem, does that mean that one group did better than the other? If a hiring committee takes longer to make a decision than another, it may do so while attaining a higher degree of consensus than another, and thus the additional time may be justified. Therefore, while task time may be a useful metric for evaluations of collaborative systems, it should not be used in isolation, and in particular, it should be paired with a measure of solution quality whenever possible.

5.2.2 Subjective Workload

Subjective taskwork measures are also commonly employed, such as preference and subjective workload. These measures indicate what aspects of the system people liked and disliked, and how effortful they found the system to use. Subjective workload is typically measured using post-study questionnaires such as the NASA Task Load Index (TLX) (e.g. Biehl & Bailey, 2006; Hart & Stavenland, 1988; Wallace et al., 2008). While these tools are often useful in obtaining an numerical value with which systems can be compared, they fail to discriminate between potential sources of workload, such as the task itself or teamwork with collaborators, and thus provide limited insight into design issues.

5.3 Measures of Teamwork

While the above taskwork measures can be used to explore the work performed to produce an outcome, they often fail to provide insight into why that outcome occurred, particularly in collaborative settings. For example, two groups might take an equal number of actions to complete a task, but one might do so while reaching a greater level of consensus, a more optimal solution, or one with fewer errors. Teamwork measures aim to discern a system's impact on the group process and on overall group functioning, and provide insight into how a group ultimately worked together to achieve (or not achieve) their goals. Four types of measures that are commonly used in the literature to study teamwork are now described: communication, awareness, coordination, and equity of participation.

5.3.1 Communication

Communication is a key aspect of teamwork, and is the target of many evaluative measures for groupware systems. Communication between collaborators is often assessed through objective measures of efficiency such as the number of words and utterances spoken by groups (e.g. Gergle et al., 2004b; Gutwin & Greenberg, 1999;

Tan et al., 2008), or frequency of physical deixis, which are hand gestures accompanying verbal references such as “that” and “there” (Baker et al., 2002). These measures are important because they reflect the level of effort exerted by participants in performing the teamwork components of the task. Detailed conversational analyses can also be used to measure communication effectiveness. These analyses often focus on communication breakdowns and conversational repairs (Gergle et al., 2004a; Hancock & Dunham, 2001) that occur during group work, but are extremely time consuming and have been used primarily to evaluate distributed groupware systems (Pinelle & Gutwin, 2008).

5.3.2 Awareness

Awareness of other’s activities and intentions during group work is also important for effective teamwork (Gutwin & Greenberg, 1998). It is particularly important for group members to be aware of each other’s task actions in a shared physical and/or virtual workspace offered by a groupware system in order to mitigate access to shared task resources and coordinate team member’s individual efforts; this aspect of awareness is often called workspace awareness (Gutwin et al., 1996). Awareness can be measured in a number of ways, including post-task measures such as standardized questionnaires and interviews (e.g. Hart & Stavenland, 1988; Pinelle, 2000; Taylor, 1989). Questionnaires and interviews are less invasive than in-task measures, and are typically easy to administer. However, periodically polling participants during a task can provide more accurate information, as awareness is not necessarily at the forefront of a persons consciousness, making post-task questionnaires or interviews less reliable. Consequently, for precise measurements, more invasive measures, such as the Situational Awareness Rating Technique (SART) (Taylor, 1989), are often required (e.g. Hawkey et al., 2005; Pinelle et al., 2008).

5.3.3 Coordination

Effective coordination of group taskwork activities is also essential for successful teamwork. Coordination in group work systems is typically measured by seeking counter evidence of smooth coordination, that is, evidence of coordination breakdown. A common measure of coordination breakdown in groupware evaluations is interaction conflicts, or instances where multiple group members attempt to access or modify the same shared resource (e.g., a tool, region of the workspace, a le, or text in a document). Such coordination breakdowns tend to indicate a lack of awareness and/or miscommunication on some level. Conflicts in groupware tend to be easy to measure through analysis of computer interaction data that were logged during the task, as long as the appropriate software instrumentation is available (Gutwin & Greenberg, 1998; Nacenta et al., 2007a).

5.3.4 Equity of Participation

Finally, there has been recent interest in understanding the extent to which participation is equitable amongst group members. That is, using measures of task efficiency on a user-by-user basis to understand if one group member is contributing more effort to the group than others. To analyse equity of participation for logged interaction data, Gini Coefficients (Gini, 1912) are computed. Gini Coefficients were historically used in economics and sociology as a measure of distribution of income or wealth, but have recently been adopted in CSCW research as a measure of equity of participation (e.g. Harris et al., 2009; Lopes et al., 2011; Martínez et al., 2011b,c). The Gini Coefficient is a normalized value, ranging from 0 to 1, with 0 representing equal contributions from all members. It can be calculated for a response variable r as:

$$G_r = \frac{\sum_{i=0}^{n} \sum_{j=0}^{n} |x_i - x_j|}{2n\mu} \tag{5.1}$$

Where n is the number of participants, x_i and x_j are response measures for participants i and j, and μ is the mean response over all participants.

There is a growing consensus that for some tasks, such as sensemaking tasks studied in Chapter 8, more equitable participation is associated with effective performance (Isenberg et al., 2010; Vogt et al., 2011). In general, more equitable participation may also be associated with tools that support parallel work. For example, Begole et al. (1999) noted that groups were able to perform a task more quickly when their working environment allowed for parallel work by individuals. Thus, while equity of participation is not yet an established metric, there is potential that it may yield important insights as to how well a group worked together. A discussion of the utility of equity of participation measures in this dissertation is presented in Chapter 8.

5.4 Summary of Research Approach

Through literature review, Chapter 3 established that the technology that a group uses to support its work may subtly influence internal processes, and identified a gap in the literature regarding how this may occur. Chapter 4 discussed the appropriateness of alternative research strategies for studying how collaborative technologies may impact these processes, and identified a mixed-methods approach as most appropriate for this research. Finally, this chapter discussed how, by incorporating measures of both teamwork and taskwork into analyses of collaborative work, a better understanding can be gained of how effective a groupware system is at supporting a group, as well as how it impacts a group's internal processes.

Having identified this gap in the literature and an appropriate research approach for exploring it, Chapters 6, 7, and 8 present empirical studies that elucidate the impact of alternative technologies on the teamwork and taskwork performed by groups.

Each of the presented studies combines quantitative and qualitative analyses to explore the impact of technology on group performance and process. Study I (Chapter 6) begins by investigating the use of technologies commonly found in environments used for collaborative knowledge work: laptops and shared, projected displays. Study II (Chapter 7) follows up on activities identified in Study I, and in particular investigates the role that shared displays play in supporting group work. Both of these studies require participants to collaboratively perform the Job Shop Scheduling intellective task using two alternative display configurations. An additional within-subjects factor is included for task allocation, which varies the degree to which participants can manipulate task artefacts. The use of these experimental controls allows for the study of both teamwork and taskwork support provided by personal and shared devices in each display condition, and the identification of collaborative and task activities supported by each type of device.

Study III (Chapter 8), builds on the shared display uses identified in Study II, and further identifies collaborative activities that arise from the use of shared devices. While Study III utilizes the same measures of teamwork and taskwork as Studies I and II, several differences in its experimental design are introduced to accommodate for limitations in the designs of Studies I and II. First, Study III utilizes a new experimental task, the Bonanza Paper Forms sensemaking task, to allow for the transfer of task materials between displays and for more in-depth discussion of the task materials by participants. Second, it explores the use of novel personal and shared displays, interactive tabletops and handheld tablets, instead of the laptops and projected displays in Studies I and II. Finally, in Study III display configuration is a between-subjects independent variable to reduce participant fatigue. These differences allow for a more careful examination of the teamwork and taskwork activities performed by groups, for a task that involvs a more active discussion and manipulation of task materials than required in Studies I and II.

As Studies II and III are presented, an interpretation of their findings through the lens of sensemaking process model by Yi et al. (2008), described in Chapter 2, is also provided. This discussion is motivated by qualitative analyses of group activities, grounded in the sensemaking process model, to identify how specific personal and shared devices support group process. These qualitative results, in combination with quantitative analyses of performance and taskwork, provide a comprehensive view of the impact of personal and shared devices on collaborative work.

Chapter 6

Study I: The Role of Personal Devices in Collaborative Optimization Tasks

To begin the investigation of how personal and shared devices impact collaborative performance and process, an exploratory study was conducted [1]. As the initial step in this investigation of personal and shared device use, the primary goal of this study was to identify potential performance and process differences that could be investigated in more depth throughout the rest of the research program.

In particular, this study provided an opportunity to study how the use of personal and shared devices found in a typical office, such as laptops and projected displays, may support the teamwork and taskwork performed by groups. Collaboration was studied in SDG and MDG configurations; previously studied technologies that provided an opportunity to ground analyses in reported data and theories from the

[1] Material ideas, figures, and tables from this chapter have previously appeared in Wallace et al. (2009). Appropriate permissions have been obtained for the re-use of these materials, and can be found in the Permissions section at the end of the dissertation.

literature. Further, as shared displays are components of both SDG and MDG configurations, a comparison of interactions between the two configurations provided an opportunity to carefully study how shared display use changes in the presence of personal devices.

The study method is first described. Then, the results of the study are described, in particular focusing on the performance advantages observed in MDG environments, and the process advantages observed in SDG conditions. Finally, a discussion of how the results informed the next stage of the investigation is presented.

6.1 Study Method

Before presenting the results of this study, its design is first discussed. In particular, the participants, experimental task, experimental conditions, setting, procedure, and data collection and analysis techniques are now described.

6.1.1 Participants

Eighteen participants (9 female, 9 male), aged 18 to 28 ($\bar{X} = 20.6, \sigma = 3.11$) were recruited on campus at the University of Waterloo. Participants were predominantly Math, Science or Engineering students, a population representative of knowledge workers since they are in training to perform knowledge work after graduation. In a recent survey of knowledge workers, Reinhardt et al. (2011) reported that 47% of respondents were between the ages of 25 and 30 years, thus the age range of participants recruited on a university campus is also a close approximation to knowledge workers in the field. Finally, the student population was expected to be familiar with working in small groups and the technologies provided to participants in the study. For example, 15/18 participants in this study reported using laptops on a 'weekly' or 'daily' basis. However, fewer participants reported being familiar with the use of displays larger than 20", with only 4/18 participants reporting their use on a 'daily' or 'weekly' basis. Participants completed the study in groups of three. Three groups were recruited together and three groups consisted of pairs who volunteered together matched with an individual.

Since the experimental task involved participants working with visual data on a nearby shared display, participants were screened to ensure that they had normal or corrected to normal vision, and were tested for colour-blindness prior to beginning the study with the Ishihara colour blindness test (Ishihara, 1917). Colour blindness tests were administered to reduce potential confounds in how groups communicated, for example the potential confusion that could arise if two participants were discussing the colour of elements on a shared display. All but one participant reported being right-handed, however two of the right-handed participants reported using their left hand occasionally when using a mouse. Participants were paid $25 each for their participation in the study.

6.1.2 The Job Shop Scheduling Task

Participants performed the Job Shop Scheduling (JSS) task (Tan et al., 2008), which is an intellective task that simulates optimization tasks such as the scheduling of manufacturing apparatus on a plant floor. Tan et al. (2008) reports that the JSS task is useful for the study of group work in laboratory settings because it elicits information sharing behaviour and requires coordination between group members. For example, in their study of alternative input and display configurations, Tan et al. (2008) observed that users adapted their communication to the available collaboration tools, a property of the task that theoretically would aid comparison of group process under the shared display configurations. The JSS task also has objective measures of performance, such as solution time, solution quality, and solution efficiency, which should simplify taskwork comparisons between display configurations and groups.

To complete the JSS task, participants optimize the scheduling of six 'jobs', each composed of six ordered operations (Figure 6.1, A). These operations are dependent on six resources (Figure 6.1, B) that can only be in use by one operation at a time. A solution is considered valid if no two operations are simultaneously utilizing a shared resource (an overlap error), and if no two operations within the same job are scheduled to occur at the same time (an order error). However, even though there are many valid solutions, participants are required to find an optimal solution — a valid solution in which all jobs are completed in the minimal amount of time. Once a candidate solution is found, each group member must agree on a final solution using the 'Submit' button on their personal display (Figure 6.1, G).

Solutions can be compared between trials and groups using quantitative measures of the task's outcome: solution quality and number of errors. Solution quality is defined as the degree to which a solution is optimal; the difference between a solution's completion time as measured by the total scheduled time to complete all jobs and that of an optimal schedule. Errors are defined as the total number of overlap and order errors present in a submitted solution. Similarly, quantitative measures of job component moves, conflicts, and utterances provide a means to compare the taskwork performed by the group, and are measured at both the group and individual levels. Job component moves are defined as the number of times a participant clicks and drags a job component to a new position in the

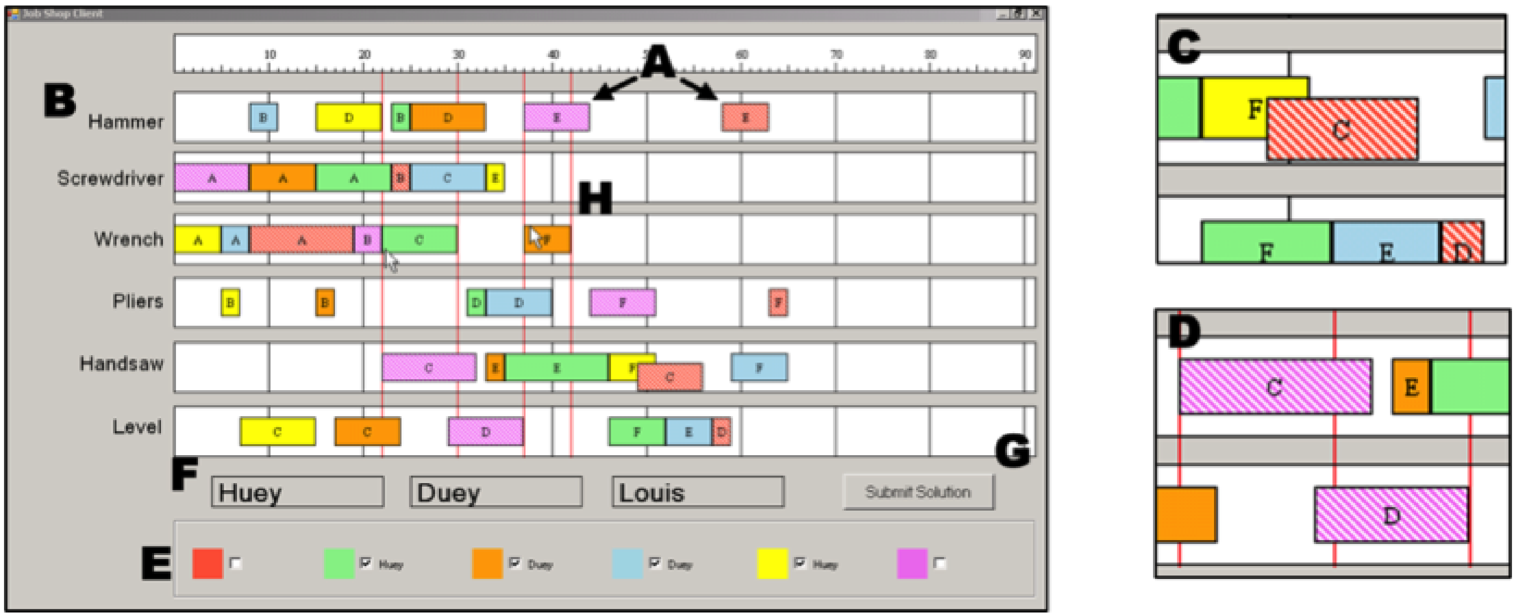


Figure 6.1: The Job Shop Scheduling task interface (left): each job is indicated by blocks of a particular colour, with six operations (A) per job. Each job has one operation that must be completed by each of the six resources (B). Overlap (C) and order (D) errors are shown in the interface cut-outs (right). Reference lines (H) are provided to help minimize order errors. Group member job assignments are indicated at the bottom of the JSS interface (E). Participant submit label indicators (F) and the submit button (G) are also provided.

solution space. Conflicts are defined as the number of times that two participants simultaneously click on the same job component. Utterances are defined as the number of times a participant spoke during the trial.

6.1.3 Experimental Design

A 2 (display configuration) x 3 (task structure) within-subjects design was used. Groups of three completed the task under each condition for a total of six trials each. A within-subjects design was utilized to minimize known between-groups differences in performance, communication, and coordination. To minimize learning effects between groups, the order of presentation of the display configuration and task structure conditions were counter-balanced.

The two display configurations used in the study were single-display groupware (SDG) (Figure 6.2, left) and a multi-display groupware (MDG) (Figure 6.2, right). The SDG configuration that consisted of a large, shared projected wall display with three mouse inputs (one for each participant), whereas the MDG configuration consisted of the shared display and three laptops. In particular, laptops and projected displays were selected since they represent technologies that are often used to support knowledge work in practice (Plaue & Stasko, 2009). For example, a typical business meeting might occur in a room with a single shared projector, where individuals are able to bring in and interact with personal laptops. Further, extensive research has been conducted on laptop and vertical display connectivity in the literature (e.g. Booth et al., 2002; Johanson et al., 2002; Wallace et al., 2006), and the study of such devices in use provided an opportunity to contribute an understanding of how this connectivity may impact collaborative performance and process.

In the SDG condition, all participants viewed the same interface on the shared display and all group member's mouse cursors were shown in the interface. In the MDG condition, the interface shown on the shared display was identical to the interface in the SDG conditions, however participants viewed a personalized interface on the personal displays that included two modifications. First, each personal display showed only one mouse cursor, corresponding to the group member using that particular display. Second, operation components on the personal displays were visually differentiated to increase the salience of resources allocated to each group member. In contrast, unallocated operations and operations currently allocated to other group members were visually de-saturated using white stripes (Figure 6.1, right). Thus, components which a participant could manipulate would appear 'filled in' on their personal display, whereas those that are only accessible to their collaborators would appear less salient, but would be present on their laptop display.

The differences between the content shown on the personal laptop displays and the shared, projected display were developed through an iterative design process, in which prototypes were developed and pilot tested. The shared display was designed to resemble those studied in Tan et al. (2008) as closely as possible, and remained unchanged throughout the iterative design process beyond minor bug fixes (Figure 6.1, left). However, the laptop displays were modified to provide a personalized view of the workspace, and in particular provided feedback to participants regarding which pieces were accessible to themselves, and which were accessible only to their collaborators. This design choice was made to reduce the potential confusion of attempting to interact with job components that were inaccessible to users, and to make those that were accessible more salient to the participants.

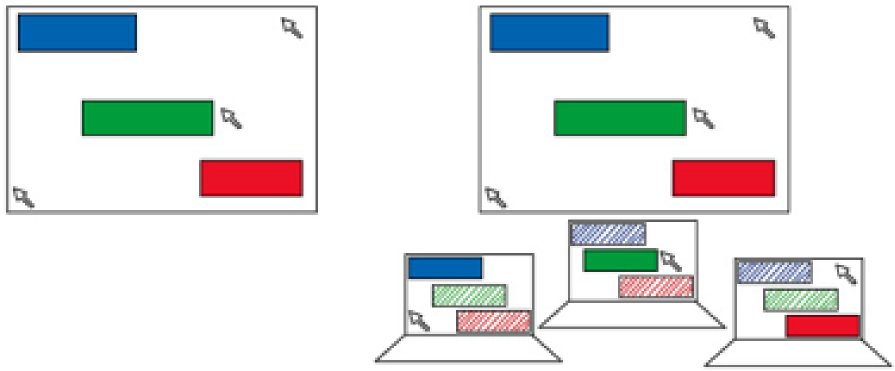


Figure 6.2: The single-display groupware condition (top, left) consisted of a large, projected wall display with one mouse input for each participant. The multi-display groupware condition (top, right) consisted of the same large, projected display and three laptops.

Task structure was also included in the study as an independent variable in order to understand the impact of possible collaboration strategy and task complexity on taskwork and teamwork across the different display configurations. In the literature, JSS groupware interfaces typically impose few constraints, or task structure, on how a group completes the JSS task (Tan et al., 2008). Group members are free to decide as to whom completes which portions of the task, including negotiating amongst themselves responsibility for moving different job operations, and checking for possible errors while completing a solution. Previous work on groupware systems indicates that group members working on personal displays often have reduced awareness of their team member's actions and intentions (e.g. Baker et al., 2002; Hart & Stavenland, 1988), which may negatively impact their ability to coordinate the use of shared resources, such as the job operations in the JSS task. Thus, limiting the amount of shared task resources that require group member coordination may provide certain task advantages in groupware environments that provide limited awareness. In order to investigate this issue, three levels of task structure were included, each of which required different levels of negotiation of responsibility over job operations among group members during the JSS task: *shared access* (SA) to all job operations, *negotiated access* (NA) in which only one group member can access a set of job operations at a time, and *fixed access* (FA) where each group member is responsible for an assigned, unchanging set of job operations.

In the SA condition, the JSS interface allowed any group member to access any job operation throughout the task session; thus, the group had to coordinate their interactions with the available operation blocks to avoid conflicts in which more than one group member tries to move the same piece at the same time. A 'give' protocol (e.g. Nacenta et al., 2005) was used in the software to handle these situations: the first person to access a job operation block maintained control of the component, locking out subsequent access attempts until they drop the component. In the NA condition, the JSS interface allowed participants to negotiate job assignments via checkboxes in the task interface (Figure 6.1, E); one checkbox was provided for each job, and participants had to claim ownership of a job in order to move its corresponding component operations by selecting the respective checkbox. Once selected, participants maintained ownership until they released the job by selecting the checkbox a second time. In the FA condition, the JSS interface provided automatic assignment of two jobs per participant, which could not be changed throughout the task session (assignments were performed manually by the experimenter before the trial begins through an experimental control interface). In this condition, the checkbox control panel (Figure 6.1, E) indicated the current job assignments, but could not be altered.

Figure 6.3: The single-display groupware condition (right) consisted of a large, projected wall display with one mouse input for each participant. The multi-display groupware condition (left) consisted of the same large, projected display and three laptops.

6.1.4 Setting

The study was conducted in a controlled laboratory space with a 2m x 1m table. In all conditions, a shared display was projected on a wall approximately 2m away from the table at a resolution of 1024x768 pixels over a 2m x 1.5m area. In the MDG condition, three Lenovo T61 Thinkpad laptop computers (2x2GHz, 1GB RAM) were placed on the table and provided individuals with input to the shared display via a dedicated 802.11g wireless network secured using WPA authentication. Each laptop had a mouse attached for input, and each participant's mouse cursor was displayed on both their personal and shared workspaces in the MDG condition using the Swordfish software framework (Wallace et al., 2006). Figure 6.3 illustrates configurations for both SDG and MDG conditions. In all conditions, participants were seated around the three sides of the table that were facing and adjacent to the shared display, and seating positions were kept constant across all trials in both experimental sessions.

6.1.5 Procedure

Participant groups performed the study in two separate sessions; one for each display configuration. All groups participated in both sessions, with the second session occurring within a week of the group's first session. Once participants arrived at the first session, an introduction to the study was given, and informed consent forms (see Appendix A.2) and a demographic questionnaire (see Appendix A.3) were completed. The demographic questionnaire included a colour blindness assessment (Ishihara, 1917) and questions concerning laptop and large display usage. After the paperwork was completed, the experimenter presented a 10 minute PowerPoint tutorial describing the JSS task goals, and error cases (Appendix A.4). After the tutorial, participants completed one practice trial for each of the SA and NA task structure conditions in their first assigned display condition. These trials were limited to 10 minutes each and were conducted to provide participants with an opportunity to understand the task and reduce anticipated learning effects (Gergle et al., 2004a). Participants were encouraged to discuss optimal strategies for completing the task during these training sessions, as such discussions are believed to improve group performance (Hackman et al., 1976).

After the practice trials, participants completed three experimental trials, one for each of the three task structure conditions (SA, NA, and FA). The order of presentation of these conditions was counter-balanced across participant groups. Participants were given a twenty-minute time limit to complete each trial, at which point their existing solution was considered final. After each experimental trial, participants completed a post-trial questionnaire (Appendix A.5) eliciting their opinions on how well the task environment supported a number of taskwork and teamwork factors, including group awareness, communication, and coordination, on a seven-point Likert scale. After the third trial and post-trial questionnaire was completed, participants were thanked and their next session was scheduled.

When each participant group returned for their second session, the tutorial and practice trials were repeated to ensure that groups remembered the instructions and strategies from the previous session. After the practice trials, participants again completed three, twenty-minute experimental trials in the second assigned display condition, one for each of the three task structure conditions. Participants completed the post-trial questionnaire after each experimental trial. Once all trials were completed, each group participated in a semi-structured interview aimed to gather more in-depth perceptions on the impact of the different experimental conditions on task- and teamwork factors. In particular, participants were asked to discuss what was most difficult about the task, what features they felt would have helped perform the task, and which condition(s) they preferred. Finally, participants were thanked for their time and paid for their participation.

6.1.6 Data Collection and Analysis

Participants' interactions with the JSS interface were automatically captured by the software into computer logfiles. Their conversations and their interactions with each other and in the physical workspace were captured on integrated audio and videotapes. Participant opinions on the task environment and their group interactions were also recorded via the post-condition questionnaires and the post-experiment semi-structured interview.

These data were then used to perform both quantitative and qualitative data analyses to help understand the overall impact on the experimental conditions on various teamwork and taskwork measures. In particular, two-way repeated measures analysis of variance (RM-ANOVAs) were conducted to discover any statistical differences in task performance, as measured by the solution time (faster being better), number of order or overlap errors (fewer errors being better), and task efficiency (fewer number of job component moves being better). A one-way RM-ANOVA was performed to determine the impact of display configuration on the number of conflicts that occurred in the SA condition (simultaneous access to job components was not possible in the other task structure conditions). RM-ANOVA tests were also used for the analysis of the post-trial questionnaire responses data to account for the non-independence of group member's responses. An alpha of 0.05 was used for all tests, with results with a significance between 0.1 and 0.05 being considered marginally significant. Where sphericity assumptions were violated, the Huynh-Feldt method was used for corrections. Tukey tests using the Bonferroni adjustment were used for pairwise post-hoc comparisons.

Analyses of teamwork measures for communication efficiency required that video data be transcribed and coded. A single coder was responsible for transcribing each group's sessions, and these transcriptions were used for analyses of utterance and word counts. Based on these transcriptions, the number of utterances and words spoken by groups were analyzed using a two-way RM-ANOVA to determine whether the study conditions had any impact on the communication efficiency. In a second coding phase, an *a priori* coding scheme was applied based on similar analyses in the literature (e.g Tan et al., 2008) that coded occurrences of non-verbal communication such as physical deixis. In particular, videos were reviewed for gestures, such as pointing towards both the shared and personal displays, that accompanied verbally communicated third person possessive adjectives such as 'it', and demonstratives such as 'this' and 'that'. Finally, the video, questionnaire, and interview data were reviewed to identify behavioural or conversational patterns and participant opinions that might provide insight into a group's use of technology. This video review was performed to elicit a range of participant activities and opinions in order to reduce the likelihood of limiting the analysis via confirmation bias, and to provide a more comprehensive overview of the different roles that personal and shared devices played in supporting group work.

6.2 Results

The results of Study I are now presented. Recall from Chapter 5 that the analyses of group process involve measures of teamwork and taskwork. Where taskwork reflects the work performed by individuals as they complete the task, and teamwork reflects the work performed coordinating activities between group members. Analyses revealed that while groups working under MDG conditions tended to perform better at the task, groups working under SDG conditions experienced fewer conflicts with one another.

6.2.1 Taskwork and Performance

Table 6.1 summarizes the mean values, standard deviations, and RM-ANOVA results for the analyzed task performance measures, including task time, solution optimality, error rate, and task efficiency.

The statistical analysis of task time revealed no significant differences for the task time across either display configuration (DC, $F_{(1,5)} = 0.052$, $p = 0.828$) or task structure (TS, ($F_{(2,10)} = 0.960$, $p = 0.415$) conditions. Groups in SDG conditions took an average of 13.4 minutes ($\sigma = 4.28$), whereas groups in MDG conditions took an average of 12.9 minutes ($\sigma = 4.11$) to perform the JSS task. Across task structure conditions, groups in the SA conditions took an average of 13.38 minutes ($\sigma = 3.728$), groups in NA conditions took an average of 14.57 minutes ($\sigma = 3.93$), and groups in FA conditions took an average of 12.6 minutes ($\sigma = 4.53$)

Table 6.1: Mean values, standard deviations (in parentheses), and RM-ANOVA results for task efficiency and solution quality (taskwork) measures. Significant results denoted by **, marginally significant results denoted by *.

	SDG			MDG			RM-ANOVA Results	
Study Measures	SA	NA	FA	SA	NA	FA	DC/TS	
Task Time (s)	673.33 (155.531)	937.67 (131.074)	797.83 (391.871)	807.83 (291.621)	811.167 (326.698)	711.33 (139.788)	$(F_{(1,5)} = 0.052, p = 0.828)$ $(F_{(2,10)} = 0.960, p = 0.415)$	
Solution Optimality (distance from optimal, in seconds)	10.00 (14.142)	15.00 (21.213)	15.00 (21.213)	25.00 (35.355)	25.00 (21.213)	35.00 (21.213)	$(F_{(1,5)} = 0.64, p = 0.459)$ $(F_{(2,10)} = 1.3, p = 0.315)$	
Error Rate (# of errors / trial)	.167 (0.373)	.500 (.500)	.167 (.373)	.167 (.373)	.000 (.000)	.000 (.000)	$(F_{(1,5)} = 10.0, p = 0.025)$ $(F_{(2,10)} = 0.455, p = 0.647)$	**
Task Efficiency (# of component moves/trial)	316.67 (67.57)	226.50 (78.82)	248.33 (123.72)	399.83 (208.30)	234.83 (95.41)	206.50 (67.22)	$(F_{(1,5)} = 0.199, p = 0.674)$ $(F_{(2,10)} = 4.815, p = 0.034)$	 **

to perform the task. No significant interaction effects between display and task structure conditions were found for task time ($F_{(2,10)} = 0.006$, $p = 0.994$).

Similarly, the statistical analysis of solution optimality found no differences between display ($F_{(1,5)} = 0.64$, $p = 0.459$) or task structure conditions ($F_{(2,10)} = 1.3$, $p = 0.315$) for solution optimality. Groups in SDG conditions found solutions to the task that were on average 26.4 units ($\sigma = 29.2$) worse than optimal, whereas groups in MDG conditions found solutions to the task that were on average 25.9 units ($\sigma = 22.8$) worse than optimal. Across task structure conditions, groups in the SA conditions found solutions an average of 33.6 units ($\sigma = 29.6$) worse than optimal, groups in NA conditions found solutions an average of 13 units ($\sigma = 14.9$) worse than optimal, and groups in FA conditions found solutions an average of 31 units ($\sigma = 25.1$) worse than optimal. Thus, the variations in display configuration and in task structure had no significant impact on the quality of the JSS solutions developed by the groups or the overall time they required to develop these solutions. No significant interaction effects between display and task structure conditions were found for solution optimality ($F_{(2,10)} = 1.567$, $p = 0.256$).

However, the statistical analysis of error rate revealed significant differences across display conditions. Participants in SDG conditions committed more errors than those in MDG conditions ($F_{(1,5)} = 10.0$, $p = 0.025$). Out of six errors made across all trials, five were made in SDG conditions, and all errors were order errors (no overlap errors were committed). No difference in errors were found across task structure conditions ($F_{(2,10)} = 0.455$, $p = 0.647$). Groups submitted solutions with an average of 0.167 ($\sigma = .373$) errors in SA conditions, an average of 0.25 ($\sigma = 0.433$) errors in NA condition, and an average of 0.0833 ($\sigma = 0.276$) errors in FA conditions. No significant interaction effects between display and task structure conditions were found for error rate ($F_{(2,10)} = 0.217$, $p = 0.808$).

The statistical analysis of task efficiency also found significant differences across task structure conditions. Groups working under SA conditions moved an average of 358.25 ($\sigma = 160.34$) job components, groups working under NA conditions moved an average of 313.17 ($\sigma = 179.76$) job components, and groups working under FA conditions moved an average of 227.42 ($\sigma = 101.74$) job components. Analyses of these data revealed that groups moved significantly more job components in the SA condition than in the NA or FA conditions ($F_{(2,10)} = 4.815$, $p = 0.034$). However, no difference in task efficiency was found across display conditions ($F_{(1,5)} = 0.199$, $p = 0.674$). Groups working under SDG conditions moved an average of 263.83 ($\sigma = 100.85$) job components, whereas groups working under MDG conditions moved an average of 280.39 ($\sigma = 162.1$) job components. Finally, no significant interaction effects between display and task structure conditions were found for task efficiency ($F_{(2,10)} = 0.895$, $p = 0.439$).

6.2.2 Teamwork

A summary of teamwork data collected during the study is now presented. Table 6.2 summarizes mean values, standard errors, and ANOVA results for the teamwork related measures of communication efficiency, conflicts, physical deixis, and equity of participation. These results are now presented as analyses of communication, coordination, awareness, and equity of participation.

Communication

Two analyses were conducted on communication efficiency, based on transcribed video from the experimental trials. The first analysis compared the number of

Table 6.2: Mean values, standard deviations (in parentheses) and ANOVA results for teamwork study measures. Significant results denoted by **, marginally significant results denoted by *.

	SDG			MDG			ANOVA Results	
Study Measures	SA	NA	FA	SA	NA	FA	DC/TS	
Utterances per trial	111.5 (77.761)	194.00 (107.779)	148.50 (100.814)	120.00 (70.973)	166.17 (70.061)	155.50 (67.61)	$(F_{(1,5)} = 0.032, p = 0.866)$ $(F_{(2,10)} = 5.776, p = 0.022)$	 **
Words Spoken per trial	830.67 (629.983)	1414.83 (761.471)	1112.17 (843.510)	973.00 (639.142)	1315.00 (647.960)	1115.33 (435.913)	$(F_{(1,5)} = 0.197, p = 0.678)$ $(F_{(1.15,5.74)} = 5.414, p = 0.058)$	 *
Conflicts per trial	5.00 (2.582)	n/a	n/a	14.83 (6.618)	n/a	n/a	$(F_{(1,5)} = 12.567, p = 0.016)$ n/a	**
Physical Deixis directed at Personal Display per trial	n/a	n/a	n/a	2.50 (2.950)	2.83 (4.262)	2.67 (4.676)	n/a $(F_{(2,10)} = 0.06, p = .942)$	
Physical Deixis directed at Shared Display per trial	2.5 (3.728)	3.67 (3.502)	3.50 (4.461)	.83 (2.041)	.167 (.408)	1.00 (1.549)	$(F_{(1,5)} = 0.130, p = 0.734)$ $(F_{(1.127,5.637)} = 0.175, p = 0.720)$	
Equity of Participation (# of component moves/trial)	0.147 (0.072)	0.100 (0.080)	0.130 (0.064)	0. 150 (0.098)	0.136 (0.081)	0.117 (0.058)	$(F_{(1,5)} = .028, p = .869)$ $(F_{(2,10)} = .545, p = .586)$	

utterances (or speaking turns) made across conditions. The second compared the total number of words spoken by each group across conditions. No significant differences were found between the number of utterances across display configurations ($F_{(1,5)} = 0.032$, $p = 0.866$), with groups in SDG conditions making an average of 151.3 ($\sigma = 94.17$) utterances and groups in MDG conditions making an average of 147.2 utterances ($\sigma = 66.5$). However, a significant difference was found across task structure conditions ($F_{(2,10)} = 5.776$, $p = 0.022$). Groups produced an average of 115.75 ($\sigma = 68.1$) utterances in SA conditions, 180.1 ($\sigma = 84.1$) utterances in NA conditions, and and average of 152 ($\sigma = 78.4$) utterances in FA conditions. A pairwise, post-hoc test revealed that participants produced significantly fewer utterances in the SA conditions than they did in the NA conditions ($p = 0.023$), but no difference was found between the FA and NA or SA conditions ($p = 0.588$, and $p = 0.436$, respectively). No significant interaction effects between display and task structure conditions were found for utterances spoken per trial ($F_{(2,10)} = 0.350$, $p = 0.713$).

The analysis of the total words spoken per trial revealed a similar trend. Groups spoke similar amounts of words per trial across display configurations, with groups working under SDG conditions speaking an average of 1030.6 ($\sigma = 633.2$) words and groups working under MDG conditions speaking an average of 1166.5 ($\sigma = 417.6$) words. However, a marginally significant difference was found across task structure conditions ($F_{(1.15,5.74)} = 5.414$, $p = 0.058$). Groups spoke an average of 962.1 ($\sigma = 498.6$) words in SA conditions, an average of 1301.6 ($\sigma = 488.4$) words in NA conditions, and an average of 1031.9 ($\sigma = 570.4$) words in FA conditions. The analyses revealed that groups spoke fewer words in the SA conditions than in the NA conditions ($p = 0.011$), but no differences were found between the FA and NA or SA conditions ($p = 0.954$ and $p = 0.279$, respectively). No significant interaction effects between display and task structure conditions were found for words spoken per trial ($F_{(2,10)} = 0.950$, $p = 0.402$).

Physical deixis was analyzed through coding of the recorded video data. Videos were reviewed and coded for gestures, such as pointing towards the shared display or the personal displays, that accompanied verbally communicated third person possessive adjectives such as 'it', and demonstratives such as 'this' and 'that'. No significant differences were found across display configurations for the amount of deixis directed at the shared display ($F_{(1,5)} = 0.130$, $p = 0.734$). Groups working under SDG conditions utilized an average of 3.22 ($\sigma = 3.61$) deictic references towards the shared display, whereas groups working under MDG conditions utilized an average of 3.33 ($\sigma = 3.55$) deictic references towards the shared display. Similarly, no significant differences were found based on task structure conditions ($F_{(1.127,5.637)} = 0.175$, $p = 0.720$). Groups working under the SA conditions utilized an average of 2.91 ($\sigma = 3.04$) deictic references per trial, whereas groups working under NA conditions utilized an average of 3.33 ($\sigma = 3.61$) deictic references per trial, and groups working under FA conditions utilized an average of 3.58 ($\sigma = 4.01$) deictic references per trial. Finally, no significant interaction effects between display and task structure conditions were found for the amount of physical deixis directed at the shared display ($F_{(2,10)} = 1.013$, $p = 0.397$).

However, in MDG conditions, physical deixis was divided between the personal and public display. In these conditions, groups on average made 3.33 ($\sigma = 3.55$) deictic references towards personal devices. Overall, these references accounted for 75% of participants' physical deixis. However, the difference between deixis directed at the shared and personal displays was not statistically significant ($F_{(1,5)} = 1.432$, $p = 0.285$). No significant differences in the amount of deixis direct at personal displays were found ($F_{(2,10)} = 0.06, p = .942$). Groups working in SA conditions utilized an average of 2.50 ($\sigma = 2.95$) deictic references, groups working under NA conditions utilized an average of 2.83 ($\sigma = 4.26$) deictic references, and groups working under FA conditions utilized an average of 2.67 ($\sigma = 4.68$) deictic references towards their personal displays.

Finally, participants marginally agreed more strongly with the statement "I was able to interpret my peers' communications" in the MDG conditions ($F_{(1,5)} = 4.091$, $p = 0.099$), however no significant differences were found for task structure ($F_{(2,10)} = 1.932$, $p = 0.259$). For the inverse statement, "I was able to communicate well with my peers", no significant differences were found between display configurations ($F_{(1,5)} = .268$, $p = 0.627$); however, significant differences based on task structure were observed ($F_{(2,10)} = 10.892$, $p = 0.003$), with the NA conditions eliciting more positive responses than the FA ($p = 0.014$) condition, and marginally more positive responses than the SA ($p = .078$) condition.

Coordination

In the FA task structure condition, participants were each assigned two specific jobs to manage, so no decisions were necessary regarding who should move which job component. In the NA condition, participants had to negotiate who would be assigned each job, and then, similar to the FA condition, participants could only move the components of the jobs they 'owned'. While in reality, participants could change the job assignments dynamically throughout the task, in practice most groups assigned each person two jobs each (similar to the FA condition) and did not change these initial assignments. The software would not let them move pieces assigned to someone else.

In contrast, in the SA condition, participants were free to move any component of any job in the schedule. Thus, participants had to coordinate their use of these shared resources, and it was possible for multiple participants to interact with a single job component simultaneously. These incidents were classified as conflicts, since they can reveal instances where participants were not optimally coordinating interactions with their collaborators. The statistical analysis of participants' interaction conflicts revealed that groups working under the MDG/SA condition conflicted an average of 14.83 ($\sigma = 6.618$) times per trial, whereas groups working under the SDG/SA condition conflicted an average of 5.00 ($\sigma = 2.58$) times. This difference was statistically significant ($F_{(1,5)} = 12.567$, $p = 0.016$).

Awareness

On the post-trial questionnaire, participants were asked how aware they were of their collaborator's actions, and how aware they felt their collaborators were of their own actions. No significant differences were found for either question across display configurations (own awareness: $F_{(1,10)} = 0.009, p = 0.930$; collaborators' awareness: $F_{(1,10)} = 0.214, p = 0.663$). However, one participant did comment in the post-study interview, "[In MDG conditions] it just seemed like a piece was moving randomly. I couldn't figure out who was doing it or where it was going", indicating that workspace awareness in MDG conditions was degraded. When analyzing results based on task structure conditions, participants reported that they felt their peers were more aware of their actions in the NA conditions ($F_{(2,10)} = .5.120, p = 0.029$) than in the SA ($p = .001$) conditions, and marginally more than the FA conditions ($p = 0.087$). Additionally, participants reported that they felt they were marginally less aware of their collaborators' actions ($F_{(2,10)} = 3.148, p = 0.074$) in the SA condition than in the NA conditions ($p < 0.09$), but no difference was found for the FA condition ($p = 0.102$).

Equity of Participation

Finally, the equity of participants' interactions was also analyzed by computing Gini coefficients based on the number of mouse interactions each participant contributed over the course of performing the task. Gini coefficients calculated for groups working under MDG conditions averaged 0.134 ($\sigma = 0.074$), whereas Gini coefficients calculated for groups working under SDG conditions averaged 0.126 ($\sigma = 0.069$), a difference that was not found to be statistically significant ($F_{(1,5)} = .028, p = .869$). Similarly, no significant differences were found between Gini coefficients calculated for task structure conditions ($F_{(2,10)} = .545, p = .586$). Gini coefficients calculated for groups working under SA conditions averaged 0.148 ($\sigma = 0.078$), for groups working under NA conditions averaged 0.118 ($\sigma = 0.056$), and for groups working under FA conditions averaged 0.134 ($\sigma = 0.74$). No significant interaction effects between display and task structure conditions were found for equity of participation ($F_{(2,10)} = 0.780$, $p = 0.484$).

6.3 Discussion

The collected quantitative data revealed performance and taskwork efficiency differences between groups, and analyses of this data identified trends for further investigation. In particular, the analyses identified two issues that elucidate the role of shared and personal devices in supporting collaborative work: balancing awareness and cognition, and supporting group members' communication. A discussion of these two issues follows, in which the reported quantitative data is interpreted through the lens of qualitative data and existing theory.

6.3.1 Balancing Awareness and Cognition

In order to accomplish a joint task, a group of people must communicate and coordinate their actions, as well as spend periods of time concentrating on their individual task duties. With limited human cognitive resources, these activities can compete for each team member's attention. The inconsistent effect of display configuration and task structure conditions across study measures reflects this tension in providing an environment that supports both taskwork and teamwork. For instance, participants exhibited more coordination problems in the MDG configurations than in the SDG configurations ($p = 0.016$), suggesting that participants were less aware of their collaborators' workspace actions in the MDG conditions. On the other hand, participants produced more accurate solutions with fewer errors in the MDG conditions ($p = 0.025$), suggesting that participants were more effective at checking their work on the personal display than on the public display. One explanation for these results may be that the proximity of the laptop displays in the MDG setup helped block out visual distractions in the environment, enabling group members to better focus their cognitive resources.

The differences in the software interfaces in each configuration may have also contributed to the results. The effective coordination of workspace actions in the SDG configuration ($p = 0.016$) was likely facilitated by a participant's ability to see everyone's cursors on the public display, which promoted workspace awareness. However, the video data revealed that despite the presence of the public display in MDG conditions, it was rarely used. When participants did look at the public display, it appeared to be at times when they were assessing the current state of their solution to 'get a bigger picture'. Thus, it appears that the different displays (personal and public) supported different task functions for participants, as evidenced by participants' interview comments such as: "It was easier to do [the task] on the laptop, but then in the end, you know, to look at the final solution it was easier to look [at the public display]" and "I think we like, we talked more when we were like doing that thing [points to public display], but we did more of our own thing when we were using our laptops."

The tailored interfaces corresponding to the current job assignments provided on the personal display in the MDG configuration may have contributed to the lower error rates in this configuration ($p = 0.025$). All of the errors committed were order errors. Though not directly indicated by either the MDG or SDG interface, these errors were more salient in the MDG configuration since job components which participants could not interact with were 'faded out' on the personal displays. This tailored view may have simplified the task of aligning corresponding job components across multiple resource lines and among multiple jobs, therefore reducing the error rate in the MDG conditions.

6.3.2 Communication

One might expect groups to require more verbal communication in MDG configurations, given the reduced level of awareness provided by this environment, as discussed above. However, no differences were found across display configurations for either the number of utterances ($p = .866$) or number of words ($p = .678$) spoken by groups in MDG conditions. Despite the lack of statistically significant differences between the amount of communication produced by groups in each display configuration, participants' subjective responses in the post-trial questionnaires and post-study interview indicated that they felt the MDG configuration provided a more effective communication environment. In particular, they felt that they could effectively convey information to their partners, and could better interpret others' communications in this configuration.

The differences found in communication efficiency across task structure conditions were also surprising. It was expected that the least structured condition would require the most communication to coordinate access and sharing of common resources (i.e. the job components). The results, however, indicate that participants simply worked independently in the SA condition, moving whichever job component they desired at will. If someone else was moving the one they wished to move, they would select a different component to move. As there were many shared components to go around, groups uttered significantly fewer utterances in SA conditions than in NA conditions ($p = 0.022$). In contrast, groups communicated more in the NA condition as participants were forced to ask someone else to move the job components to which they were not assigned. A benefit of this additional verbal communication is that it provides information about participants' actions and intentions, which helps to increase a participant's awareness of the activities of others. In the post-study interview, most participants indicated a preference for performing the task under the FA condition, potentially due to the added engagement and group interaction resulting from the necessary communication over task resources outside of each member's direct control.

In terms of non-verbal communication, no significant difference in the amount of physical deixis used by participants was found between display conditions ($p = 0.734$). However, in the MDG conditions, 75% of deixis was directed at personal displays, and was therefore not effective as a communication tool. These results correspond to research on Single-Display Privacyware (SDP) systems that have shown that people frequently gesture inside virtual private spaces and expect their collaborators to be able to see these gestures (Shoemaker & Inkpen, 2001). The system configurations employed in this study differ from a SDP system in that they involved physically separate displays, while a SDP configuration involves two virtually separate displays superimposed onto the same physical space (users wear head-mounted displays to achieve this effect).

However, consistent user behaviour observed in both system setups suggests a potential communication issue with groupware systems in general: users may not be able to effectively estimate which elements of the workspace their peers are able to see. Similar behaviour can often be observed during meeting or conference presentations when the speaker gestures to their laptop screen when attempting to highlight an on-screen item instead of to the projected display, seemingly unaware that the audience cannot see what they are pointing to. People's incorrect assumptions of their collaborators' awareness also explains why participants felt that they were able to communicate with their collaborators, but that they had difficulty in understanding their collaborators' communications. These results provide evidence that the lack of understanding extends to the physical environment as well as the virtual.

6.4 Summary

As an initial exploration of the use of shared and personal devices in collaborative work, this study revealed two important results. First, this study revealed that there was a tradeoff between enhanced task performance and a reduced group awareness with the MDG configuration. The study data suggests that enabling participants to work within a personal workspace decreased a group's error rate for the intellective task used in this study, but that working primarily in the personal workspace reduced an individual's awareness of their collaborators' activity. Second, that when working in MDG conditions, participants may have encountered difficulties when interacting with one another. For example, physical deixis was often directed at a personal rather than the shared display.

Moreover, observational data revealed that participants spent the majority of their time working with their personal device when it was present, and only briefly glanced at the shared display in MDG conditions. This observation raised an important question – if participants were spending the majority of their time working on their personal devices, what value did the shared display provide in MDG conditions? Informal observations suggested that the shared display seemed to enable individuals to mentally 'step back' from their task interactions in order to obtain an overview of the group's progress. On the other hand, participants utilized their personal displays to adjust job components and explore the problem space. This process closely mirrored the sensemaking process model proposed by Yi et al. (2008), described earlier in Chapter 2 (Figure 6.4), where participants used the shared display to gain an overview of the task, but used personal devices to 'adjust' task artefacts. This apparent difference in the purposes served by the shared and personal displays called into question the utility of replicating the task workspace content on the shared display, rather than using that display to provide other possible content views. If users were mentally 'stepping back' when viewing the shared display, for example, perhaps displaying an overview of the task would be more appropriate. To explore this issue further, a follow-up study was conducted, and is described next in Chapter 7.

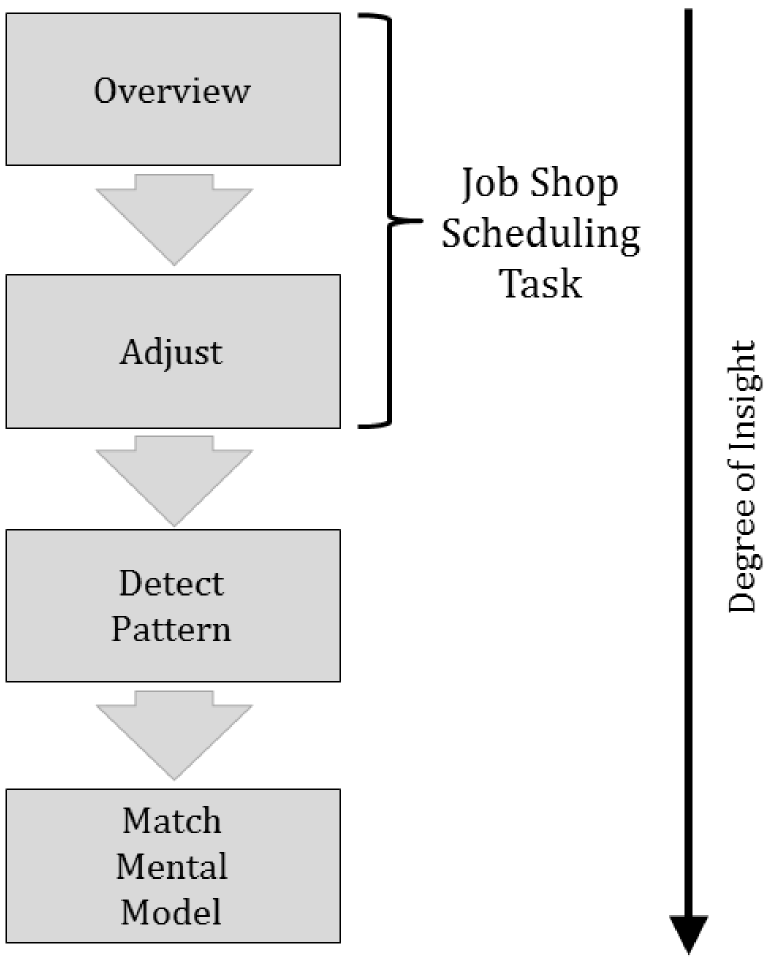


Figure 6.4: Participants in Study 1 appeared to perform tasks in a similar manner to the sensemaking process model by Yi et al. (2008). In particular, groups appeared to move between 'overview' and 'adjust' processes throughout the task.

Chapter 7

Study II: The Role of Shared Devices in Collaborative Optimization Tasks

In Study I, presented in Chapter 6, the impact of SDG and MDG display configurations on taskwork and teamwork during a collaborative optimization task was investigated. That study revealed that providing groups with only a single, shared display promoted group awareness ($p = 0.016$), whereas providing each group member with a personal display with customized views, in addition to a shared display, promoted task accuracy as group members could easily focus on their individual aspects of the task ($p = 0.025$). In addition, the study revealed that in the configuration in which both personal and shared displays were available (i.e. the MDG condition), participants rarely used the shared display, even though the display provided such additional information as the other group members' mouse cursors.

Informal observations in Study I, however, suggested that when participants did use the shared display, it appeared to play a different role than their personal displays, and allowed participants to 'step back' from their personal workspace. These activities were linked to the 'overview' and 'adjust' modes of work in the sensemaking process model. Study II aimed to understand how two types of shared displays support an individual's ability to transition between these two modes of work[1]. Status displays consist of non-interactive data, and are used to help monitor group activity, whereas shared workspace displays support synchronous, tightly-coupled communication and coordination. These two classes of shared display were selected as representative of typical uses based on the literature review discussed in Chapter 3, and their incorporation into the study design provide an opportunity to identify their support for teamwork and taskwork performed during collaborative work.

7.1 Study Method

Before presenting the results of this study, its design is first discussed. In particular, the participants, experimental task, experimental conditions, setting, procedure, and data collection and analysis techniques are now described.

7.1.1 Participants

Thirty six participants (20 male, 16 female), aged 18 to 27 ($\bar{x} = 20.6, \sigma = 2.26$) were recruited on campus at the University of Waterloo as 12 groups of 3. As in Study I, participants were predominantly Math, Science or Engineering students, groups who are representative of knowledge workers, whose day-to-day activities are typically learning and group work, and are familiar with the use of many new

[1]Material ideas, figures, and tables from this chapter have previously appeared in Wallace et al. (2011). Appropriate permissions have been obtained for the re-use of these materials, and can be found in the Permissions section at the end of the dissertation.

technologies. For example, all participants indicated that they used a laptop on a weekly or daily basis. However, they were less familiar with using displays larger than 20", including desktops and large TVs, with 21/36 participants reporting using a large display on a monthly basis or less.

Groups were recruited as groups of three whenever possible, and were randomly assigned to the between-groups factor, task structure, with six groups completing each of the SA and NA task structure conditions. In the SA condition, three groups consisted of participants who knew each other and volunteered together, two groups consisted of pairs who volunteered together matched with individual volunteers, and one group consisted of three randomly matched individual volunteers. In the NA condition, three groups consisted of participants who knew each other and volunteered together, one group consisted of a pair who volunteered together matched with an individual volunteer, and two groups consisted of three randomly-matched individual volunteers. While previous research (e.g. Shah & Jehn, 1993) has found that groups of friends perform better than groups of acquaintances for decision-making tasks, the recruitment of both homogenous and heterogeneous groups should improve the generalizability of results obtained from this study. Further groups consisting of only friends were balanced across task structure conditions, reducing the impact of friendship as a potential confound.

All participants had normal or corrected-to-normal vision, and were tested for colour-blindness prior to beginning the study. Participants were paid $15 each for their participation in the study; no monetary compensation was awarded based on performance.

7.1.2 A Revised Job Shop Scheduling Task

The experimental task and software interface from Study I (Figure 6.1) were utilized to study the role of shared displays in this study, with a number of minor performance and technical improvements made based on experience from that sutdy. Additionally, one significant change was made to the task interface: a solution 'scrubber' that enabled users to view and load previous task states was added to the personal displays (Figure 7.1, D). In Study I, groups took an average of 13 minutes to perform the JSS task, out of a possible 20 minutes. Informal observations suggested that groups were unwilling to more fully explore potential solutions to the JSS task, as doing so required moving away from a potential solution with no provision for groups to 'save' that solution for later use. The scrubber was included to better facilitate exploration within the problem space. In particular, the scrubber could be used to backtrack to previous solutions, or to restart the puzzle entirely. A similar backtracking tool was found to be particularly beneficial in supporting groups conducting a city planning task in the Caretta project (Sugimoto et al., 2004).

7.1.3 Experimental Design

A 2 (shared display type) x 2 (task structure) design was used, with shared display type as a within-subjects factor, and task structure as a between-subjects factor. Thus, each group completed 2 display configuration trials, in one of two task structure conditions. The two shared display type configurations used in the study included status display and shared workspace display (Figure 7.1). In all conditions, each personal display acted as a personal workspace that showed only its owner's mouse cursor. Operation components on the personal displays were visually differentiated to increase the salience of resources assigned to each group member.

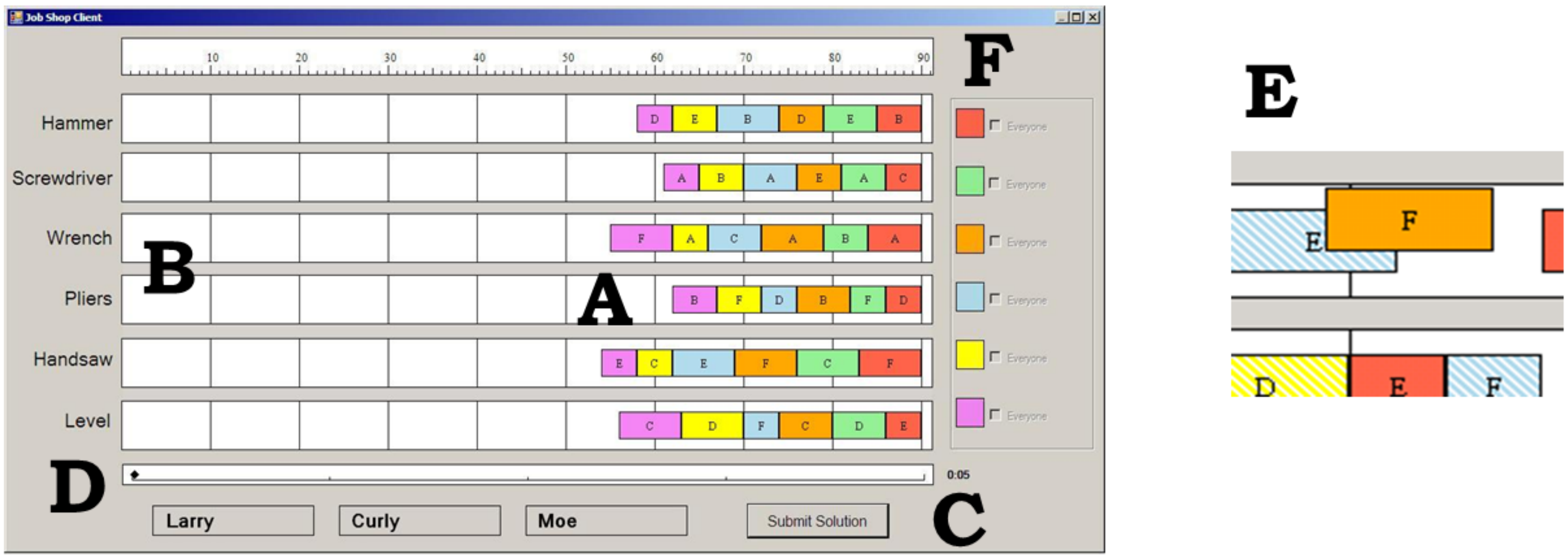


Figure 7.1: A revised Job Shop Scheduling Task interface. Each job is indicated by blocks of a particular colour, with six operations (A) per job. Each job has one operation that must be completed by each of the six resources (B). Group member job assignments are indicated on the right side of the JSS interface (F). Participant submit label indicators and the submit button (C) are also provided. In this iteration of the study. a solution scrubber (D) was also incorporated into the interface to facilitate backtracking to a previous solution. The excerpt on the right (E) shows a close-up view of a personal display, where unassigned job components are displayed in a less salient fashion to provide a personal workspace for the task.

In contrast, unassigned operations and operations assigned to others were visually de-saturated (Figure 7.1, E). In Study I, task structure was a within-subjects factor, whereas in this study task structure was a between-subjects factor. This change was made in conjunction with the introduction of the scrubber feature, as described above, to reduce the number of tasks that groups were required to perform, in the hope of eliciting more effortful participation in the study.

In the shared workspace display configuration, the shared display also contained a view of the JSS interface that was shown on the personal displays. As with Study I, the shared and personal displays had two key differences. First, a mouse cursor for all three participants was visible on the shared display. Second, job components were visually differentiated (i.e. semi-transparent) only if no participant maintained control over them. The shared and personal display interfaces were carefully aligned to ensure that mouse coordinates were mapped identically between both displays. This mapping was used to facilitate virtual deixis across displays (e.g. pointing or gesturing with the mouse cursor).

The status display condition also displayed a mouse cursor for each participant, but provided an alternate content view on the shared display (Figure 7.2). In this view, participants were able to see task status graphs corresponding to efficiency measures (Figure 7.2, A), a clock indicating remaining trial time (Figure 7.2, B), and an error display which indicated any job components which overlapped (Figure 7.2, C).

Analyses of group performance in Study I indicated that group members working on personal displays have reduced awareness of their team member's actions ($p = 0.016$). Such reduced awareness may reduce the ability to coordinate the use of shared resources, such as the job operations in the JSS task, thus limiting the

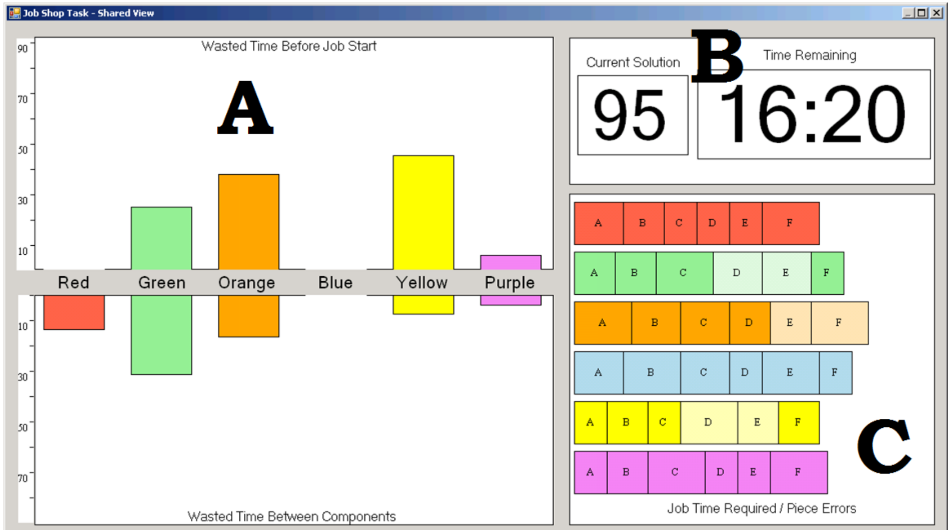


Figure 7.2: The status display interface. Participants using this interface were presented with (A) graphs representing the optimality of their current solution, (B) a clock and (C) an error display, in which job components which were overlapping with other pieces were visually less salient.

number of shared task resources that require group members to coordinate may provide advantages in content replication-based environments that provide limited awareness. In Study I, three levels of task structure were incorporated into the experimental design: shared access (SA), negotiated access (NA), and fixed access (FA). As the experimental measures were unable to detect significant differences between groups working in the NA and FA conditions, observational data did not indicate significant differences in group process between these conditions, and participants experienced fatigue due to the large number of experimental conditions, the FA condition was eliminated from this investigation.

7.1.4 Setting

The study was conducted in a controlled lab space with a 2m x 1m table. In all conditions, a shared display was projected on a wall approximately 2m away from the table at a resolution of 1024x768 pixels over a 2m x 1.5m area. In the MDG

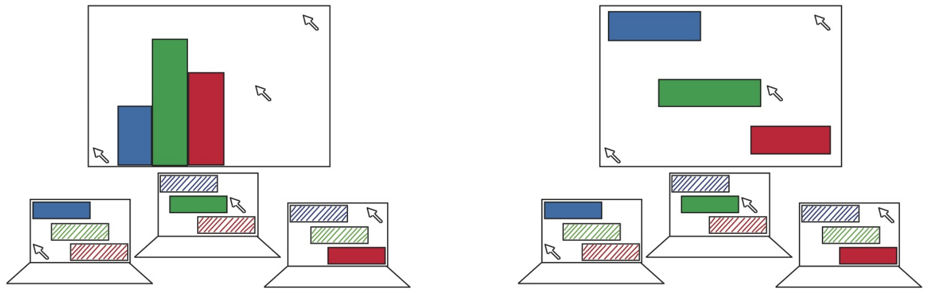


Figure 7.3: Interface differences between display type configurations: status display configuration(left) shows task interface on laptop displays, and an overall status display on the shared display; shared workspace configuration (right) shows a replicated copy of the task interface on the laptop displays as well as on the shared display.

condition, three Lenovo 15” T61 Thinkpad laptop computers (2x2GHz, 1GB RAM) were placed on the table and provided individuals with input to the shared display via a dedicated 802.11g wireless network secured using WPA authentication. Each laptop had a mouse attached for input, and a participant’s cursor was displayed on both the personal and shared workspaces using the Swordfish software framework (Wallace et al., 2006). Figure 7.3 illustrates configurations for both display conditions. In all conditions, participants were seated around the three sides of the table that were facing and adjacent to the shared display, and seating positions were kept constant across all trials in both experimental sessions.

7.1.5 Procedure

Participants first received a brief introduction to the study from the experimenter, and then completed an informed consent form, colour-blindness test, and a demographic questionnaire (Appendix B.3) that included questions concerning laptop and large display use. Next, the experimenter presented a 10 minute PowerPoint tutorial describing the JSS task, the task goals, and error cases (Appendices B.4

and B.5). Participants then completed one 10-minute practice trial in each display condition to reduce anticipated learning effects (Tan et al., 2008), and to ensure that participants were familiar with all of the interface features before proceeding to the experimental trials. Thus, participants completed two 10-minute practice trials in total.

Next, participants completed two 20 minute experimental trials, one for each of the two display conditions. The order of presentation of the shared display content conditions was counter-balanced across groups. After each trial, participants completed a post-condition questionnaire (Appendix B.6) eliciting their opinions on the shared display, and their experienced workload via a NASA-TLX (Hart & Stavenland, 1988). Once all trials were completed, each group participated in a semi-structured interview which elicited responses regarding difficulties with the task, features missing from the shared display interfaces, and preference data. Finally, participants were thanked for their time and paid for their participation.

7.1.6 Data Collection and Analysis

Participant task and group interactions were captured in a number of ways. Participant interactions with the JSS interface were automatically captured by the software into computer logfiles. Participant conversations and interactions with each other and in the physical workspace were captured on integrated audio and videotapes. Participant opinions on the task environment and their group interactions were also recorded via the post-condition questionnaires and the post-experiment semi-structured interview.

These data were then used to perform both quantitative and qualitative data analyses to help understand the overall impact on the experimental conditions on various teamwork and taskwork measures. In particular, two-way repeated measures analysis of variance (RM-ANOVAs) were conducted to discover any statistical differences in task performance, as measured by the solution time (faster being better), number of order or overlap errors (fewer errors being better), and task efficiency (fewer number of job component moves being better). A one-way RM-ANOVA was performed to determine the impact of display configuration on the number of conflicts that occurred in the SA condition (simultaneous access to job components was not possible in the other task structure conditions). Where sphericity assumptions were violated, the Huynh-Feldt method was used for corrections. Tukey tests using the Bonferroni adjustment were used for pairwise post-hoc comparisons. The Likert-scale ratings collected from the post-condition questionnaires were also analyzed using RM-ANOVAs to account for the non-independence of group members' responses. An alpha of 0.05 was used for all statistical tests.

The video and interview data were reviewed to identify any interesting behavioural or conversational patterns and participant opinions. The video data were then transcribed and a basic conversational analysis was performed to identify overall patterns in communication efficiency and content across study conditions. In particular, the number of utterances was analyzed, using a two-way RM-ANOVA, to determine whether the study conditions had an impact on a group's communication efficiency.

Analyses of teamwork measures for communication efficiency required that video data be transcribed and coded. A single coder was responsible for transcribing each group's sessions, and these transcriptions were used for analyses of utterance counts. Based on these transcriptions, the number of utterances spoken by groups were analyzed using a two-way RM-ANOVA to determine whether the study conditions had any impact on the communication efficiency. Unlike Study I, word counts were not analyzed in this study since they appeared to be less sensitive to differences in communication based on analyses in that study.

In a second coding phase, incidents in which participants ‘looked’ at the shared display were coded. In particular, videos were reviewed for cases where participants directed their gaze at the shared display. Physical deixis was not coded in this study as it was in Study I, since the expected use of status displays was to monitor group activity, and thus would not involve deixis. Thus, gaze was adopted as an experimental measure in order to obtain a more accurate measure of display use. Finally, the video, questionnaire, and interview data were reviewed to identify any interesting behavioural or conversational patterns and participant opinions.

7.2 Results

The quantitative data analysis revealed that the shared display type and the task structure factors had minimal impact on the taskwork and teamwork measures included in this study. The results do, however, reveal interesting differences between data collected from this study and those collected during Study 1. Surprisingly though, the analysis of participant questionnaire responses revealed that the perceived value of the shared display type differed across conditions. The results from both quantitative analyses are detailed below.

7.2.1 Taskwork and Performance

To understand the impact of the shared display content on taskwork and performance, a number of metrics were collected across shared workspace display and status display conditions, including number of errors committed, solution quality, conflicts, task time, and number of job components moved was examined. No significant differences were found across these measures. Moreover, these data were similar to the same measures collected for the MDG condition in Study I. Table 7.1 summarizes these results and the complementary data from our previous study.

On average, however, groups in this study took 14% longer to complete the task, and produced schedules that were 40% shorter (i.e. more optimal) than groups in the MDG condition in Study II. Though these improvements are well within the large between-group variation in task times and solution optimality observed in both studies, it is possible that the trend of increased performance may be caused by the addition of the 'scrubber' feature in this second study (it was not available in Study II). The ability to 'rollback' solutions seems to encourage more exploration of the solution space, possibly leading to more time spent performing the task. As groups more fully explored the solution space, they were more likely to come across more optimal solutions to the JSS task. The interaction logs show that 7/12 groups took advantage of this capability, and that groups loaded a previous solution state an average of 3.00 times per trial ($\sigma = 1.95$).

To understand the impact of task structure on taskwork, the same task performance metrics discussed above across NA and SA task structure conditions were tested. Similarly, no significant differences were found for errors, solution quality, and job component moves between task structure conditions, and conflicts were only possible in the SA condition, so no comparison was made. The data for these metrics were consistent with those found in the MDG condition of our previous study. Finally, the number of utterances across display conditions were compared to understand the impact of task structure on teamwork. No significant differences

Table 7.1: Mean values and standard deviations (in parentheses) for taskwork and performance measures, and ANOVA results for comparisons between experimental conditions. Significant results denoted by **, marginally significant results denoted by *.

Study	Measures							
	Job Component Moves		Task Time (Seconds)		Errors Per Trial		Solution Optimality	
	NA	SA	NA	SA	NA	SA	NA	SA
Study I (N = 6) (MDG Condition Only)	234.83 (104.52)	399.83 (228.19)	811.17 (326.70)	807.83 (291.62)	0.00 (0.00)	0.167 (0.408)	25.00 (21.213)	25.00 (35.355)
Study II (N = 12) Status Display	240.67 (95.43)	351.00 (109.64)	867 (337.22)	935.83 (257.44)	0.00 (0.00)	0.167 (0.408)	23.33 (22.51)	14.00 (19.494)
Study II (N = 12) shared workspace display	274.83 (71.86)	361.17 (149.86)	903.33 (190.97)	990 (264.89)	0.167 (0.408)	0.167 (0.408)	12.00 (16.432)	10.00 (10.00)
Study II, Comparison Between Display Conditions	$F_{(1,10)} = .856$, $p = .377$		$F_{(1,10)} = .422$, $p = .531$		$F_{(1,10)} = 2.000$, $p = .188$		$F_{(1,7)} = .718$, $p = .425$	
Study II, Comparison Between Task Conditions	$F_{(1,10)} = 2.248$, $p = .165$		$F_{(1,10)} = .259$, $p = .622$		$F_{(1,10)} = 2.000$, $p = .188$		$F_{(1,7)} = .021$, $p = .890$	
Study II Total (Average over entire study)	257.75 (86.18)	356.08 (131.40)	885.17 (285.58)	962.92 (271.34)	0.083 (0.289)	0.167 (0.389)	18.182 (19.909)	12.00 (14.757)

were found. Therefore, overall task structure did not appear to impact teamwork or taskwork in this study.

7.2.2 Teamwork

Teamwork measures were also collected during experimental trials, and as with the taskwork measures, no statistically significant differences were found for these measures between either display or task structure conditions. Table 7.2 summarizes these results and the complementary data from Study I. In particular, no significant differences were found in the number of utterances groups made across shared display types ($F_{(1,10)} = 1.036, p = .332$). Similar to the task time results, though, there was an increase in the average number of utterances in both shared display type conditions compared to the MDG condition in Study I (64% increase in the status display condition and 78% increase in the shared workspace condition). The increase in group communication between the two studies may result from the introduction of the scrubber feature, and the resulting tendency of groups to explore the solution space.

As in Study I, the equity of participant interactions within groups was also analyzed via Gini coefficients calculated based on the number of job components moved by each participant. Groups working under shared workspace conditions had Gini coefficients that equalled on average 0.133 ($\sigma = 0.111$), whereas groups working under status display conditions had Gini coefficients that equalled on average 0.135 ($\sigma = 0.063$). No significant differences were found between display configuration conditions based on this data ($F_{(1,10)} = 0.10, p = .921$). Similarly, groups working under SA conditions had Gini coefficients that equalled 0.130 ($\sigma = 0.086$), and groups working under NA conditions had coefficients that equalled 0.138 ($\sigma = 0.094$) on average. No significant differences were found for equity of participation based on task structure conditions ($F_{(1,10)} = 0.31, p = .865$).

Though no significant differences for these teamwork measures were found across shared display type conditions, analyses of questionnaire data revealed that participants perceived the status display condition to be more helpful than the shared workspace display, as evidenced by participants agreeing more strongly with the statement, "The shared display helped us solve the puzzle" in the status display condition than in the shared workspace display condition ($F_{(1,10)} = 6.665, p = 0.027$). However, no significant differences were found for other preference measures such as "I felt our group worked well together" ($F_{(1,10)} = 1.247, p = 0.290$) or "I felt that it took a lot effort to solve the puzzle" ($F_{(1,10)} = .549, p = 0.476$). Similarly, subjective workload, as assessed by the NASA-TLX (Hart & Stavenland, 1988), was not significantly different across shared display type or task structure conditions for any of the six assessed dimensions.

7.2.3 Qualitative Analyses of Shared Display Use

As in Study I, informal review of the recorded video data and the field notes suggested that throughout the JSS task, groups would alternate between 'overview' and 'adjust' phases of work. In the overview phases, groups would actively discuss job component moves, whether to load a previous solution, or overall strategy in performing the JSS task. After deciding on a course of action, participants moved to an adjust phase in which they would focus primarily on their individual laptop displays to complete their task moves. The overview phases were relatively short, and overall, participants spent most of their time working on their personal laptop displays during the study trials. Groups looked at the shared display more frequently in the status display condition than the shared workspace display condition ($p = .004$). The increased display use in the status display condition suggested

Table 7.2: Mean values and standard deviations (in parentheses) for teamwork measures, and ANOVA results for comparisons between experimental conditions. Significant results denoted by **, marginally significant results denoted by *.

Study	Measures					
	Utterances		Equity of Interaction		Shared Display Use	
	NA	SA	NA	SA	NA	SA
Study I (N = 6) (MDG Condition Only)	166.17 (70.06)	120 (70.97)	0.136 (0.081)	0.150 (0.098)	n/a	n/a
Study II (N = 12) Status Display	293.50 (191.01)	176.00 (123.70)	0.139 (0.108)	0.126 (0.113)	44.33 (22.76)	64.143 (50.58)
Study II (N = 12) Shared Workspace	302.50 (131.56)	207.67 (127.78)	0.121 (0.053)	0.151 (0.068)	25.67 (9.66)	23.14 (16.99)
Study II, Comparison Between Display Conditions	$F_{(1,10)} = 1.037$, $p = .332$		$F_{(1,10)} = 0.100$, $p = .921$		$F_{(1,10)} = 14.395$, $p = .004$ **	
Study II, Comparison Between Task Conditions	$F_{(1,10)} = 1.555$, $p = .241$		$F_{(1,10)} = 0.31$, $p = .865$		$F_{(1,10)} = .481$, $p = .504$	
Study II Total (Average over entire study)	298 (156.44)	191.83 (126.75)	0.130 (0.086)	0.138 (0.094)	35.0 (19.8)	46.3 (44.9)

that there may be underlying behavioural differences between display conditions.

To investigate these differences, an in-depth video analysis was performed on a subset of the data to identify potential uses of the shared display. In conducting this analysis of group behaviour, a sample of 4/12 groups were selected for more detailed analysis. Two groups were selected to represent groups that minimally explored the solution space and submitted one of the first solutions they found without loading previous solutions, whereas the other two groups more fully explored the solution space and used the scrubber more frequently in their problem-solving process. The analysis of this sample of groups provided an opportunity to investigate critical incidents during their collaborative work, and to identify ways in which the shared display supported group process.

Monitoring

While working on their personal displays, regardless of which display condition they were working under, users continuously monitored the shared display; participants would look up from their personal displays, glance at the shared display, and then return to working on their personal display. Groups looked at the shared workspace display 1.51 ($\sigma = 0.88$) per minute on average, whereas groups looked at the status displays approximately 3.83 ($\sigma = 2.75$) times per minute on average ($p = 0.004$). This behaviour was not specifically inquired about during the post-condition questionnaire or post-study interview; however it appeared from the video that users were briefly consulting the portion of the display which indicated if there were errors in the solution. By glancing up at the status display's error indicator, participants seemed to be able to maintain awareness of the overall solution state without significant effort.

Figure 7.4: Participants 2 and 3 refer to the shared workspace display after Participant 1 unexpectedly loads a previous solution state.

In the shared workspace condition, participants did not exhibit monitoring behaviour as frequently; however the shared workspace display was used as a 'safety net' when unexpected events occurred. For example, in the case of Group 7's shared workspace display trial, Participant 1 loaded a previous solution state without realizing that it would do so for the entire group (Figure 7.4). When Participants 2 and 3 realized that their solution state had changed, they immediately referred to the shared workspace display to identify the source of confusion. The transcript follows:

```
(4:13) G7P3: yea, now I move ... [p1 loads solution]
(4:15) G7P3: ... oh wait, what, what?  [p1 checks shared screen]
(4:16) [p3 checks shared screen]
(4:16) [p2 checks shared screen]
(4:17) G7P2: hey why'd you do that
(4:18) G7P1: oh crap it happens for everybody?
(4:20) G7P3: yea man
```

```
(4:21) G7P1: I didn't know that
(4:22) G7P2: of course, we're ... [shakes head]
(4:23) G7P1: don't worry we'll go back
(4:24) G7P1: we'll go back in time
[p1 loads previous solution state, and group resumes work]
```

Communication Grounding

Verbal references to the shared display tended to embody the puzzle or JSS task as a whole or the group state rather than fine-grained references to individual job components. However, in some cases, participants were more active in using the shared display to explicitly communicate fine-grained task details. Grounding typically occurred when participants were engaged in the 'adjust' phases of the task, when there was difficulty in gaining the attention of fellow collaborators who were actively engaged with their personal display. One example of grounding occurred when Group 5 was considering the submission of a solution in their status display trial. Participant 1 suggested that they submit the solution. Before submitting, Participant 3 identified an error in the solution, and had to get Participant 2's attention on the shared display by tapping him on the shoulder repeatedly until he was acknowledged (Figure 7.5).

```
(30:13) G5P1: okay?
(30:13) G5P3: good
(30:15) G5P3: eh?
(30:15) [p2 checks shared screen]
(30:19) G5P1: sure?
(30:20) G5P3: yes
(30:21) G5P3:oouya
```

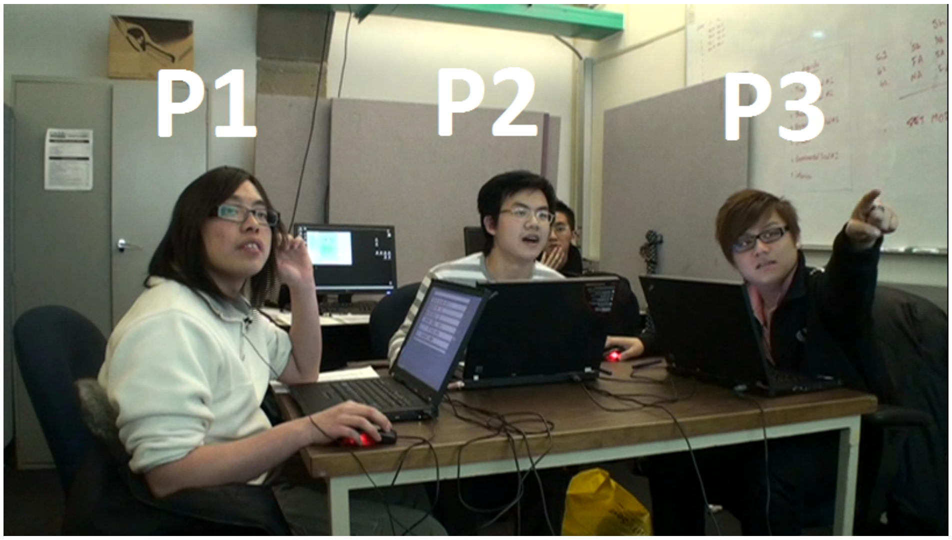


Figure 7.5: Participant 3 uses the status display to explain a problem with the current solution state to Participant 2.

```
(30:22) G5P1: [laughs]

(30:22) [p2 checks shared screen]

(30:31) [p3 checks shared screen]

(30:35) G5P3:wha [repeatedly taps p2 until p2 looks up] [points at shared screen]

(30:37) [p2 checks shared screen]

(30:38) [p1 checks shared screen]

(30:38) G5P2: what?

(30:40) G5P3: green ‘‘C’’ ‘‘D’’

(30:46) [p3 checks shared screen ]

[p2 and p3 go back to working on their personal displays ]
```

Instances of grounding were not limited to the shared display; some participants also used their collaborators' personal displays as tools for grounding. For example in Group 7's shared workspace display trial, Participant 2 decided to get Participant 1's attention by pointing directly on her (P1s) personal display (Figure 7.6). By pointing directly on a personal display, users could bypass the 'getting attention'

Figure 7.6: In Group 7's shared workspace display trial, Participant 2 explains a series of job component moves by directly referring to Participant 1's personal device.

phase.

In addition to these active examples of grounding, participants would refer to the shared display on their own when receiving instructions from a collaborator that they did not understand. For example, in one case Group 4's Participant 2 asked if a job component could be moved using verbal deixis (e.g. "Move this 'A' "). Since Participant 3 could not see Participant 2's mouse cursor on their personal display, they quickly glanced at the shared display where all cursors were present (Figure 7.7).

```
(26:13) G4P2: can we move this 'A' forward more?
(26:14) [p3 checks shared screen]
(26:15) G4P2: so the rest of this can move back again?
(26:16) G4P3: yea
[ p2 continues working]
```

Figure 7.7: After Participant 2 suggests a job component move, Participant 3 checks the shared display to resolve verbal deixis.

Synchronization

Participants frequently monitored one another's posture, orientation and physical gestures while performing the task, and the awareness gained from this monitoring aided in synchronizing group activity. The most common example of this synchronization activity was observed when groups were nearing the end of the task and were deciding whether or not to submit their current solution. Typically, as participants emerged from activity phases on their personal display, they would look up at the shared display. Other participants would recognize their body language and would face the shared display as well. Once all three participants were focused on the shared screen, a consensus was reached and a solution was submitted. Figure 9 illustrates a group shifting from an activity phase of work towards submitting a final solution, with participants in varying states of transition.

7.3 Discussion

Consistent with Study I, participants in this study focused on their personal displays while performing taskwork. This tendency appears to arise from a combination of the cognitive nature of the JSS task and the personalized workspace provided on the laptop displays, since participants were better able to focus on the task. Subjective reports from participants indicated that they did not feel that the shared display was necessary to complete the task, and that they felt they would be satisfied with a personal workspace that integrated the shared display's functionality. While these comments suggest that the shared display was not overtly perceived to add significant value to the task, observed use suggests it offers an important, if subtle, benefit in fostering teamwork.

An analysis of recorded video revealed ways in which shared devices supported group process. In particular, the status display was monitored more frequently by participants while solving the task ($p = .004$), however the shared workspace display was identified as serving as a 'safety net' when participants were uncertain of the problem state on their personal displays. Analysis of using the shared display for communication grounding identified cases in which participants experienced difficulty in shifting focus between shared and personal displays. Finally, the physical presence of a shared display played a role in synchronizing group activity. These observations will now be discussed.

7.3.1 Shared Workspace Displays and Grounding

Observations of participants working in MDG environments suggest some difficulty in utilizing the shared workspace display for grounding. That is, alternative views of task resources in MDGs allow users to simultaneously work in a personal workspace while maintaining awareness of shared task resources. By working in such a hybrid environment, users can effectively work as individuals while retaining ties to the group. This hybrid working environment, however, may come at the expense of an increased cost of communication between individuals (Clark & Brennan, 1991). For example, participants would occasionally gesture towards their personal display when talking to peers with the (often mistaken) expectation that their peers would understand their deictic references.

In this study, grounding behaviour was observed on the shared display despite the personal displays providing awareness of much of the group activity. In both shared display conditions, all task components were visible on each of the personal displays (only the salience of components was altered between personal displays), however all participant cursors were only visible simultaneously on the shared display. Thus, when participants needed to regain awareness of their peers' actions, they often looked to the shared display where cursor information was available for the entire group. This display appeared to provide a type of 'openness', similar to the team-optimized tools described by Hutchins' investigations of naval navigation tools (Hutchins, 1990). Such tools provide a visibility of the other's taskwork which contributes to task awareness and coordination. The observed use of the shared workspace display would indicate that participants were able to work with a cursory awareness of each other's activity most of the time, however the more open shared display was useful for repairs when communication broke down (Clark & Brennan, 1991).

The observation of these phenomena, primarily in the shared workspace display condition, suggests that such shared display content is particularly effective in supporting grounding in group work, even when personalized views may replicate much of the shared workspace display. These results are particularly interesting because, while environments that provide access to shared resources via personalized views (e.g. Berry et al., 2004; Sugimoto et al., 2004) have been explored in the literature, the hardware configuration in this study provides a unique perspective on the role of personal and shared displays. For example, Sugimoto et al. (2004) found that in the Caretta environment consisting of a table and handheld computers, personal work was conducted on handhelds while group work and negotiations predominantly occurred on the shared tabletop. These results provide an example where groups working with more powerful personal devices (e.g. laptops) relied more heavily on their personal devices, and use of the shared workspace display was primarily for managing group awareness.

7.3.2 Status Displays and Monitoring

Groups working under the status display condition tended to utilize the shared display for monitoring, rather than grounding. In this condition, only one view of the shared workspace can be seen on participant laptops, limiting the opportunity for users to be aware of peer task interactions, and thereby increasing the amount of effort required for grounding. Despite these shortcomings, the shared display's alternate task view was useful in that participants were able to more seamlessly monitor task progress. This utility was demonstrated not only by the participants repeatedly using the display (i.e. looking at the status display approximately three times as often as the shared workspace display), but also through participant self-reported preference for the status display configuration on the post-condition questionnaires.

As Grudin (2001) discusses for single-user settings, an advantage of multi-display configurations is that the division of tasks amongst multiple displays can reduce the cognitive load associated with transitioning between tasks. In this study, the partitioning of task information appeared to provide participants support for transitioning between group and individual work, as illustrated by observations of participants shifting their attention from personal to shared displays, and vice-versa. In this sense, the shared display not only acted as a common workplace for the group, but also as a secondary display for individual work. These findings support observations by Biehl et al. (2007) in their evaluation of FASTDash, a tool developed to support workspace awareness in programming teams. In their study, Biehl et. al. found that most programmers preferred to maintain an open copy of FASTDash on a secondary monitor, rather than refer to the large, shared workspace display projected nearby. One interpretation of these results is that displays designed to support activity awareness (Carroll et al., 2003) may be viewed by group members as supporting an individual task (i.e. the act of monitoring) rather than group work, and may therefore be best implemented as secondary displays within a personal workspace.

The implementation of an active status display in this study also contrasts observed use of MDGs in which shared displays are used to display less frequently updated content. Study II, and the work of Biehl et al. (2007), placed an emphasis on sustained use of shared displays for the display of real-time information regarding the state of the shared workspace display. In other cases, the "at-a-glance" availability of the status display has previously been identified as a strength of shared displays used for monitoring group work (Huang et al., 2006; Plaue et al., 2009). For example, in a field study of conference meeting room use at a global corporation, Plaue et al. (2009) suggest that idle displays be used for peripherally relevant information such as performance metrics. The variety of monitoring activity observed in this study may be indicative of the flexibility required when displaying content in MDG.

7.3.3 Physical Design of MDGs and Synchronization

The results of this study suggest that the physical presence of the shared display appears to have been beneficial in synchronizing group activity regardless of its content. One participant commented that "if [the status display] was on the laptop, then we wouldn't be communicating as much." Often, participants glancing at the display would trigger group interactions through a change in body position, and participants concentrated on this phenomenon during the post-study interviews. One participant explained, "sometimes looking at the shared [display, it's] like everyone's actually talking like instead of looking at their screens like it's a time to gather around."

While alternative participant seating positions were not explicitly tested, the 'around the table' configuration employed in the study may have helped to facilitate the use of body language in collaboration. This hypothesis varies somewhat from findings reported in Sommer (1969), in which collaborators preferred to sit side-by-side during cooperative work, but in adjacent corner configurations for conversations, citing the ability to share physical artifacts as motivating the preference for adjacent seating position in collaborative settings. In the case of collaborative environments using content replication, the sharing of physical artifacts is not a major concern. In contrast, Study II participants reported that a seating configuration in which body language is more easily observed promoted group interactions. One participant explained their preference for "around the table" seating configurations by saying "if we sat in a straight row we wouldn't be discussing in a circle, we'd be talking to a wall." Such comments suggest that the face-to-face configuration augmented with content replication utilized in this study may provide a "best of both worlds" setup in regards to Sommer's reported seating preferences.

The benefits of face-to-face configurations are further clarified by the F- formation theory reported in Kendon (1990) and its description of the role of gaze and body language in moderating collaboration. Kendon (1990) reports that group members' orientation dictates 'transactional space', or the common workspace utilized by a group, and that a peer's orientation and gaze relative to the group's transactional space is often used to communicate intent or motivation in conducting group work. For example, a group of peers working around a table would define the physical space between them as transactional space (i.e. the table's surface), and group interactions would then be carried out in that shared space. This theory reported in Kendon (1990) suggests that gaze and body position relative to this transactional space often moderates collaboration (see also, Cook's description of gaze in moderating conversation (Argyle & Cook, 1976; Cook & Lalljee, 2009).

An interesting difference between this work and the work motivating Kendon's theory is that F-formations were, like Sommer's (1969) theory, developed in a purely physical domain. These results help to interpret the theory's application in cases where digital devices are used to support collaboration. These observations suggest that users maintained a transactional space at the shared display, whereas personal displays were maintained largely as separate, personal workspaces. As participants shifted their gaze and body orientation between the shared and personal displays, transactional space was established, broken, and re-established, marking transitions between group and individual work. Kendon observed similar behaviour in that participants often rapidly shift between group and individual work (e.g. quickly check to see if anyone new is in the room), or establish more long term shifts in gaze (e.g. synchronize with new group members entering the group).

Notably, the physical layout of participants in this study closely resembles a commonly used configuration in today's workplace. Collaborators were seated at a table, each with laptops open in front of them, and a projected display on a nearby wall. As Kendon's F-formation theory was first published in 1990, before mobile computing, and in particular laptops, became common, our results provide an opportunity to elaborate on how it may be applied to more technically-driven environments. In our study, the laptops' vertical displays created a partial visual barrier between participants, effectively dividing what would traditionally be called the group's transactional space. These results suggest that having users seated in a face-to-face configuration facilitates the use of body language and gaze to synchronize activity between personal and shared displays in MDGs.

7.3.4 The Sensemaking Process Model

Even though the JSS task was not identified by Tan et al. (2008) as a sensemaking task, the sensemaking process model described in Chapter 2, at least in part, appears to be a useful tool for understanding how technologies supported group process in the JSS task. This utility should not necessarily be surprising, since participants must 'make sense' of the JSS task as they optimize the scheduling of job components. However, while both overview and adjust activities were identified in this study, the 'detect pattern' and 'match mental model' phases of work were not observed. While it is possible that these activities were performed by participants, the experimental design in this study did not provide a means of investigating them. This limitation is addressed in Study III (Chater 8).

Study II was motivated by the differences in observed use of personal and shared displays in Study I. Qualitative analyses revealed that participants appeared to move between overview and adjust phases of work. The shared display was used to

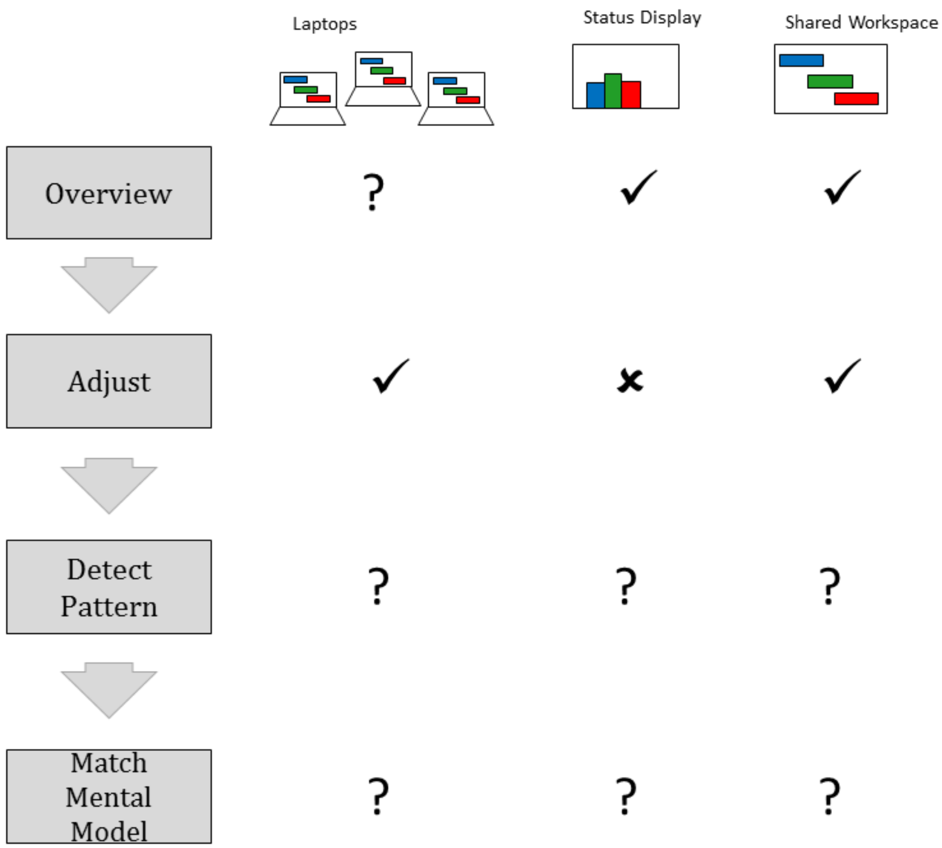


Figure 7.8: Participants in Studies I and II appeared to perform tasks in a similar manner to the sensemaking process model by Yi et al. (2008). In particular, groups appeared to move between 'overview' and 'adjust' processes throughout the task. Due to the limited ability of participants to manipulate task artefacts, it was difficult to determine if the 'detect pattern' and 'match mental model' phases were supported, or by which displays. These limitations were addressed in Study III.

sit back and 'get a bigger picture', whereas job components were adjusted primarily on personal displays when they were provided. In this study, similar behaviours were noted. For example, status display configurations supported taskwork by providing an overview of a group's task progress, and enabled participants to quickly identify errors in the group's working solution. Further, qualitative analyses in this study build on previous analyses, and in particular, they identify two types of scenarios in which the presence of the shared display aided group teamwork.

First, the shared workspace display supported communication grounding, and was often used by participants to coordinate work when adjusting job components. For example, in cases where one participant required that actions be coordinated with another, the shared workspace display provided a shared visual reference with which to coordinate actions. Second, the physical presence of either display appeared to assist in synchronizing group activity. For example, individuals within the group were able to monitor one another's body position, and determine when collaborators were ready to submit a final solution. These uses of the shared display appeared to aid in coordinating activities between individuals who may be active in different modes of work. For example, the personal displays allowed individuals to work independently in the 'adjust' phase of work, however in NA task structure conditions the task could not be completed independently. In these cases, the shared display facilitated coordination of individuals, even though they may be involved in different working modes. As the sensemaking process model was developed for single-user use cases, it does not currently account for transitions between working modes based on collaborators' activities, or for maintaining awareness of group state. These observed uses suggest that a such a process model for collaborative sensemaking should take these activities into account.

7.4 Summary

The study presented in this chapter examined the effect of display configuration and task structure on a group's performance and process for the JSS task. While performance differences were not identified in this study, a review of critical incidents recorded during trials did reveal interactions between the shared displays and group process. In particular, the status display was monitored more frequently by participants while solving the task ($p = .004$), however the shared workspace display was identified as serving as a 'safety net' when participants were uncertain of the problem state on their personal displays. Analysis of using the shared display for communication grounding identified difficulties in shifting participants' focus between shared and personal displays. Finally, the physical presence of a shared display played a role in synchronizing group activity.

Studies I and II have investigated how personal devices can support cognitive work, and how user transitions between personal and shared devices can serve to support aspects of teamwork such as grounding, monitoring, and communication. While these studies have been useful in evaluating the impact of shared and personal devices on group process, analyses of data collected during these studies suggest limitations in their design that can be addressed in future investigations. In particular, limitations of the types of devices studied and the experimental task are now discussed.

First, in Studies I and II only two types of devices have been utilized, laptops and projected displays, and taskwork has primarily been performed on the personal displays. Participant comments in Study II suggested that the shared displays were not necessary, and that the study of groups working without a shared display may be useful in investigating how these devices can support group process. Further, the focus on laptops and projected displays, which physically delineate between shared and personal space, limited the types opportunities for interaction. That is, work could be characterized as either 'personal' or 'shared', but there was no middle ground. Thus, there was an opportunity to explore more 'fluid' technologies such as digital tabletops and tablets that allow for interaction in personal and shared spaces, in addition to more ambiguous and transitionary phases.

Second, the JSS task was characterized in these studies as demanding a high degree of personal work, where participants spent the majority of their time focused on personal devices. The use of a task that more heavily relied on the use of shared space may assist in understanding how personal and shared devices can impact group performance and process. In the first two studies, task structure conditions were incorporated to simulate restricted access to task resources, but did not provide an opportunity to explore how groups would interact with artefacts that were visible to only a limited number of participants. Further, while Studies I and II provided an opportunity to explore the impact of personal devices that provide personalized input and output, functionalities established in the literature review in Chapter 3, the ability to transfer task artefacts between personal and shared devices has remained unexplored. The adoption of a new experimental task that incorporated both personal and shared artefacts would provide an opportunity to explore these questions.

In the final stage of this research a third empirical study is conducted which addresses these limitations and builds on the results obtained from analyses of data collected in Studies I and II. Study III is described in Chapter 8.

Chapter 8

Study III: The Role of Personal and Shared Devices in Collaborative Sensemaking

The analyses of the previous two studies provided important insights into how groups transitioned between working with personal and shared devices. In particular, personal devices were found to enhance group performance for cognitively demanding tasks, and the presence of a shared display facilitated the grounding of communication, monitoring, and synchronization of activities. However, Studies I and II focused on environments in which content is fixed to one device or another, and were limited to investigations of laptops and projected displays. In this chapter, these limitations are addressed through a study focused on the role of personal and shared devices in a new intellective task (sensemaking) in a more flexible collaborative environment (personal tablets and a shared table).

The role that personal and shared displays play in supporting a group's sensemaking activities are discussed. Quantitative analyses revealed that groups working with a shared, digital tabletop were able to perform significantly better at the sensemaking task. Further, qualitative analyses elucidate the activities performed by groups, and suggest sensemaking processes that were supported by the presence of the shared, digital tabletop. In particular, the digital tabletop facilitated the prioritization of task materials, the comparison of task materials, and the formation of tableaux that served to embody a group's working hypothesis. These activities are discussed in detail, and their utility in relation to the sensemaking process model is described.

8.1 Study Method

Before presenting the results of this study, its design is first discussed. In particular, the participants, experimental task, experimental conditions, setting, procedure, and data collection and analysis techniques are now described.

8.1.1 Participants

84 participants (51 male, 33 female) were recruited as 21 groups of 4. Participants ranged in age from 17 to 33 years old, with a average age of 22.6 years ($\sigma = 3.69$). Participants were predominantly Mathematics, Engineering, and Science students recruited on campus at the University of Waterloo. While the young, technically savvy student population was expected to have extensive experience with tablets, only 22/84 of the participants reported owning one, indicating that there was some novelty in having access to a tablet. Those participants who did report owning a tablet reported using them on a 'daily' or 'bi-daily' basis.

Groups of 4 were chosen for this study to provide opportunities to observe group process in larger groups than those in Studies I and II. The use of larger groups permits potentially more flexible process, as groups can divide their work amongst individuals, or even two pairs. Also, Ryall et al. (2004) have previously identified that artefact usage may change with group size when working with interactive tabletops and that while groups of 2 and 3 could orient task materials such that they were visible by all group members, groups of 4 were unable to do so. As digital tabletops were used in this study, recruiting groups of 4 provided an opportunity to observe groups working in a more challenging configuration for the management of task materials.

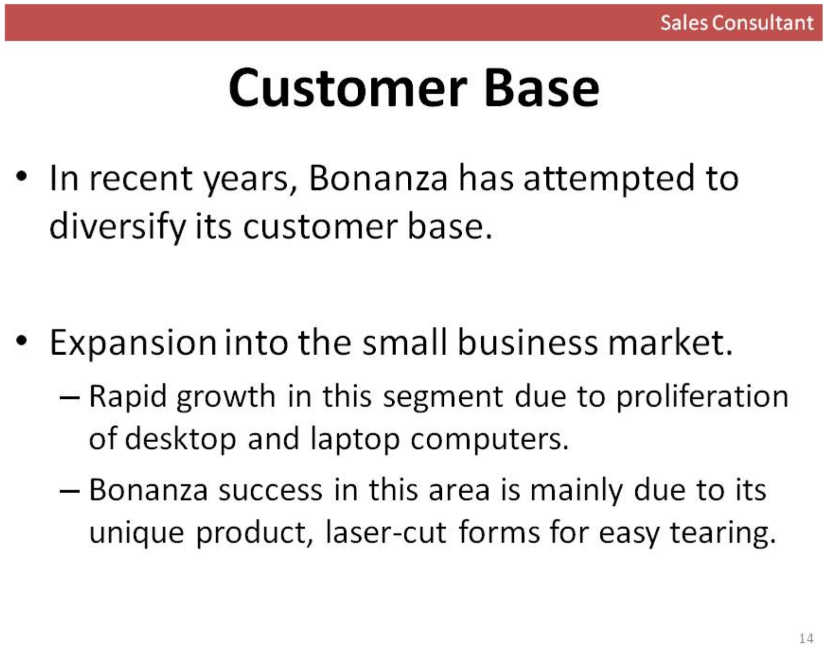
An effort was made to recruit groups of friends, however 3/21 groups were created from randomized individual participants. These 3 groups were balanced across each of the three experimental conditions, with one group participating in each. One group consisted of two pairs of friends, this group was assigned to the Tablets Only condition. The remaining groups were recruited as groups of 4, and previously knew each other, however for two of these groups one participant was absent and was replaced with an individual who did not know the other three participants. Both of these groups participated in the Table Only condition. Thus 15/21 groups who participated in this study consisted of individuals who signed up as a group and had known each other prior to the study.

8.1.2 The Bonanza Paper Forms Task

The Bonanza Paper Forms (BPF) Task is a collaborative sense-making task adapted by Gallupe & DeSanctis (1988) and Plaue & Stasko (2009) from a marketing textbook example (Jarvenpaa & Dickson, 1988). Participants play the role of consultants hired to determine why the fictional Bonanza Paper Forms company has experienced an increase in sales and a decline in profits over the past three financial quarters. To determine the cause of the company's financial difficulties, participants are provided with relevant economic, financial, operational, and company background data. The task is categorized as an intellective sensemaking task (McGrath, 1984; Plaue & Stasko, 2009), as participants are asked to 'make sense' of the data provided to them in order to discover a demonstrably correct solution to the Bonanza Paper Forms company's problem. While both the BPF task and the JSS task are classified as intellective tasks (McGrath, 1984), the BPF task provides an opportunity to understand how individuals work with unique task resources that must be shared across multiple displays, a property that the JSS task lacked.

The task design utilized by Plaue & Stasko (2009), which studied groups of 6, was adapted for use with groups of 4 participants for this study. Participants in each group were randomly assigned to one of four investigative roles: Sales Consultant, Advertising Consultant, Financial Consultant, and Domain Research Consultant. For this study, PowerPoint presentations were created that were similar to those utilized by Plaue & Stasko (2009), however graphs and data were redesigned to render appropriately on both the shared digital tabletop and personal tablets provided to participants. Information was provided to participants in the form of bulleted information, charts, and graphs. As the slides provided to each participant were unique, it was not possible for the group to determine the most correct solution without individuals sharing their personal information with the rest of the group. The number of slides provided to each participant also varied from 6-10, so not all participants had an equal amount of data with which to work. See Figure 8.1 for example slide data, a complete set of task materials is provided in Appendix C.6.

The insight-based evaluation scheme developed by Plaue & Stasko (2009) was adopted for this study to analyze a group's sensemaking performance. The eval-



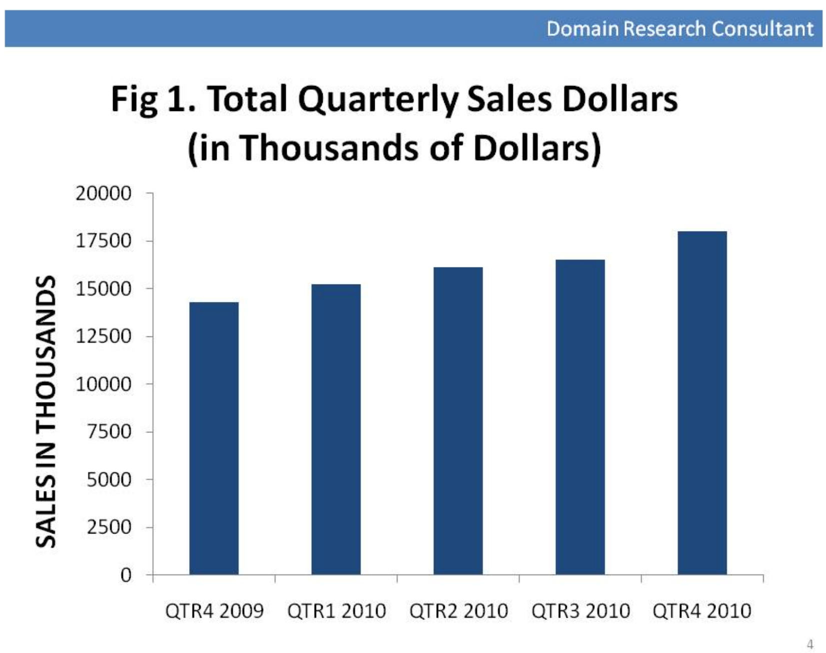


Figure 8.1: Example task materials. Task materials were based on those used by Plaue & Stasko (2009). In this study, legibility on both interactive table and tablet displays was an important design consideration, and thus text and graphics tended to be larger and more prominent than in previous work.

uation scheme consists of two performance measures: *key facts* and *insights*. Key facts are pieces of information contained on the slides provided to participants, whereas insights require groups to synthesize key facts to produce a new piece of information. In this respect, key facts can be considered a measure of the breadth of information that a group has explored, whereas insights measure the depth of the group's understanding of that information. An example of a key fact is "The current investigation points to a problem in marketing". An example insight requires a group to put the two key facts "Small business sales are profitable" and "Small business sales are low" to determine that "Small business sales are not contributing to the company's financial health". A list of 12 key facts and 5 insights was developed by Plaue & Stasko (2009) through an expert evaluation of the Bonazna Paper Forms Task by two individuals with formal business training, one expert held an MBA and the other was in the process of earning an MBA, and was used to evaluate group performance.

8.1.3 Experimental Design

To investigate the impact of display configuration on sensemaking, the study utilized a single between-subjects factor with 3 levels of control: *Tablets Only*, *Table Only*, and *Table Plus Tablets*. Groups of 4 completed the experimental task using one of the three display configurations, for a total of one session each.

Participants in the Tablets Only condition were seated around a physical table and interacted with task materials via tablets (Figure 8.3). The tablet software displayed a single slide at a time, and participants were able to move through their personal list of slides via forward and back buttons on the tablet. A pick-n-drop (Rekimoto, 1997) button on each tablet allowed participants to transfer slides between tablets. That is, participants were able 'pick' one slide up from their

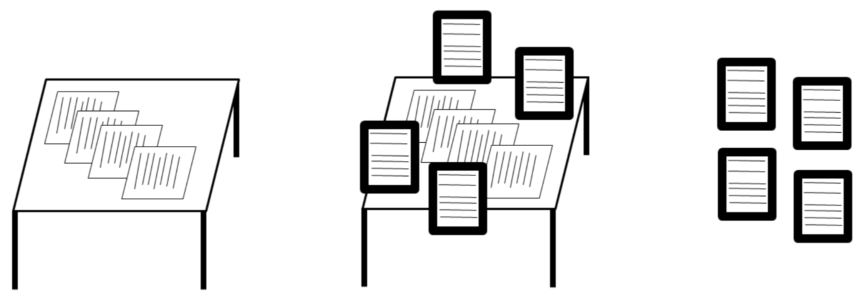


Figure 8.2: The Table Only condition (left), consisted of a single shared tabletop. The Table Plus Tablets condition (middle), consisted of the shared tabletop and four tablets, provided to each participant. The Tablets Only condition (right) consisted of only four tablets, and the shared digital tabletop (not shown) was disabled and provided only a physical workspace.

tablet via the pen button, and could then ‘drop’ that slide from their pen using the same button on another tablet. This pick-n-drop metaphor allowed for cut-and-paste functionality, not copy-and-paste, so each slide was always unique across all tablets.

Groups in the Table Only condition performed the Bonanza Paper Forms task with a shared, digital tabletop display. In this condition, to manage the each participant’s deck slides in the absense of a tablet, ‘virtual tablets’ were present on the digital tabletop (Figure 8.4). The virtual tablets emulated the tablets that were provided to groups in the Tablets Only conditions, and were designed to make the task of managing a slide deck more manageable on the table. As with the physical tablets, participants could iterate through slides on the virtual tablets, and a pick-n-drop metaphor allowed participants to move slides between the virtual tablets. However, unlike in the Tablets Only conditions, participants could also pick-n-drop slides from the virtual tablets onto space on the shared, digital table. Slides and virtual tablets on the digital table could be rotated and translated using the Rotate-and-Translate (RNT) metaphor (Kruger et al., 2005).

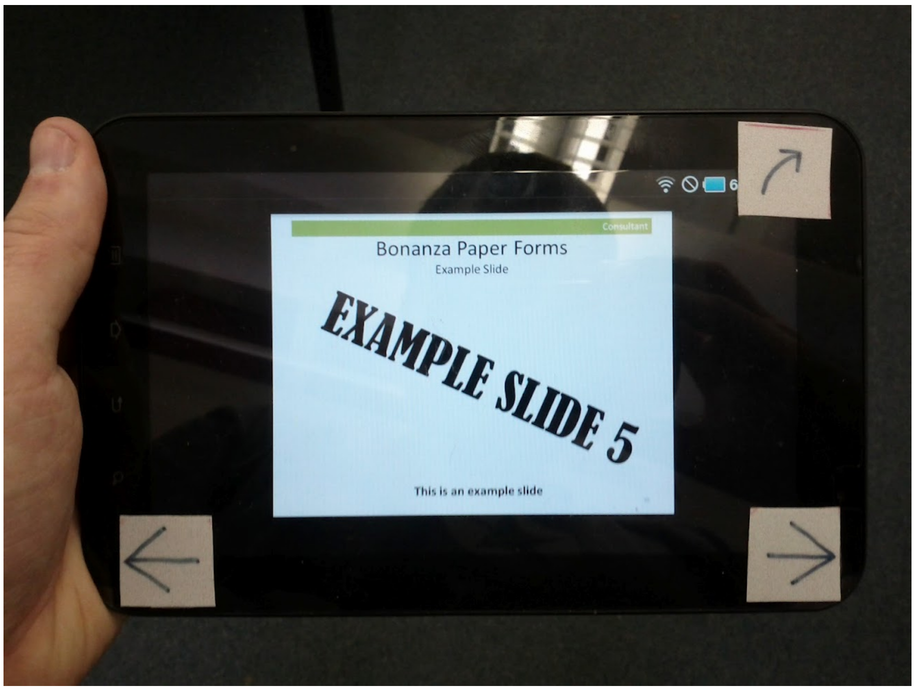


Figure 8.3: A tablet, as viewed in the Table Only and Table Plus Tablets conditions. Participants were able to iterate through slides via forward and back buttons (left/right arrows) in the lower corners of the tablet, or pick-n-drop slides between tablets and shared table space via the pen button in the upper right corner.

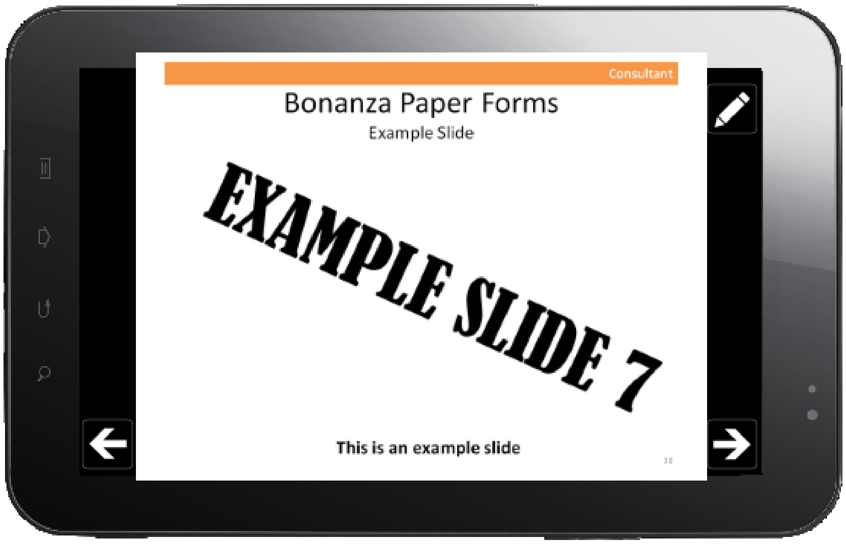


Figure 8.4: A "virtual tablet" as viewed in the Table Only condition. Participants were able to iterate through slides via forward and back buttons (left/right arrows) in the lower corners of the tablet, or pick-n-drop slides between tablets and shared table space via the pen button in the upper right corner.

Groups in the Table Plus Tablets conditions were allowed the use of both the shared, digital tabletop and their individual personal tablet devices. Virtual tablets were not provided to participants in these conditions, however participants were able to transfer content between the tablets and table using the pick-n-drop metaphor, as in the Table Only condition.

8.1.4 Setting

The study was conducted in a controlled laboratory on campus at the University of Waterloo (See Figure 8.5). Participants were seated on stools around a 80x120cm digital table that utilized Anoto pen technology (e.g. Haller et al., 2006) for user input. Two projectors, located above the table, output 1024x1536 pixels over an area of 57x82cm onto the table's surface. In conditions where tablets were available, participants were each provided a Samsung Galaxy Tab 7.1. The tablets were

Figure 8.5: While completing the Bonanza Paper Forms task, participants sat on stools around a shared digital tabletop display. For the Tablets Only conditions, participants sat around the same table, however the digital display was set to be inactive.

also outfitted with small pieces of Anoto paper at three of the four device corners to enable the pick-n-drop and slide navigation functionality, and custom software that enabled users to interact with both the table and tablet computers using the provided Anoto pen.

Software running on the shared digital tabletop was implemented in C#, and ran on an Intel Core 2 Duo system with 4GB RAM. Software running on the tablets was implemented using the Android SDK, and communicated with the tabletop server via a secured wireless local area network.

8.1.5 Procedure

After arriving at the laboratory and being greeted, participants individually completed an informed consent form and a background questionnaire that gathered demographic and collaborative work experience data (Appendix C.3). Participants were then introduced to the study software and given time as a group to familiarize themselves with its use and ask any clarifying questions about the interface. Participants then collaboratively completed the Bonanza Paper Forms task, and were given as much time as they required to come to a consensus. Before starting the experimental trial, groups were reminded to work towards the most correct solution they could find, in the shortest amount of time possible. After each trial, participants individually completed a post-trial questionnaire that gathered their opinions on the interface and their collaborative experience (Appendix C.4). Participants were each paid $10 for their participation in the study, with each member of the group who found the most correct solution in the least amount of time receiving a $20 bonus. Study sessions lasted approximately one hour.

8.1.6 Data Collection and Analysis

The experimental software was designed to facilitate the capture and analysis of multi-modal study data. As such, effort was taken to ensure that data was collected in realtime and recorded to a database over the local area network. Participant interactions with the study software were captured in computer logs. Since each participant used a different Anoto pen, the logs identified the participant who performed each action, in addition to which task materials were manipulated. Each participant wore a head-mounted Apex 570 microphone that logged voice data throughout the study to the same computer logs as the other interaction data. Microphone thresholds were calibrated on an individual basis prior to each session to ensure that microphones captured audio data exclusively from their wearer, as described by DiMicco (2005).

Analyses were conducted on solution quality, task efficiency, and equity of participation based on data logged to computer files. To analyse equity of participation for logged interaction and audio data, Gini Coefficients were computed for the number of pen interactions, and number of seconds in which participants were verbally communicating. One-way analysis of variance (ANOVA) statistical tests were conducted to examine differences between display conditions for the interaction data. Further, a correlational analysis was conducted on equity of participation data to investigate potential links to performance identified in the literature (Isenberg et al., 2010; Vogt et al., 2011). In particular, previous work (Isenberg et al., 2010; Vogt et al., 2011) has speculated that closely coupled work may positively correlate with improved performance for sensemaking tasks, the inclusion of equity of performance measures allowed for the investigation of such a correlation in this study.

Participants individually completed post-trial questionnaires. The questionnaires gathered participant opinions on the advantages and disadvantages of the task interface, their satisfaction with the task, and how well they felt the group performed. The questionnaire consisted of 7-point Likert scales, as well as open-ended questions that assessed their group experience and utility of the study hardware and software during the trial. Questionnaire data were analyzed using RM-ANOVA tests, with post-hoc pairwise comparisons made using the Bonferroni adjustment. All statistical tests used an alpha-value of .05, however results with an alpha-value between .05 and .10 were considered marginally significant.

Unlike Studies I and II, the video data were not transcribed and no conversational analysis was performed. Instead, communication efficiency analysis was conducted via recorded microphone data as described above. Similarly, due to the difficulty in accurately differentiating between whether participant gaze was directed at shared tabletops or the personal tablets, no analysis of physical deixis or gaze was performed. However, as in Studies I and II, the video, questionnaire, and interview data were reviewed to identify any interesting behavioural or conversational patterns and participant opinions.

8.2 Results

As with Studies I and II, quantitative taskwork and performance data are first reported before presenting a qualitative analysis of how digital tabletops and tablets were used to support a group's sensemaking process. An overview of performance and taskwork measures provided in Table 8.1, and an overview of teamwork measures provided in Table 8.2.

8.2.1 Taskwork and Performance

The 21 groups spent an average of 27.9 minutes exploring and discussing the slides before reaching consensus. However, the time it took for a group to reach consensus varied largely between groups, with the shortest time being 11.4 minutes and the longest time being 42.2 minutes. No significant differences between display conditions were found for task completion time ($F_{(2,18)} = .63, p = .543$), with groups working under the Table Only condition taking an average of 24.8 minutes ($\sigma = 544.04$) to complete the task, groups working under the Table Plus Tablets condition taking an average of 28.9 minutes ($\sigma = 560.387$) to complete the task, and groups working under the Tablets Only condition taking an average of 29.25 minutes ($\sigma = 406.35$) to complete the task.

While exploring the provided data slides, groups discussed an average of 6.5 key facts. No significant differences were found between display conditions for the number of key facts discussed ($F_{(2,18)} = 1.3, p = .296$). Groups working under the Table Only conditions discussed an average of 6.71 ($\sigma = 1.50$) key facts, groups working under Table Plus Tablets conditions discussed an average of 7.00 ($\sigma = 1.63$) key facts, and groups working under the Tablets Only conditions discussed an average of 5.86 ($\sigma = 0.90$) key facts. However, significant differences were found for the number of insights discussed ($F_{(2,18)} = 4.92, p = .019$), with groups in the Tablets Only condition ($\bar{x} = 0.714, \sigma = 0.83$) discussing significantly fewer insights than both those in the Table Only ($\bar{x} = 1.86, \sigma = 1.38, p < 0.05$) and those in the Table Plus Tablets ($\bar{x} = 1.86, \sigma = 1.51, p < 0.05$) display configurations. No significant difference was found between the Table Only and Table Plus Tablets display configurations ($p = 1.00$).

The amount of taskwork performed by individuals as they interacted with both the shared digital table and tablets was also analysed. No significant differences were found between display configurations for the average total number of pen interactions with the digital tabletop and tablets ($F_{(2,18)} = 2.5, p = 0.110$) between the display configurations. However, marginally significant differences were found for the average number of interactions on the shared table ($F_{(1,12)} = 3.63, p = 0.080$), with participants in the Table Only configuration ($\bar{x} = 295, \sigma = 187$) interacting with the table less on average than those in the Table Plus Tablets configuration ($\bar{x} = 483, \sigma = 183$). No shared table was present in the Tablets Only condition, so no comparison was made.

A significant difference was also found between display conditions for the number of tablet interactions ($F_{(2,18)} = 14.53, p = 0.001$), where participants in the Table Only ($\bar{x} = 238, \sigma = 67$) and Table Plus Tablets ($\bar{x} = 224, \sigma = 67$) conditions made significantly fewer interactions with the tablets than those in the Tablets Only configuration ($\bar{x} = 491, \sigma = 141.90$). No significant differences were found between the Table Only and Table Plus Tablets conditions ($p = 1.00$).

Table 8.1: Mean values and standard deviations (in parentheses) for performance and taskwork measures, and ANOVA results for comparisons between experimental conditions. Significant results denoted by **, marginally significant results denoted by *.

Condition	Measures							
	Solution Quality			Pen Interactions			Slides Placed	Voice
	Key Facts	Insights	Task Time (seconds)	Total	Shared Table	Tablet	on Table	Interactions
Table Only	6.71 (1.39)	1.86 (0.83)	1486 (544.04)	542.714 (170.091)	295 (187)	238 (67)	12.3 (5.93)	1796.29 (1056.41)
Table Plus Tablets	7 (1.51)	1.86 (0.83)	1734.29 (560.387)	707.8571 (210.8848)	483 (183)	224 (67)	18.4 (2.76)	2978 (847.2829)
Tablets Only	5.857 (0.83)	0.714 (0.451)	1755.571 (406.3478)	491.2857 (141.9041)	n/a	491.2857 (141.9041)	n/a	3067 (1571.991)
ANOVA Results	$F_{(2,18)} = 1.3$, $p = .296$	$F_{(2,18)} = 4.92$, $p = .019**$	$F_{(2,18)} = .63$, $p = .543$	$F_{(2,18)} = 2.5$, $p = .110$	$F_{(1,12)} = 3.63$, $p = .08*$	$F_{(2,18)} = 14.53$, $p = .0001**$	$F_{(1,12)} = 6.16$, $p = .029**$	$F_{(2,18)} = 2.11$, $p = .1502$

8.2.2 Teamwork

In order to investigate how the different types of devices were used by groups as they made sense of the data, the sharing of slides and devices between participants was also investigated. When the digital tabletop was available, groups placed an average of 15.4 slides on that display. However, groups in the Table Plus Tablets configuration ($\bar{x} = 18.4, \sigma = 2.76$) placed more slides onto the shared tabletop space than those in the Table Only conditions ($\bar{x} = 12.3, \sigma = 5.93$), a difference that was significant ($F_{(1,12)} = 6.16., p = 0.029$). For the Tablets Only configuration, no shared display space was available, and thus no comparison was made.

A comparison of the equity of shared table interactions, as defined by the Gini Coeffcient for all pen-based interactions on the table, revealed no significant differences between display conditions ($F_{(1,12)} = 2.27, p = 0.158$). Groups working under the Table Only conditions yielded Gini Coefficients equal to 0.478 ($\sigma = 0.0259$) on average, whereas groups working under the Table Plus Tablets conditions yielded Gini Coefficients equal to 0.444 ($\sigma = 0.478$) on average. Groups working under the Tablets Only conditions did not have a shared display with which to interact. However, a marginal difference was found for the equity of interactions made on the tablets ($F_{(2,18)} = 2.76, p = 0.090$), with the Tablets Only condition yielding more equitable participation ($\bar{x} = 0.410, \sigma = 0.042$) than the Table Only ($\bar{x} = 0.468, \sigma = 0.034$) and Table Plus Tablets ($\bar{x} = 0.451, \sigma = 0.063$) conditions.

Correlational analyses of equity of participation and overall group performance revealed two relationships. First, that equity of pen interactions on the shared table space was positively correlated with the number of key facts and insights discussed by groups ($r = 0.584, p = 0.02844$). Second, equity of interaction on the tablets was negatively correlated with the number of key facts and insights discussed by groups

Table 8.2: Mean values and standard deviations (in parentheses) for teamwork measures, and ANOVA results for comparisons between experimental conditions. Significant results denoted by **, marginally significant results denoted by *.

Condition	Measures			
	Equity of Participation			Average Number of Participants Who Interacted with each Tablet
	Shared Table	Tablet	Voice	
Table Only	.478 (.0259)	.468 (.031)	.499 (.0697)	1.68 (.703)
Table Plus Tablets	.444 (.0478)	.451 (.0585)	.493 (.0606)	1.32 (.319)
Tablets Only	N/A	.410 (.0384)	.476 (.0643)	2.857 (.350)
ANOVA Results	$F_{(1,12)} = 2.27$, $p = .158$	$F_{(2,18)} = 2.76$, $p = .090*$	$F_{(2,18)} = 0.21$, $p = .813$	$F_{(2,18)} = 16.16$, $p < .0001**$

$(r = -0.548, p = 0.0102)$. No significant correlation was found between the amount that individuals spoke and number of slides on their tablet ($r = 0.111$,$p = 0.4145$), or the number of interactions with their tablet ($r = 0.0367$, $p = 0.7882$).

However the analysis did investigate the degree to which tablets were shared in each display condition. A significant difference was found between display conditions for the number of participants who interacted with each tablet ($F_{(2,18)} = 16.16, p < 0.0001$). More participants in the Tablets Only condition interacted with each tablet ($\bar{x} = 2.86, \sigma = 0.377$) than those in the Table Only ($\bar{x} = 1.68, \sigma = 0.760$) or Table Plus Tablets ($\bar{x} = 1.32, \sigma = 0.345$) conditions. No significant difference was found between the Table Only and Table Plus Tablets configurations ($p = 0.223$).

For the post-session questionnaire, a significant difference was found for participant agreement with the statement "I felt it was easy to compare data between slides" ($F_{(2,18)} = 5.907, p = 0.011$), with participants in the Tablet Only configurations agreeing significantly less with the statement than those in the Table Only ($p = 0.016$) and Table Plus Tablets ($p = 0.04$) configurations. No significant differences were found between participant responses in the Table Only and Table Plus Tablets configurations ($p = 1.00$).

No significant differences were found between conditions for the amount ($F_{(2,18)} = 2.11, p = 0.1502$) or equity of voice interactions ($F_{(2,18)} = 0.21, p = 0.813$). Correlations between voice interactions and their interactions with task materials and overall performance were also investigated. No significant correlation was found between the equity of voice data and the number of key facts and insights discussed by the group ($p = 0.928$).

8.2.3 Qualitative Analyses of Personal and Shared Device Use

In order to more fully investigate how the table facilitated group discussion of the task information, a qualitative analysis of group information sharing activities was conducted. The analyses focused on the use of the shared digital tabletop and tablet computers, and found that three primary activities defined the sensemaking process for groups in this study: finding and bringing attention to relevant task information, making direct comparisons between slide information, and the formation of tableaux that describe the group's current understanding of the problem space. The results of this analysis are now presented, including a description of how the two devices supported these activities, beginning with the use of the shared, digital tabletop. A discussion follows that describes how these activities supported participant transitions between work phases in the sensemaking process model.

Sensemaking Process with Digital Tabletops

Post-hoc analysis of the sensemaking groups revealed 3 common activities. First, 11/14 groups with a digital tabletop display began by placing materials on the shared table space as they foraged through their personal slide deck. This placement of slides on the table established a pattern by which the shared space acted as a cache for the most relevant materials. Less relevant materials were relegated to the outside of the table, and materials that were deemed irrelevant were left on the tablets or pushed towards the outside of the table where their content was no longer visible. While most groups made this decision implicitly, without any verbal agreement, the process was verbalized by one participant to their collaborators in a Table Plus Tablets trial as "Anything important we should keep it on the table ... and once we rule it as insignificant, take it back."

Second, as materials were moved to the digital tabletop, participants were able to see and work with multiple slides at once. The digital tabletop's flexibility in manipulating digital artefacts played a role in facilitating both comparisons between slides and foraging through new materials. Participants frequently commandeered space for one activity, only to later clear and repurpose it for another. For one group, this flexibility was demonstrated in the evolution of how their workspace was partitioned throughout the trial. At the beginning of their session, individuals pulled slides from their tablets and placed single relevant slides directly in front of themselves to share with the group (Figure 8.6, top). As the table began to fill up, participants made comparisons on one side of the table, while leaving the rest of the table for storage space of potentially relevant materials (Figure 8.6, middle). By the end of their session, the group had formed a tableau that spanned nearly their entire workspace (Figure 8.6, bottom).

Finally, as participants progressed through the sensemaking task, the table's contents evolved into a tableau of the materials that each group viewed as most relevant to their decision making process. This tableau often served to form a group consensus, and to support the critique of working hypotheses. For one group, this process was triggered by a need to reduce the amount of clutter on the table. Like the group in Figure 8.6, individuals started by placing materials from their own tablets in front of themselves on the digital table (Figure 8.7, top). However, this group did not repurpose a section of the table for comparisons, and instead made comparisons on top of other slides, which some members found unwieldy to work with (Figure 8.7, middle). At this point, one participant made a request to reorganize task materials on the table, which led to the construction of a tableau for their final solution (Figure 8.7, bottom).

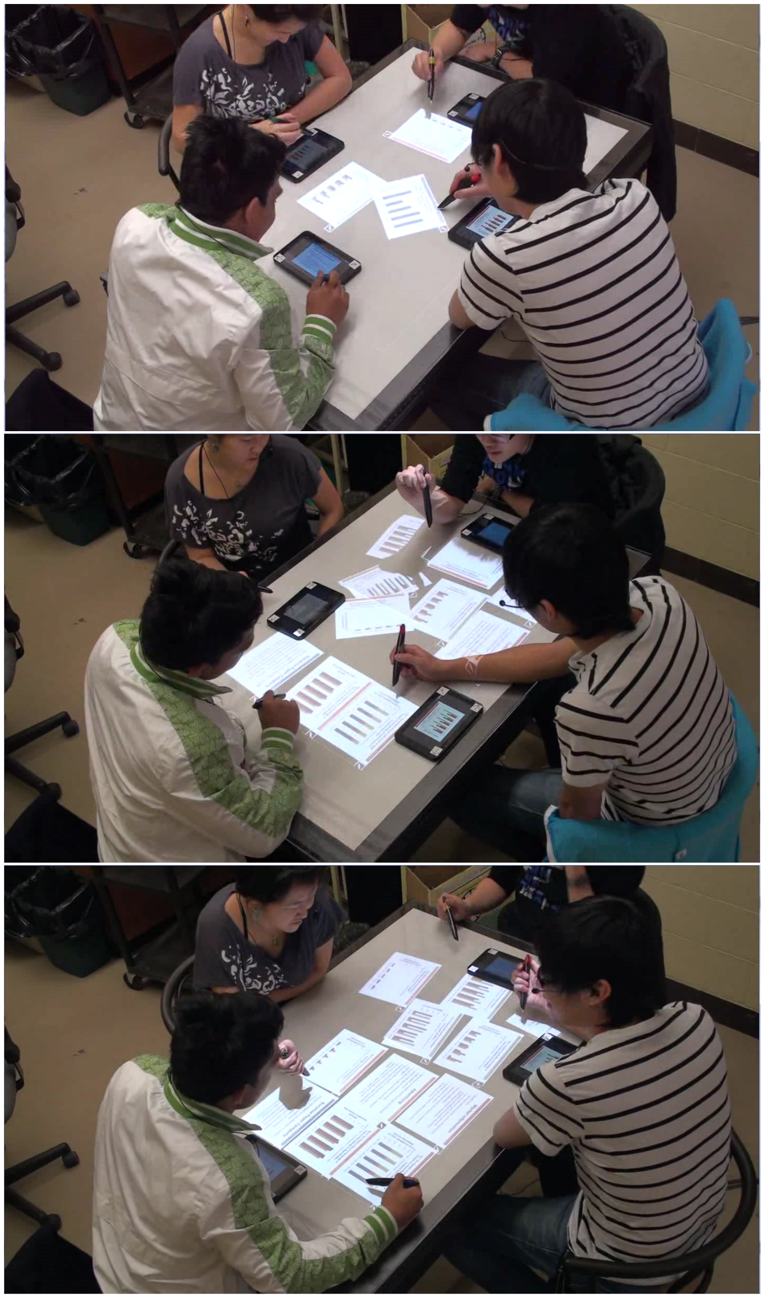


Figure 8.6: Participants utilized display space in a number of different ways, often repurposing that space as their sensemaking processes progressed. (top) Groups often started by sharing relevant slides with their collaborators on the shared surface. (middle) Groups would repurpose display space to facilitate the comparison of slides. (bottom) As groups shifted towards the end of the trial, a tableau was formed that encompassed the current understanding of the task materials.

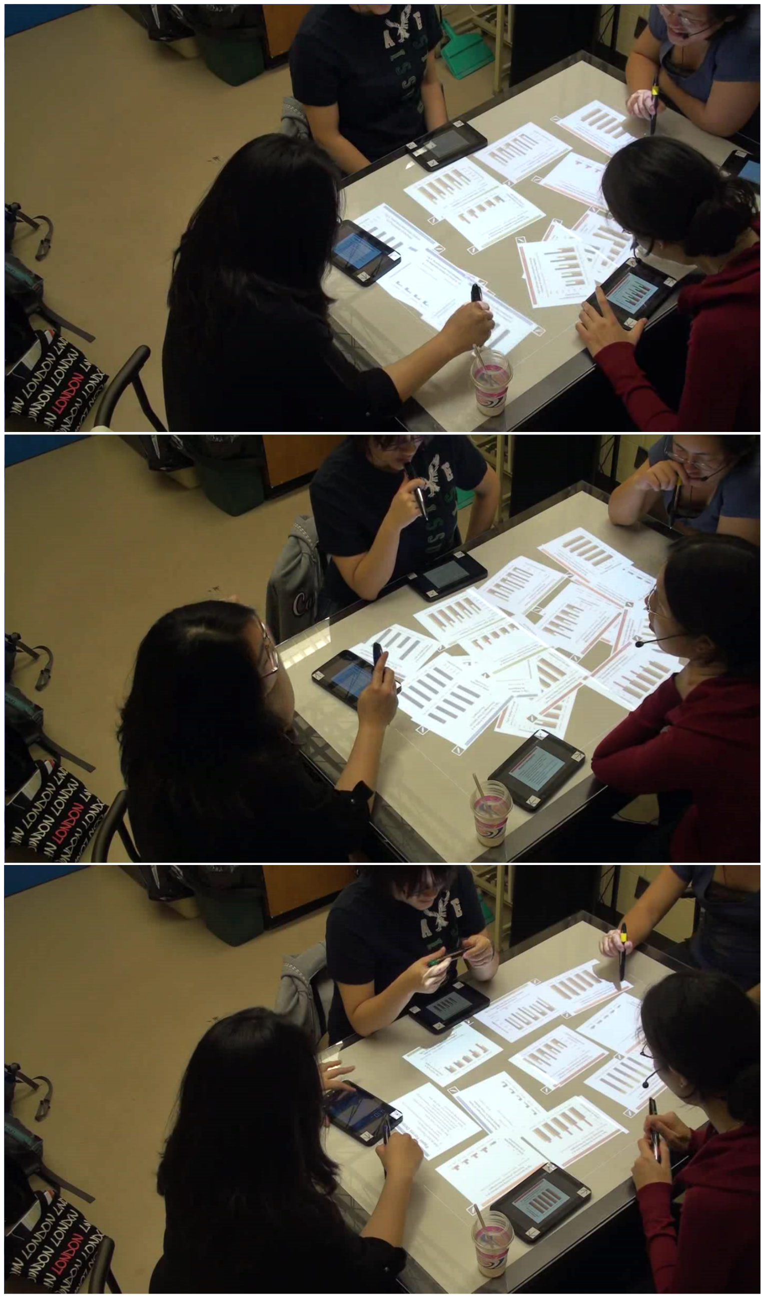


Figure 8.7: 1) participants pull important slides out from their decks individually. 2) Participants make sense of the slides collaboratively. 3) Once the table was too messy, the group tried to isolate the important slides and create a tableau which illustrated their final solution.

Sensemaking Process with Tablets

Groups working in the Tablets Only conditions were more limited in their ability to share and organize materials, but followed a three stage process that closely resembled the process groups utilized when the table was present. Participants started by exploring data on their personal tablets. However, as they were unable to set aside slides that they deemed relevant, participants offloaded much of the work of 'discovering' relevant information to a talk-aloud protocol. That is, participants would discuss slide content as they came across it, and then move on to viewing other slides on their tablets.

While comparing data between slides, participants used their tablets as shared, rather than personal, devices. This sharing was reflected in the quantitative analysis, where an average of 2.86 users ($\sigma = 0.350$) interacted with each tablet display in the Tablets Only conditions, compared to an average of 1.68 users ($\sigma = 0.703$) in the Table Only condition and an average of 1.32 users ($\sigma = 0.319$) in the Table Plus Tablets condition. Frequently, participants would push one or more tablets into the shared space in the middle of the table to compare slides. 4/7 groups went so far as to pass their tablets around the table, so that each participant had a chance to inspect the data on each tablet. In an extreme case (Figure 8.8, bottom), one group decided to move all relevant slides to a single tablet, and to discuss the data together via that tablet. The strategy of moving all task materials to a single tablet may have proven disadvantageous, as their performance was among the worst in the study. The group discussed only 5 key facts and 0 insights, tied for the worst performance out of all groups who participated in the study.

It was found that as the group progressed through the task, tablets fluidly transitioned between different regions of the table. A relationship was identified between

Figure 8.8: Participants reviewed materials individually on tablets placed near the edge of the shared table (top). Whereas, when discussing materials collectively, participants pushed the tablets in towards the centre of the table (middle), or in one case, moved task materials onto a single tablet that was placed in the middle of the table and viewed as a shared space (bottom). Viewing slides on a single tablet limited the group to viewing a single slide at a time when compared to the use of multiple tablets or the shared, digital tabletop, which facilitated the viewing and comparison of multiple slides.

participants' placement of their individual tablets towards the centre of the table and periods of closely coupled work. This placement of the tablets towards the centre of the table facilitated comparisons between adjacent tablets, much as did the placement of slides in the Table Only and Table Plus Tablets conditions. Conversely, when participants were reviewing task materials individually, tablets were typically placed towards the outside of the table, enabled individuals to review their task materials in a relatively sheltered work environment. These tablet placements appear to be associated with territoriality (Scott et al., 2004), where tablets placed in personal territories supported independent work, and tablets placed in shared territories supported collaborative work.

Finally, only 2/7 groups in the Tablets Only condition used a combination of tablets to explain their decision to the investigator at the end of their trial, and groups did not typically form tableaux as was observed in the other two conditions. Unlike the Table Only and Table Plus Tablets conditions, participants tended to either review slides on a single tablet, or recite the groups' working hypothesis from memory when explaining their rationale to the investigator at the end of their trial.

8.3 Discussion

Quantitative analyses revealed performance differences between display configurations, and suggest that the shared space on the tabletop supported several key behaviours. Subsequent qualitative analyses identified behaviours supported by the digital tabletop such as prioritizing, caching, and sharing important slides, making comparisons between multiple slides at once, and forming tableaux to synchronize the sensemaking process between group members that supported group teamwork and taskwork. Links between these qualitative and quantitative findings, with a focus on connections between performance and process, are now discussed. In particular, a focus is placed on how the shared display directly influenced the ability of groups to repurpose display space, and how equity of participation on the shared display influenced group performance by supporting sensemaking processes.

8.3.1 Performance Benefits of Shared Display Space

The quantitative and qualitative analyses revealed that providing groups a larger, shared workspace to complete the sensemaking task provided several advantages over personal displays alone. These results indicate that not only did groups perform better – discussing approximately 20% more insights when the tabletop display was present ($p = 0.019$) – but that individuals also perceived that data was more easily shared in these conditions ($p = 0.011$). Where related work has established that factors such as awareness (e.g. Sharoda & Madhu, 2010; Vogt et al., 2011) and persistence (e.g. Andrews et al., 2010) are important for supporting collaborative sensemaking, the qualitative analysis of group process in this study suggests that the shared display space facilitated three sensemaking activities: prioritization, comparisons, and the formation of tableaux.

Plaue & Stasko (2009), in a study of the Bonanza Paper Forms task, reported that participants using wall-mounted screens that could display a maximum of two slides at once overwhelmingly requested "more" display space. Plaue & Stasko (2009) cited that the projected displays they used did not allow the comparison of materials in a manner that fit the task. However, as their study was limited to at most two displays, they were unable to establish any bounds on the utility of the space. Comparisons between the Table Only and Table Plus Tablets conditions in our study provide some context for the bounds of these performance benefits. Participants in the Table Plus Tablets condition were able to work with more display space than those in the Table Only condition, and consequently shared more slides on average in the shared tabletop space ($p = 0.029$). However, despite this additional space to share slides, no significant performance differences were found between these conditions, indicating that additional display space may not provide additional benefits.

Moreover, the results indicate that the qualitative difference between digital tabletops and their vertical counterparts (i.e. the wall display studied in Plaue & Stasko (2009)) is an important distinction. That is, the ability to manipulate multiple slides on a single display, to establish spatial relationships between the data and users, and the positioning of the shared display in the transactional space between users all appeared to contribute to the digital tabletop's value in supporting sensemaking. Thus, while more display space may have better supported the task, an equally important question is what types of display space are useful to groups.

Plaue & Stasko (2009) reported that the use of whiteboard and secondary projected displays supported two group activities that were not observed in this study. First, displays were used to prioritize and organize content as the group made sense of the data. An important property of these displays is that they allowed groups to write notes, functionality that was not provided in this study. Second, participants were able to transition group discussion by setting up a new slide on an empty display, or on a display that had not recently been used for group discussion. The provision of such displays in their study may have also been beneficial to groups, and future studies of collaborative environments may benefit from a richer understanding of when these displays provide the most utility to sensemaking groups.

8.3.2 Repurposing Display Space

Regardless of their display condition, all groups repurposed display space regularly throughout their trial. The shared digital tabletop supported the repurposing of space through the flexibility provided by the pick-n-drop (Rekimoto, 1997) and rotate-and-translate (Kruger et al., 2005) metaphors. On the other hand, even though groups in the Tablets Only conditions had a more restrictive display space to work within, the flexibility of the hardware allowed groups to seamlessly transition between different modes of work. This analysis of group process suggests the importance of providing flexible, repurposable workspaces for groups when supporting collaborative sensemaking activities. These results are consistent with the recommendations of Isenberg et al. (2010) to support transitions between collaborative coupling styles (discussed in Chapter 3), and of Jetter et al. (2011) to support low viscosity interaction.

It has been argued that a challenge facing the development of single display groupware is clutter (Stewart, 1997; Wigdor et al., 2009; Yi et al., 2008). That is, as groups work with many artefacts in a shared space, overhead from working with those artefacts may be detrimental to the group's performance. While some evidence collected during this study supports this claim, and in particular the group mentioned in Section 8.2.3 who reorganized their table space to reduce clutter, post-condition questionnaire responses do not suggest that participants perceived that clutter impacted their ability to perform the task. Overall, groups rated their agreement with the statement "I felt that we had enough space to share documents" with an average of 4.4/7 and an average of 4.9/7 for the statement "I felt the tools we were given to solve the problem were enough". No differences were found between display conditions. These responses were neither overwhelmingly positive or negative, but can be interpreted as suggesting that the provided tools were adequate for the sensemaking task, even though they were rudimentary and did not include interaction techniques that allowed participants to manage multiple slides at once.

The presence of shared task artefacts on the tabletop, and the ability of participants to continuously repurpose that space, enabled the discovery of task materials. It also enabled groups to engage and transition between individual and group work fluidly. The sensemaking model utilized by this dissertation involves four phases of work: overview, adjust, detect pattern, and match mental model as described in Chapter 2. However this process is not linear, and effective sensemakers often will transition between the different phases of work at seemingly random times, for often unknown reasons. Isenberg et al. (2008) argue that sensemaking support tools need to support flexible temporal sequences of work process. Observational data collected in Study III supports this theory, and further, suggests that providing simple, lightweight tools that may allow for a cluttered interface, but can adapt to their users, is an appropriate design for sensemaking tasks.

8.3.3 Equity of Participation and Sensemaking

There is a growing consensus that for sensemaking tasks, closely coupled participation is associated with more effective performance (Isenberg et al., 2010; Vogt et al., 2011). The analyses of equity of participation supports this hypothesis, and more equitable participation on the shared portions of the tabletop display correlated with the a higher number of key facts and insights discussed by a group ($p = .028$). Furthermore, no correlation was found between the amount of interaction on the shared tabletop and the number of key facts and insights discussed. Thus, while the previous section discussed the benefits provided by the shared table, the study results also suggest that *how* it is used by the group is important.

Moreover, when looking at interactions on the tablets, these results indicate a *negative* correlation between equity of tablet interactions and the number of key facts and insights discussed by groups ($p = .028$). That is, more equal interaction on the tablets by participants, regardless of which tablets they interacted with, was associated with decreased group performance. These results are, at least in part, explained by the unequal distribution of task materials; in order for groups to fully explore the task materials, an unequal amount of participation was required across each tablet. However, in the Tablet Only conditions, which were those in which insights were discussed the least, the tablets were shared to a much higher degree than they were in the other conditions, which in theory negates the impact of the unequal distribution of task materials. With these considerations in mind, further investigation is required to understand if there is a duality between these two results: increased equity in shared space mirrors decreased equity in personal space, and both correlate with improved collaborative outcomes.

Finally, the utility of equity of participation measures in these analyses warrants further investigation into the use of this measure in the future. These results have demonstrated that Gini coefficients as a measure of equity may correlate with the trends of "closely coupled" collaboration described by Vogt et al. (2011) and Isenberg et al. (2010), but do not rely on time consuming video analysis or the subjectivity of inter-coder reliability. Thus, this approach may be useful as a rapid analysis technique for future studies, but requires further development before results can be interpreted fully by experimenters.

8.3.4 Sensemaking Process Model

This study provided an opportunity to investigate the activities involved with transitioning between phases in the sensemaking process model through the lens of teamwork and taskwork. In particular, qualitative analyses revealed that the shared digital table in the Table Only and Table Plus Tablets conditions seemed to support some activities that were not supported in the Tablets Only condition. In particular, three activities identified in this study appear to support transitions between different modes of work in the sensemaking process model (Figure 8.9). First, the ability of participants to prioritize materials on the shared tabletop appears to assist in transitions between 'overview' and 'adjust' phases of work. This prioritization allowed participants to filter task materials, and focus on understanding the most interesting and relevant materials in detail. Second, the ability to manipulate and compare multiple slides at once appears to support the ability of participants to detect patterns in task materials. And third, as tableaux are formed, so are active hypotheses, facilitating the transition between 'detect pattern' and 'match mental model' phases of work.

An important difference between the use of shared displays in Studies I and II and the use observed in this study is that in the previous two studies, teamwork and taskwork intentions were more explicit. That is, gestures or glances towards shared displays in Studies I and II tended to be categorized as either serving teamwork or taskwork. The activities observed in this study appeared to serve both functions. For example, a tableaux might aid a single user in organizing their thoughts, but also communicated to others what the active hypothesis was, and facilitated the questioning of one participant's active hypothesis by the others. This lack of explicitness is tied to the mobility of task materials. In Studies I and II, content was replicated across all displays. Whereas in Study III, only one copy of each slide existed in the task at once, and participants tended to move task materials into shared space to support group interactions with the shared material. The analyses of interactions in this study built on analyses of Studies I and II, and further de-

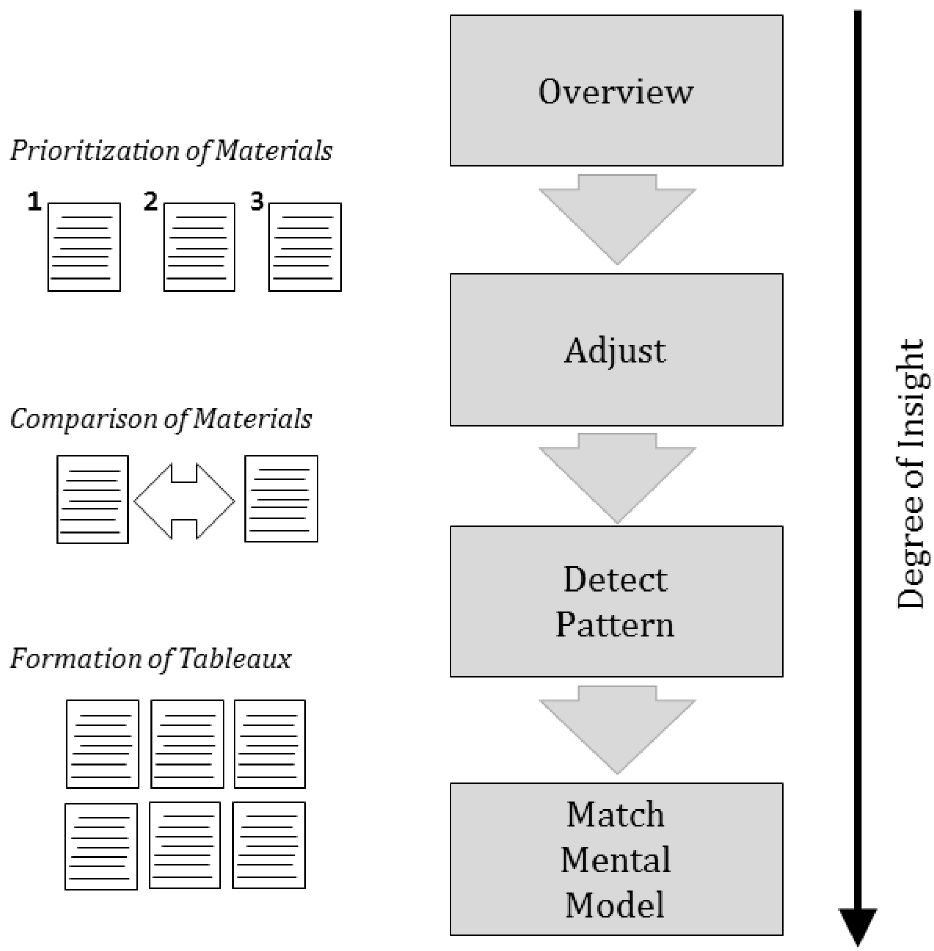


Figure 8.9: Participants in Study III appeared to perform tasks on the digital tabletop that supported transitions between working modes in the sensemaking process model by Yi et al. (2008). In particular, an individual's prioritization of task materials appeared to support transitions between 'overview' and 'adjust' processes. The ability to fluidly compare materials assisted individuals as they moved from 'adjust' to 'detect pattern' modes of work. And the formation of tableaux aided in forming active hypotheses, and transitioning between the 'detect pattern' and 'match mental model' modes of work.

veloped an understanding of how teamwork and taskwork are supported by shared displays.

8.4 Summary

Study III has revealed key differences between the performance and process of groups performing a sensemaking task. The mixed-methods approach allowed for the exploration of performance benefits provided by tabletop displays to sensemaking groups. The primary contribution of the analyses presented in this chapter was that the shared table facilitated the prioritization, discussion, and synthesis of task materials, and that this support led to a significant performance difference ($p = 0.019$). Qualitative analysis of use of both the digital table and tablets underlined the importance of repurposable display space, and revealed how the ability to repurpose space aided group process. Finally, a positive correlation was found between equity of participation on the shared table space and task performance ($p = .02844$), and a negative correlation was found between equity of participation on the tablets and group performance ($p = .0102$). These correlations may be useful in future studies of collaborative work, to build on a growing consensus that equity of participation may be an important measure when evaluating collaborative groupware.

Chapters 6, 7, and 8 have presented empirical studies of technology and its support for collaborative performance and process. The analyses of data collected during these studies, and their implications for the use of technology to support group work are now discussed. In particular, four primary contributions are discussed: establishing performance differences based on the presence of personal and shared devices, identifying transitionary activities between shared and personal devices that contribute to group communication, coordination, and awareness, and methodological improvements that were developed over the course of this investigation.

Chapter 9

Personal and Shared Devices

In Chapters 1 and 3 of this dissertation, three questions were raised about the impact of personal and shared devices on collaborative process. The literature review in Chapter 3 concluded with an important question: If group process is seldom consciously determined and is influenced by a number of tacit factors that can significantly impact a group's performance, could the technology used by collaborators also tacitly impact their process and performance? In Chapter 1, two related questions were raised about the use of personal and shared devices. First, what are the relative strengths and weaknesses of personal and shared devices? And second, how should these devices be used together to support collaborative work? The contribution that this dissertation makes towards answering these three questions is now discussed. In answering these questions, empirical data collected in Studies I, II, and III is interpreted, and considerations for the design of collaborative environments are discussed. In particular, the impact of personal and shared devices on performance and process are discussed, in addition to how this impact may influence the appropriateness of alternative hardware and software choices for collaborative environments.

9.1 Influence on Performance and Process

The central premise of this dissertation is that the personal and shared devices that a group uses to solve a collaborative task influence its process and performance. While the literature has identified instances where personal and shared devices may influence an individual's performance, such as in affecting participant motivations or trust (e.g. Birnholtz et al., 2007; Nguyen & Canny, 2007), understanding how this impact is linked to performance and process is an emerging area of study. This dissertation builds on previous work, such as Plaue & Stasko (2009), to carefully examine the impact of personal and shared devices on the teamwork and taskwork performed by groups. Analyses of the three studies presented in this dissertation identify cases where both group performance and process can be impacted by the devices provided to a group.

Studies I and III found that the choice of personal and shared devices can significantly impact group performance. In Study I, the presence of personal displays was found to provide a sheltered workspace that supported individual work during the JSS task, improving group performance ($p = 0.025$). In Study III, the presence of a shared, digital table was found to improve a group's ability to make logical inferences between task materials ($p = 0.019$). Groups provided with the shared digital table performed approximately 20% better than those without. These results demonstrate the potential advantages of providing groups appropriate technological support for intellective tasks, and may help to justify the additional monetary cost of an additional shared, large-screen display. For example, in an office environment where knowledge workers are expected to perform sensemaking tasks the potential improvement in group performance may justify the additional cost of deploying a shared device.

Moreover, qualitative analyses conducted for each of the studies illustrate how the use of personal and shared devices influences group process. In Study I, the improved performance afforded by personal displays came at the cost of reduced coordination between group members. Qualitative analyses of group work in that study identified participants shifting between 'overview' and 'adjust' phases of work, where individuals adjusted task materials primarily on their personal displays. This focus on personal displays reduced a group's ability to effectively coordinate their activities ($p = 0.016$), and prompted Study II which investigated the role that shared displays play in supporting group work in MDG settings. Qualitative analyses in Study II identified collaborative activities that were supported by shared displays, and in particular, differences in how status displays and shared workspace displays were used by groups. In particular, participants monitored status displays more frequently than shared workspaces ($p = 0.004$), but used shared workspaces to ground conversation with collaborators who were engrossed in individual work on their personal displays. The physical presence of a shared display was also found to aid in synchronizing activity in both display conditions. Finally, analyses of group work in Study III identified sensemaking activities that were supported by the shared, digital table such as prioritization of task materials and the formation of tableaux. These activities were associated with phases of work in the sensemaking process model, and helped to explain the performance differences identified between groups working with and without a shared, digital tabletop.

The literature review in Chapter 3 cited research by Hackman et al. (1976) and Wittenbaum et al. (1998) that asserts that while the processes utilized by groups in performing collaborative tasks can significantly impact performance, these processes used by a group are also rarely a conscious decision. They further assert that many tacit factors, such as the social or cultural contexts in which groups are working, may influence the processes adopted by groups. These assertions lead to the question of whether personal and shared devices might also tacitly impact group performance and process. Evidence collected in Studies I, II, and III described above builds on previous work to identify cases where personal and shared devices impact group performance and process. Throughout the studies presented in this dissertation, groups rarely discussed how to use the provided technologies to solve their experimental task[1], lending credit to the claim that the use of technologies is rarely a conscious choice made by groups. The rarity of these decisions helps to emphasize the need to understand potential benefits of deploying personal and shared devices, as the choice of devices provided to groups may help shape their collaborative process.

9.2 Device Considerations

A trade-off between supporting individual task activities and group awareness has been previously identified in the CSCW literature for single-display groupware (Gutwin & Greenberg, 1998). That is, when designing SDG interfaces there is an implicit trade-off between providing powerful interaction techniques for individual users and creating a groupware interface that facilitates group awareness. For example, a group working on a shared document together via a traditional UNIX command-line interface might have access to a wide variety of powerful commands through keyboard shortcuts, but the use of those shortcuts would reduce a collaborator's ability to maintain awareness of the changes to the document. On the other hand, groups working with a graphical text editor might be more aware of the ac-

[1]While conversations regarding the use of technologies were not explicitly coded for, they were rarely noted in investigator's field notes. Only twice is evidence of such discussions presented in this dissertation, both in Section 8.2.3. First, a group in Study III, working under the Table Plus Tablets condition, discussed how they would prioritize task materials on the shared, digital tabletop. Second, a group in Study III working under the Tablets Only condition discussed placing all relevant task materials onto a single, shared tablet.

tions taken to change a document, through monitoring of the mouse cursor and its interactions with the menu system, but the constraint of working via mouse may reduce an individual's task efficiency. The degree to which this trade-off is present in MDG groupware is still an open question. One might hypothesize that by using personal devices designed to support individual interactions with shared devices designed to support group awareness, both group activity and individual interactions could be effectively supported. In the example above, it might be possible to alleviate the trade-off between awareness and individual work by providing both laptops with access to the UNIX command-line, and a shared, projected display that conveys status information to groups.

However, analyses from Studies I and II suggest that augmenting SDG with personal displays comes with the risk of reducing an individual's awareness of their collaborators' activities. In those studies, personal devices were found to provide a workspace that enabled participants to focus on the JSS task and 'adjust' task materials. The introduction of those devices improved group performance ($p = 0.016$), however reduced the effectiveness with which groups could coordinate their activities ($p = 0.025$), mirroring the trade-off identified for SDG systems. These results suggest that in settings where shared devices serve as secondary displays, it may be difficult to enhance group awareness and task performance simultaneously. That is, providing displays that support both awareness and individual interactions may not provide optimal support for both types of activities. However, results from Study III suggest that benefits may arise when task materials are transferred between personal and shared devices.

In Study III, the shared display was shown to improve group performance for the sensemaking task ($p = 0.019$). Qualitative analyses of group work in this study revealed that as participants moved task materials from their personal devices onto the shared digital tabletop, that the placement of those materials conveyed information regarding their priority and the group's working hypotheses. These activities are examples of "consequential communication" or "feedthrough" (Gutwin & Greenberg, 2000), as the activities of one group member implicitly provided awareness to their collaborators. The analyses also revealed a positive correlation between equitable participation on the shared display and group performance ($p = 0.028$), and a negative correlation between equitable participation on personal devices and group performance ($p = 0.0102$). These analyses may suggest that more equitable participation on the shared tabletop display provides more opportunity for consequential communication to take place, and more equitable participation on personal devices may reduce opportunities for consequential communication. As the placement of task materials supported a group's sensemaking process, for example through the prioritization of task materials and formation of tableaux, the presence of the shared display, and its equitable use, can be linked to improved group performance.

These results suggest that in order to design appropriate support for groups, a detailed understanding of the processes they are likely to use, and how to appropriately support both teamwork and taskwork, is required. For example, if designing a collaborative environment in which group coordination is critical the introduction of personal devices may be inappropriate or ineffective. On the other hand, for settings where improved group performance is important and coordination may be less critical the introduction of personal devices may be an appropriate design choice. However, the literature offers relatively little advice on how to appropriately design for these tasks. For example, Yi et al. (2008) suggests how taskwork may be supported, but does not reflect the teamwork needs of a group. More broadly, the task circumplex in McGrath (1984) categorizes tasks according to their cognitive vs behavioural, and cooperative vs. competitive requirements, but does not provide any indication of the potential processes used by groups.

Thus, analyses of the studies presented in this dissertation offer no panacea. Instead, they suggest that understanding the strengths and weaknesses of personal and shared devices is an important issue for the design of collaborative environments that warrants further investigation. The two tasks studied in this dissertation fall under the same intellective category in the framework proposed by McGrath (1984), and yet the types of devices that offered the most optimal support differed in these studies. The provision of personal devices that enhance individual's taskwork at the expense of less effective teamwork in Studies I and II may not always be an appropriate design choice. Similarly, understanding when a shared display will more appropriately offer support as a shared workspace or status display is an open question. These differences suggest that the activities that are supported by personal and shared devices identified in this dissertation are only a starting point, and that future work should refine an understanding of the teamwork and taskwork performed by groups, and how personal and shared devices can support that work.

9.3 Software Considerations

Finally, in addition to understanding when to provide personal or shared devices to a group, understanding the appropriate type of interconnectivity between them is also an important consideration. In Chapter 3, three relationships between personal and shared devices were identified: personal devices that enable input to a shared workspace, personal devices that provide output from a shared workspace (i.e. 'lenses'), and supporting both personal and shared workspaces. The results presented in this dissertation illustrate an interesting contrast in the type of support that these relationships provide to groups.

In Studies I and II, an automatically 'synchronized' view of the workspace was provided across personal and shared devices. That is, no work was required on the participants part to maintain an up-to-date view of the shared task resources on either their personal or shared displays. Analyses of group process revealed that the presence of the shared display in these studies supported monitoring, communication grounding, and the synchronization of activities amongst group members. On the other hand, analyses of group processes in Study III found that participants' manipulation of task materials between personal and shared displays was also useful for coordinating group activities. The manual placement of task materials on the shared display supported the prioritization of task materials, and contributed to focusing group resources and navigating the problem space, suggesting that automating aspects of managing task artefacts may degrade some aspects of the group performance. For example, techniques that 'spill' (Olsen et al., 2007) materials from a personal device into a shared workspace should be used with caution, as they may deny participants such opportunities to arrange task materials.

Thus, settings were observed where both 'automatic' and 'manual' management of shared workspaces supported group process, raising the question of when one design is more appropriate than the other. Currently, there is a lack of guidance in the literature as to when one technique may be appropriate over another. Research presented in the literature may focus on the technical feasibility and implementation of interaction techniques (e.g. Nacenta et al., 2007b; Olsen et al., 2007; Wallace et al., 2006), but does not ground the use of these techniques in user behaviour. The activities identified in this dissertation provide some initial guidance for designers. For example, in supporting sensemaking tasks where the spatial relationships between task materials may convey information to collaborators, a pick-n-drop metaphor may be appropriate. Similarly, for optimization tasks, providing a shared display that is automatically synchronized between displays may be more appropriate.

9.4 Summary

This chapter has summarized findings from the three empirical studies presented in Chapters 6, 7, and 8, and in doing so, has provided answers to three questions posed at the beginning of this dissertation. First, that this dissertation has provided evidence that personal and shared devices can tacitly impact group performance and process. Second, considerations regarding the deployment of personal and shared devices have been identified. And third, that through an understanding of the collaborative activities supported by devices, considerations for interconnectivity between personal and shared devices have been identified. In Chapter 10, the four primary contributions of this dissertation are summarized, limitations of the methodology are addressed, and opportunities for future research are identified.

Chapter 10

Conclusions

In this dissertation the impact of personal and shared devices on collaborative work was investigated through a series of three empirical studies. While the literature has explored field studies of individual prototypes (e.g. Biehl et al., 2007; Greenberg & Rounding, 2001), comparative studies of how alternative devices support group work have been limited. For example, Plaue & Stasko (2009) compared group work with different numbers and placements of shared displays, and focused on shared displays and the insight-based performance metrics we used in Study III. Similarly, while a controlled study by Birnholtz et al. (2007) suggests that the availability of individual input devices may impact user likelihood of acting in self interest, a description of how individual and group work practices are impacted by these devices is lacking. Unlike previous work, these studies have considered the impact of personal and shared devices on performance with the teamwork and taskwork performed by groups. The analyses of data collected during these studies and their implications for the use of technology to support group work are now discussed.

Studies I and II investigated how shared displays impacted teamwork and taskwork as groups solved a collaborative optimization task. Study I revealed that multi-display configurations improved group performance at the expense of coordination and awareness of group member activities ($p = 0.025$, $p= 0.016$). It was observed that when personal displays were present, individuals rarely looked at the shared display, and implications for participant comfort and ability to communicate were identified. Study II was conducted to follow-up on these identified issues, and to more closely investigate how the shared display supports teamwork and taskwork. Study II compared the use of status displays and shared workspaces, and revealed that these displays support monitoring, communication grounding, and group synchronization. Findings from this study, interpreted in coordination with the results of Study I, highlighted the importance of spatial relationships between displays, and discussed how these behaviours help to support group communication, awareness, and coordination. The ability of participants to interact with a shared workspace, even when personal displays replicated all task content, was useful in supporting group work. And the presence of a shared display in this study, regardless of whether it was a status display or a shared workspace, appears to have been beneficial in synchronizing group activity.

Study III continued the investigation of how personal and shared devices support collaborative work by conducting a controlled experiment where participants completed a second intellective task, the Bonanza Paper Forms task. The use of this task in Study III allowed for the study of collaboration where previously identified behaviours could be studied in an environment where task artefacts were transferred between personal and shared spaces. In particular, groups performed the collaborative sensemaking task under three conditions: with a shared, digital table, a shared, digital table plus personal tablets, or with only personal tablets.

Groups who were provided with the shared, digital table formed more logistical inferences between task materials (p=0.019). Moreover, analyses revealed that providing groups a tabletop shared device supported key sensemaking activities through the ability to prioritize the sharing of task materials, to make comparisons between task materials, and to form working hypotheses for the task in a shared space.

10.1 Contributions

This dissertation provides four primary contributions to the field of CSCW: 1) establishing performance differences based on the presence of personal and shared devices; 2) identifying teamwork and activities supported by personal and shared devices; 3) a correlation between equity of participation and task performance; and 4) methodological improvements that were developed over the course of this investigation. Each of these contributions will now be summarized.

10.1.1 Trade-offs between Process and Performance

The research presented in this dissertation identfied the impact that shared and personal displays had on group performance. In Study I (Chapter 6), it was found that the cognitively sheltered workspaces afforded by the personal laptop displays enhanced group performance for the Job Shop Scheduling task (p = 0.025). In Study III (Chapter 8), it was found that the shared table enhanced group sensemaking activities, and in particular improved the ability to make inferential links between data (p=0.019). These results indicate that there are potentially significant performance benefits to understanding how and when to deploy certain devices for collaborative work. For example, the provision of a sheltered workspace for cognitively demanding tasks may improve group performance. Similarly, for a sensemaking task it was found that the presence of a tabletop display significantly improved a group's ability to make logical inferences between task materials.

Qualitative analyses also identified activities that were supported by personal and shared devices. Observations in Study I (Chapter 6) suggest that individuals may experience difficulty communicating with team members when personal devices are present, as physical deixis may be directed at personal displays that are not visible to their collaborators. Study II (Chapter 7) investigated different uses for shared devices, shared workspace and status displays, and identified positive benefits of shared devices that may enhance a group's ability to monitor, ground communication, and synchronize activities. Study III (Chapter 8) identified uses of shared digital tabletops and personal tablets that facilitated group sensemaking processes. In particular, it was observed that the shared table space enabled users to cache and compare task materials, which aided participants in prioritizing work and in the formation of tableaux. These behaviours aided in the formation of collective hypotheses and arriving at consensus. These observational results suggest potential usability issues that may be considered when designing collaborative environments, and areas for future investigation. For example, in cases where communication between collaborators is an important design consideration, it may be wise to only provide shared devices to groups to reduce the possibility that individuals may utilize physical deixis on personal devices. Similarly, the use of shared devices to facilitate many identified activities in these studies, despite the presence of personal displays, provides evidence that their presence may be justified in certain contexts despite the additional costs, software development, and physical space required by their presence.

On the other hand, certain risks may be connected with the deployment of personal and shared devices. In Study I, it was found that when personal devices were present groups conflicted with one another more often when working on the task (0.016). In Study III, the negative correlation found between equity of participation via personal devices and sensemaking performance ($p = 0.0102$) suggest that care should be taken when providing groups personal devices. Similarly, the literature suggests that the devices present in a workplace may impact a user's likelihood to act in self interest (Birnholtz et al., 2007), a user's learning processes (Piper & Hollan, 2009), and ability to trust (Nguyen & Canny, 2007). These risks suggest that caution should be taken when deploying new technologies to a working environment, as they may have unforeseen side effects that may impact a group's ability to function.

Comparisons of alternative technologies to support group work, such as those presented in this dissertation, are a timely contribution to the literature. Never before have new devices been deployed into critical environments at such a rate as they are today, with such a lack of understanding of the role these devices play within the overall ecology. The rate of adoption of these devices is growing, for example, businesses in the United States and United Kingdom are expected to double their spending on mobile devices to an average of £590,000 by 2013 (Swann, 2012). In the past year, mobile technologies have been adopted in working environments as diverse as classrooms and cockpits (Harcourt, 2012; McGarry, 2012; United Continental Holdings Inc, 2011). The deployment of personal devices to high-impact working environments such as military and commercial cockpits is also already in progress (McGarry, 2012; United Continental Holdings Inc, 2011). The benefits and risks tied to the adoption of these technologies identified in this dissertation provide evidence that these choices may impact a group's ability to perform, and that the devices that are deployed should be carefully considered.

10.1.2 Activities Supported by Personal and Shared Devices

Throughout this dissertation, the sensemaking process model provided a useful theory for understanding how activities fit together to support the overall group process. Study I identified ‘overview’ and ‘adjust’ activities as being tied to shared and personal devices, respectively. Study II investigated the use of two different types of shared displays, shared workspaces and status displays, and identified communication grounding, monitoring, and synchronization activities as being supported by the shared display. Study III identified activities that support teamwork and taskwork in a sensemaking environment. In particular, the prioritization and comparison of task materials, and the formation of tableaux. Analyses of these activities, presented at the end of Chatpters 6, 7, and 8, grounded these activities within the sensemaking process model.

Results from Study III revealed that not only does the identification of these activities provide insight into the role that personal and shared devices play in supporting collaborative work, but it also sheds light on how their interconnectivity can influence group process. Often, research into connectivity is driven by technical feasibility, and loses sight of the context that users may be collaborating in. This dissertation informs designers and researchers of the types of activities that could be better supported as users transition between collaborative and individual work. For example, the transfer and manipulation of task materials by an individual supported both teamwork and taskwork, and the manner in which materials were transferred between personal and shared devices was also identified as important (e.g. prioritizing materials as they are transferred). In Studies I and II, connectivity between personal and shared devices allowed for a shared display with up-to-date task information. The presence of this display supported activities such as monitoring, grounding, and synchronization. While the tasks studied in this dissertation were representative of the intellective tasks typically performed by knowledge workers, the activities performed by groups provide a useful starting point for understanding how personal and shared displays may support group process in practice. Researchers and designers can build on the understanding of how individuals transition between individual and group work established in this dissertation to design more appropriate tools for the transitioning of work between personal and shared devices.

10.1.3 Equity of Participation and Performance

Analysis of participant interactions in Study III revealed correlations between equity of participation and group performance. It was found that more equitable participation in the shared workspace was positively correlated with performance, whereas more equitable participation in personal workspaces was negatively correlated with performance. These results build on a growing consensus in the literature that, for sensemaking tasks in particular, the ability of a group to work closely together is positively correlated with their performance.

While this analysis is insufficient to establish causality between closely coupled collaboration and group performance for these tasks, it suggests a promising area for future research to investigate; as Edward Tufte suggests, "Correlation is not causation but it sure is a hint" (Tufte, 2003, pp.4). Additionally, unlike previous studies, this correlation is based on data that is easily collected via computer logs rather than video coding which can involve a significant investment of human time to analyze. Similar analyses could be performed with a fraction of the effort required by past investigations by utilizing equity of participation measures that are obtained through computer-logged interaction data.

Finally, research has previously explored methods of providing feedback to groups regarding their equity of participation via nearby displays for co-located, synchronous groups (DiMicco, 2005) and for distributed, asynchronous groups Kay et al. (2007). These projects have done so with the goal of providing groups with an awareness of their process in order to provide them with an opportunity to reflect and adapt in-situ to potentially enhance their performance. These projects have typically relied on realtime data such as vocalizations, or longterm data such as lines of code written and committed to a shared repository. This investigation did not find a correlation between vocalizations and performance, but equity of participation in terms of interaction may provide an alternative perspective to these groups, that more closely relates to group performance.

10.1.4 A Methodology based on Teamwork and Taskwork

Finally, over the course of this research a methodology that builds on performance data to reveal differences in how technologies are used to support group process was developed. Three empirical studies of group work were conducted that revealed relationships between the presence of personal and shared devices and both group performance and process. Moreover, by investigating both the teamwork and taskwork performed by groups, analyses identified how those technologies were able to support group processes for collaborative optimization and sensemaking tasks.

While the dichotomy of teamwork and taskwork is not a novel concept on its own Pinelle & Gutwin (2008), existing studies of collaborative environments have focused on either performance or process, and there is little understanding of how the two are linked in practice. This dissertation differs from previous work in that it provides a more complete picture of how performance and process are linked through technological support. This methodology provides a useful means by which researchers can study collaborative work, and identify trade-offs between performance and process. This research program has demonstrated the utility of this methodology over the course of three empirical studies, each of which have explored relationships between personal and shared devices, and group performance and process.

10.2 Limitations

One of the primary contributions of this work is a better understanding of how to study collaboration in controlled, laboratory settings. In particular, this work has provided a more in-depth understanding of how individual and group differences can influence appropriate experimental design, how measures of teamwork and taskwork can be used as a framework to guide mixed-methods experiments, and how existing classification schemes for collaborative tasks are lacking the required descriptive power to appropriately study technological support tools. Yet, as a controlled, laboratory study was conducted there are a number of limitations that need to be acknowledged, particularly relating to the internal validity of the results. First, the study was conducted in a controlled environment where participants were asked to perform an experimental task under laboratory conditions. Second, participants were recruited on campus at the University of Waterloo, and are not likely to be representative of larger populations in all regards. Finally, while significant time and effort were committed to building software that supported groups' needs in all three studies, only a limited set of hardware and software configurations were compared in each study.

In practice, the design of software is a complex issue, and appropriate designs may differ based on their intended tasks, environments, or users. Where possible, this dissertation has drawn on existing studies of collaborative work, in both the lab and the field, to interpret the results. Designs were grounded in 'typical' software, as described in the literature, and thoroughly pilot tested experimental software prior to conducting trials with participants to ensure that we felt that the software provided an adequate level of support. While this method was limited to evaluating a sample population, experimental tasks, and hardware and software configuration, it provided a mechanism to overcome logistical constraints that make comparable field studies infeasible. This control over the environment, participants, task, and apparatus, enabled comparisons between display conditions.

10.3 Recommendations for Future Work

Over the course of conducting three comparative studies, a number of important considerations for future work were identified, relating to both methodology and design. These research areas are now discussed. In particular, opportunities to extend the types of data collected during studies and opportunities to conduct more complex analyses of group process, to complement the data collected during this dissertation with field studies, and to address challenges in generalizing work across studies that utilize different experimental tasks are described.

10.3.1 Extensions to Data Collection and Analysis

As research methods for studies of collaborative technologies have matured, measures for evaluating the effectiveness of collaborative tools have been proposed (e.g.

Inkpen et al., 2004; Morris & Winograd, 2004). A number of these measures were discussed in detail in Chapter 5, with the goal to develop quantifiable, easily obtained metrics that shed light on how effectively and efficiently groups are able to perform a set of shared tasks. Upon the outset of this research, these measures appeared sufficient to gain an understanding of collaborative process and performance. Indeed, the approach of carefully selecting measures based on teamwork and taskwork proved effective at identifying key differences between how technologies supported group work, and how participants used the technology provided to mediate group interaction. However, as the third study was designed, technology had advanced to the point at which capturing and processing multi-modal data for multiple participants in realtime had become feasible. As a result, instrumentation for the final study included real-time recording and processing of voice and pen interaction data.

An important consideration when designing an experiment is the tension between the richness of data collected and the cost, in terms of time and computational resources, in their measurement and analysis. For example, in Studies I and II coded video data was relied upon, which involves an extensive time commitment. I subsequently worked with Martínez et al. (2011b,c) to apply machine learning techniques to the data collected during Studies I and II to more efficiently identify periods of closely coupled work. As the work presented in this dissertation progressed, one of the goals was to try and obtain data that was more efficiently analyzed, yet still provided useful information about groups' collaborative process. The analysis of Study III indicates that augmenting the collected data with alternative sensory input, such as body position as captured via low-cost depth sensors such as the Microsoft Kinect, may provide a useful dataset for future investigations. For example, tablet position was observed to be meaningful in Study III, but the experimental apparatus lacked sensors to accurately track their position, as could potentially be captured via a Microsoft Kinect. This rich collection of data can then be stored to database systems, and analyzed with complex algorithms post hoc (e.g. Martínez et al., 2011a).

10.3.2 Extensions to Field Research

As all of the data collected during this dissertation was done so in a controlled, laboratory environment one of the most significant limitations of this work is the ability to generalize results to particular environments. That is, Studies I, II, and III were conducted on campus at the University of Waterloo with participants largely consisting of students, on experimental tasks that may not reflect work in practice. The primary strength of this method was to carefully compare and contrast groups' performance and process in a laboratory setting in order to identify behaviours, such as communication grounding, monitoring, and synchronization that may be difficult to observe and isolate in the field due to the challenges of unobtrusively capturing and analyzing these interactions. However, now that these strengths and weaknesses have been identified, an important next step is to explore how environmental, user, and task contexts may impact these findings. Future investigations can study the behaviours identified in this dissertation in field settings using less obtrusive methods such as video collected via an ethnographic researcher and portable video camera, or though the analysis of user interactions collected via logging software. For example, in Chapter 1 it was noted that recent deployments of iPads to United Airline cockpits may be of concern, as the results from Study I indicate that the use of personal devices may lead to a decreased ability of individuals to monitor their collaborators' activities. A field study might investigate if pilots' awareness is in fact decreased in these conditions, and if so, whether the effect is significant enough to impact their ability to pilot commercial aircraft.

Similarly, Study III identified benefits of shared, digital tabletops. These devices are being developed and deployed to educational contexts by companies such as SMART Technologies with limited understanding of whether they effectively improve student learning outcomes. The results indicate that for tasks such as sensemaking, which share similarities with constructivist pedagogy, digital tabletops may in fact improve those outcomes and support key information sharing activities. However, while this research utilized both qualitative and quantitative methods to analyze group performance and process, the relationship between those analyses can be strengthened in future work. For example, while qualitative analyses identified a range of collaborative activities that occurred as groups worked together, their relative frequency and the degree to which they contribute to observed performance differences is yet to be determined. Future work can investigate which activities most significantly contribute to group process, and provide insight into how to most effectively support those activities throughout the development and deployment of personal and shared devices.

10.3.3 Generalizing Results Across Experimental Tasks

Experimental tasks play a critical role in determining the types of behaviour that are elicited during a study, but are also typically neglected in reports of empirical work. McGrath's task circumplex (McGrath, 1984) is widely cited when describing collaborative tasks, particularly in experimental settings. When the JSS task was introduced by Tan et al. (2008) it was classified as intellective, because it has a demonstrably correct solution and participants can objectively compare one solution with another (Tan et al., 2008). During the first investigation of groups completing the JSS task it was observed that the strategies groups used to solve the puzzle were similar to those used in a sensemaking process. That is, while in theory there is always a means to objectively compare two potential solutions and demonstrate that one is better than the other, individuals within the group were not always capable of doing so. Consequently, groups tended to adopt hill-climbing strategies where each step was suggested to the group by an individual and negotiated, and their final solution was largely dependent on the first job components they scheduled.

This difficulty in classifying collaborative tasks is not limited to the JSS task. Fjermestad & Hiltz (1997), in their review of experimental studies of collaboration, also observed that "some tasks had been described as belonging in two or three [of McGraths] categories, by different authors" (p. 6), indicating that there is at least some disagreement in the community as to how tasks should be classified. One of McGraths stated objectives in developing the circumplex was to provide a set of categories that were both mutually exclusive and useful in that they expound differences between and relations among tasks (McGrath, 1984). Based on observations of participants performing the JSS task, even though theoretically a task may fall into one classification, participants may choose to use an alternative method when completing the task. Hackman defines this behaviour as task redefinition (Hackman, 1969), and notes that it affects both group processes and collaborative outcomes. Thus, it may benefit the research community to revisit McGraths task circumplex and explore classification schemes grounded in the potential processes employed by groups while solving a task rather than the task requirements alone.

10.4 Summary

Collaboration takes place on a daily basis, in a wide variety of environments, by billions of different users, and using any combination of the many devices available today. Yet, these devices are designed primarily for use by individuals, and there is an opportunity to to deploy devices to support these collaborative activities. In this dissertation, instances when personal and shared devices provided effective support for intellective tasks that improved group performance have been identified, and a methodology that elucidated how the devices impacted groups' underlying collaborative processes was developed. Thus, this dissertation provides evidence that personal and shared devices can support group work during intellective tasks, and reveals a unique methodology for understanding how that support influences group process.

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Material ideas, figures, and tables from this dissertation have previously appeared in peer reviewed publications. In particular, the literature review of teamwork and taskwork presented in Chapter 5 and Study I, presented in Chapter 6, was based on work published in Wallace et al. (2009). Study II, presented in Chapter 7, was based on work published in Wallace et al. (2011). These materials are used with permission, and their respective licenses from the copyright holders follow for use in this dissertation.

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Appendix A

Study I Materials

A.1 Information Sheet

University of Waterloo

<u>Information Sheet for Participants</u>

Title of Project: Characterizing Communication in Group Decision-Making Tasks in Single-and Multi-Display Environments

Principal Investigator: Prof. Stacey Scott

University of Waterloo, Department of Systems Design Engineering

519-884-4567 Ext. 32236

Summary of the Project:

The overall goal of our research is to design interfaces for environments in which multiple displays are used for group work. While interactions between a single users and computer have been studied for decades, interactions within groups and with multiple devices are somewhat more difficult to study; as the number of users and devices increases, the interactions between understanding of communication process and efficiency in these environments through the observation of real groups of participants completing a collaboration task in both single- and multi-display settings. The information gathered in this study will be used to guide the design of multi-display interaction techniques that support natural collaborative behavior.

Procedure:

Your participation in this study will involve performing a group decision-making task at a computer and a group interview over two successive dates. The decision-making task will involve finding an optimal schedule for a series of jobs that need to be completed using a shared group workspace. A description of each activity follows.

In Session 1 (to be completed today) you will be asked to:

- Complete a training session on the problem solving task as a group
- Complete three problem sets using different interfaces as a group
- Complete a 5-minute questionnaire for each problem set

In session 2(to be completed on a subsequent day) you will be asked to:

- Complete three problem sets using different interfaces as a group
- Participate in a 15-minute group interview in regards to your interface preferences based on the previous two sessions
- Complete a 5-minute questionnaire for each problem set

Each session will take approximately 1.5 hours.

During each session, a researcher will observe and take notes regarding your interactions with the activity resources and tabletop, as well as your interactions with other participants in the team sessions. You will also be videotaped and any task materials produced during the session will remain with the researcher. You may decline to answer any questions, if you wish. You may to withdraw your participation in the study at any time without penalty.

Confidentiality and Anonymity:

All information you provide is considered completely confidential. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used. In these cases participants will be referred to as Participant 1, Participant 2, … (or P1, P2, …) or collectively as a group (group A, B, …). Data collected during this study will be retained in a locked office and only researchers associated with this project will have access.

You will be explicitly asked for consent for the release of photo/video/audio data captured during the study for the purpose of reporting the study's findings. If consent is granted, these data will be used only for scientific(inclusion in conference presentations, conference or journal papers) thesis' and/or teaching purposes.

All questionnaires and recordings will be kept indefinitely in a secure cabinet in a locked University of Waterloo room. Electronic data will be kept indefinitely and stored on a password protected computer and/or copied to CD.

Remuneration for your Participation:

As a participant in this study, you will receive a prorated amount at the rate of $10/hour/session to a maximum of $25. We anticipate that the study will take approximately 2.5-3 hours to complete, depending on participant skill level.

Risks and Benefits:

There are no known or anticipated risks to participation. There are no direct benefits to you, however the results of this research may contribute to the knowledge base of Human Systems Engineering research and also may lead to the development of better user interfaces.

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes at this office at 519-888-4567 Ext. 36005.

Thank you for your assistance in this project.

A.2 Informed Consent Form

UNIVERSITY OF WATERLOO

INFORMED CONSENT BY SUBJECTS TO PARTICIPATE IN A RESEARCH EXPERIMENT

Project: Characterizing Communication in Group Decision-Making Tasks in Single- and Multi-Display Environments

I have read the information presented in the information letter about a study being conducted by Prof. Stacey Scott and Jim Wallace of the Department of Systems Design Engineering at the University of Waterloo. 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 videotape clearly show 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 agree to allow video and/or digital images in which I appear to be used in teaching, scientific presentations and/or publications with the understanding that I will not be identified by name.

I also agree to allow excerpts from the conversational 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 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 by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics at 519-888-4567 ext. 36005.

	Please One	**Circle**	**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 videotaped, photographed, and audio-taped.	YES	NO	_____
I agree to let my conversation during the study be directly quoted, anonymously, in presentation of research results.	YES	NO	_____
I agree to let the videotapes/digital images/audiotapes be used for presentation of research results.	YES	NO	_____
I agree to let my actions during the study be recorded via computer logging software.	YES	NO	_____

Participant Name: ___________________________ (Please print)

Participant Signature: ___________________________ Date ___________________________

Witness Name: ___________________________ (Please print)

Witness Signature: ___________________________ Date ___________________________

A.3 Background Questionnaire

Background Questionnaire

Subject ID:____________

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

1. What is your sex?

   Female   Male

2. What is your age?

3. What is your occupation?

   If student, what degree/program are you in?

4. Which hand do you primarily use when writing?

   Left hand   Right hand

5. When using a mouse on your home computer, which hand do you primarily use?

   Left hand   either/both   Right hand

6. On a scale of 1-5, Please indicate how often you have used large displays over the past two years? (Computer displays mounted on a wall and larger than 20").

Never	Yearly	Monthly	Weekly	Daily
1	2	3	4	5

7. On a scale of 1-5, Please indicate how often you have used laptop computers over the past two years?

Never	Yearly	Monthly	Weekly	Daily
1	2	3	4	5

8. How well do you know group member ______ ?

Never Met				Very Well
1	2	3	4	5

9. How well do you know group member ______ ?

Never Met				Very Well
1	2	3	4	5

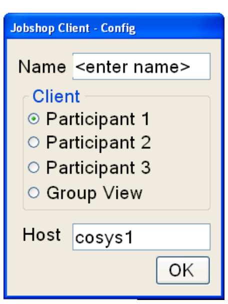
A.4 Job Shop Tutorial Materials

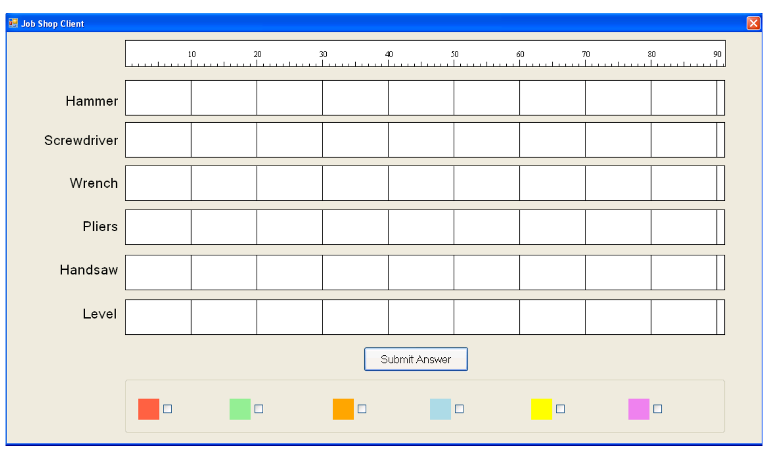
JOBSHOP SCHEDULING TASK

Multi-Display Tutorial

Start View

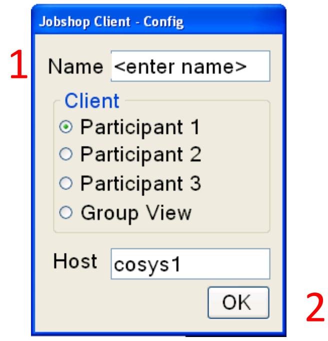
Two Windows should pop up that look like this:





Setting Up

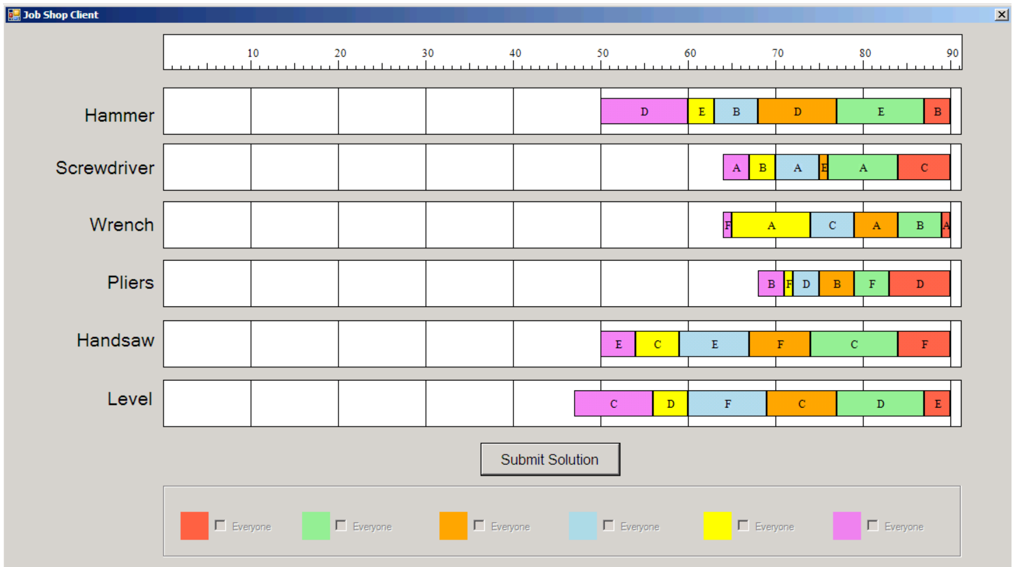
1. Enter your name
2. Click “OK”



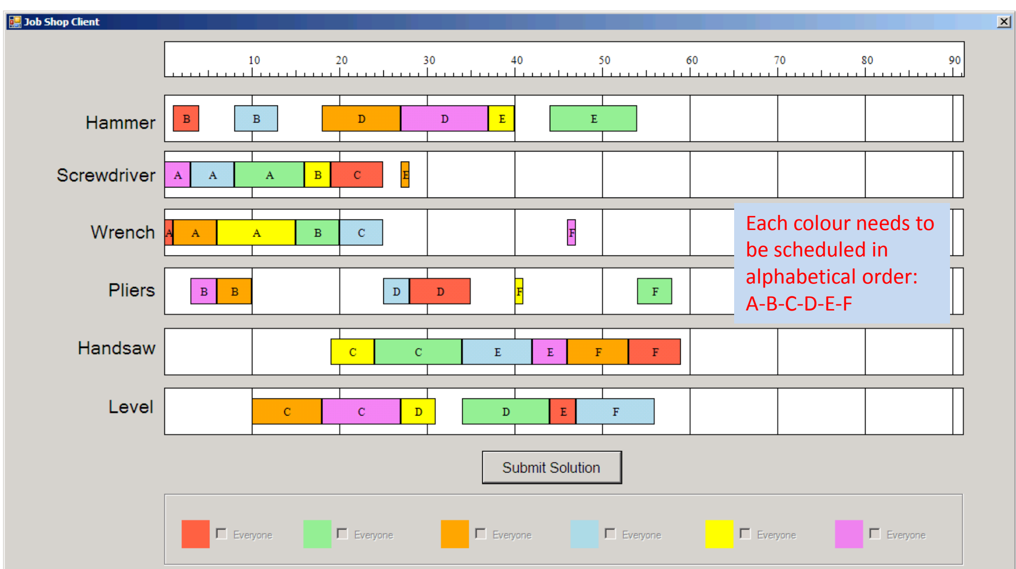
Getting Started

- The goal is to schedule all of the blocks in the smallest amount of time
- Each participant works on their own laptop moving pieces
- The shared screen (this one) will show a consolidated view of the puzzle
- It is a team effort, all three participants should ALWAYS be working TOGETHER!!

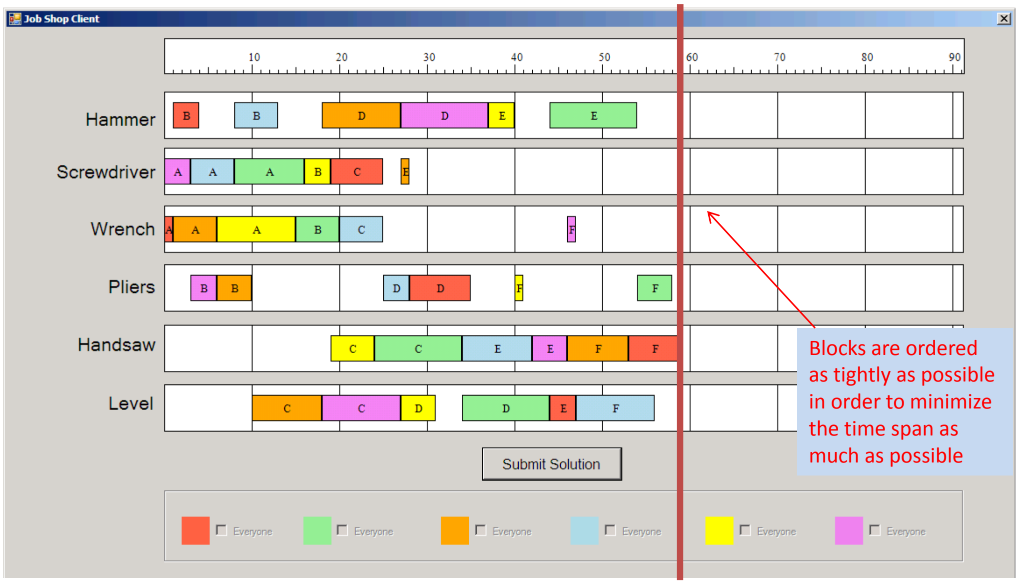
Initial JobShop Display



Ordering the Coloured Blocks



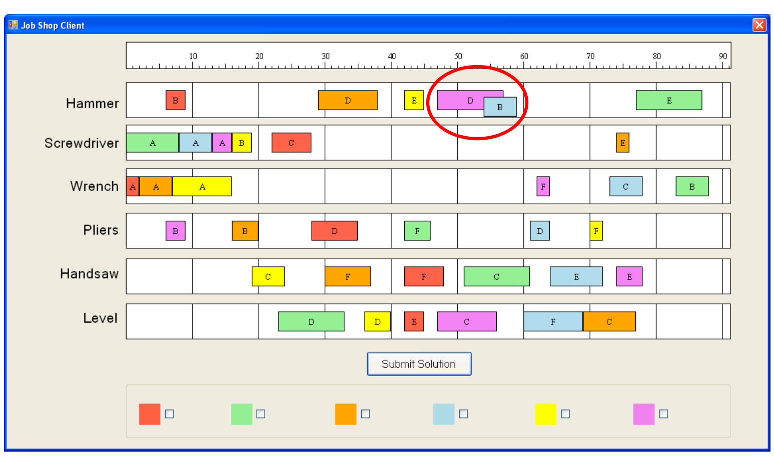
Minimizing Solution Time



Unfortunate Overlapping: Type 1

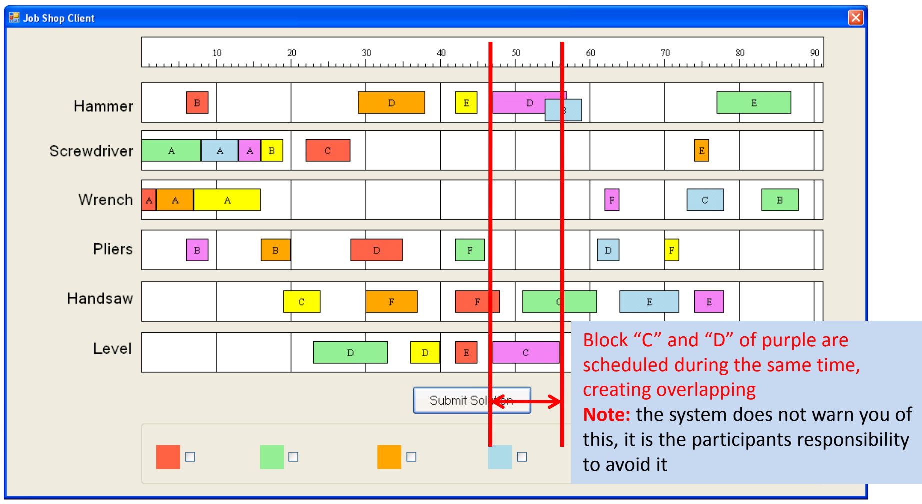
There are two types of overlapping:

1. When two blocks of different colours overlap within the same task, this is visually shown by one of the blocks off-setting on top of the other



Unfortunate Overlapping: Type 2

2. Two blocks of the same colour, scheduled for different tasks, overlapping on the time scale, this has no visual indicator



Methods to solving the Puzzle

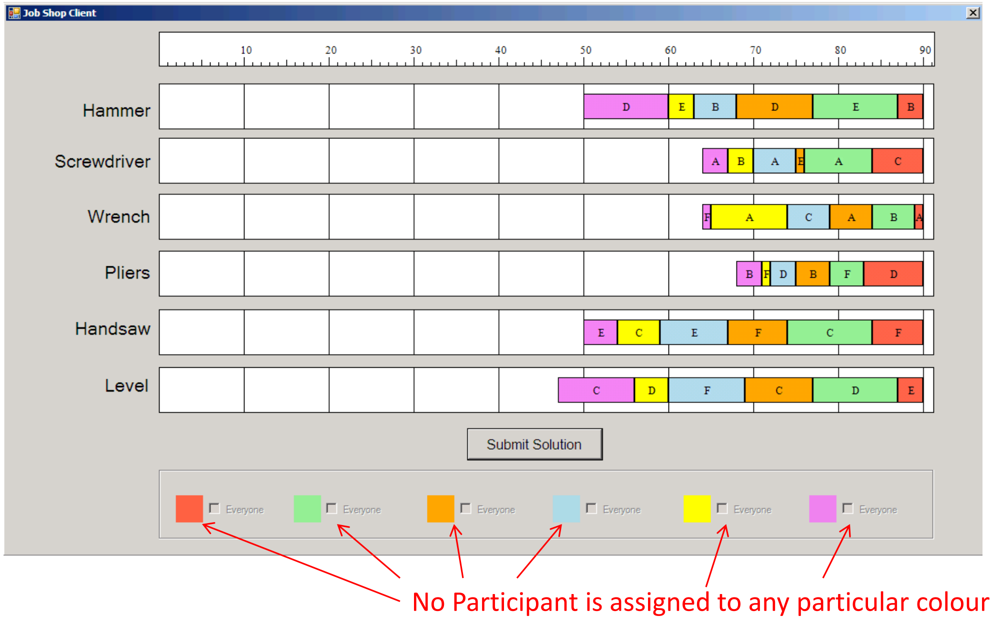
Today we're going to try the puzzle in three different ways:

1. Everyone can move every and any piece
2. Everyone picks colours they want to control, however colours can be traded between participants at any time
3. Everyone is assigned two colours

- The different types of task assignment only change how the group must approach the problem, but not the problem itself.
- It might be helpful to create strategies to solving the puzzle, depending on the method assigned
- No matter what, you are ALWAYS working as a TEAM!

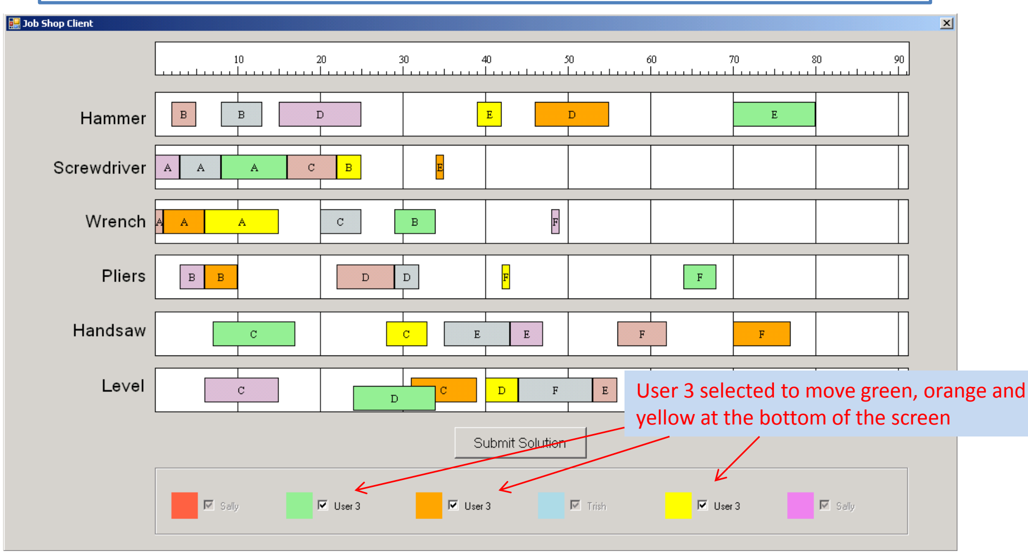
Everyone Can Move any Piece

•This is indicated by the fact that no pieces are faded in colour



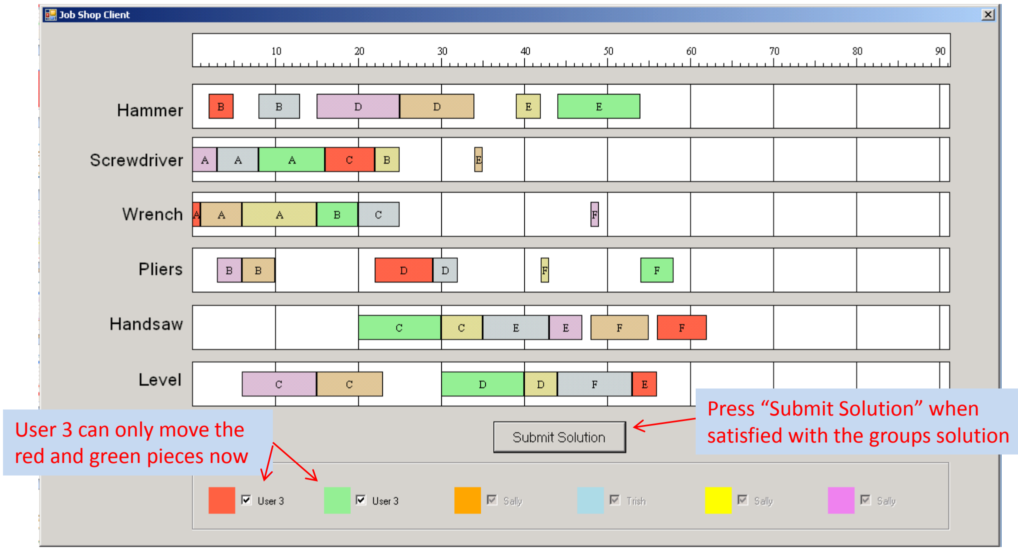
Everyone Picks Colours to Control

•Everyone picks colours they want to control, however colours can be traded between participants at any time
•Only one participant is allowed to move a colour at a time, but they can select as many colours as they wish



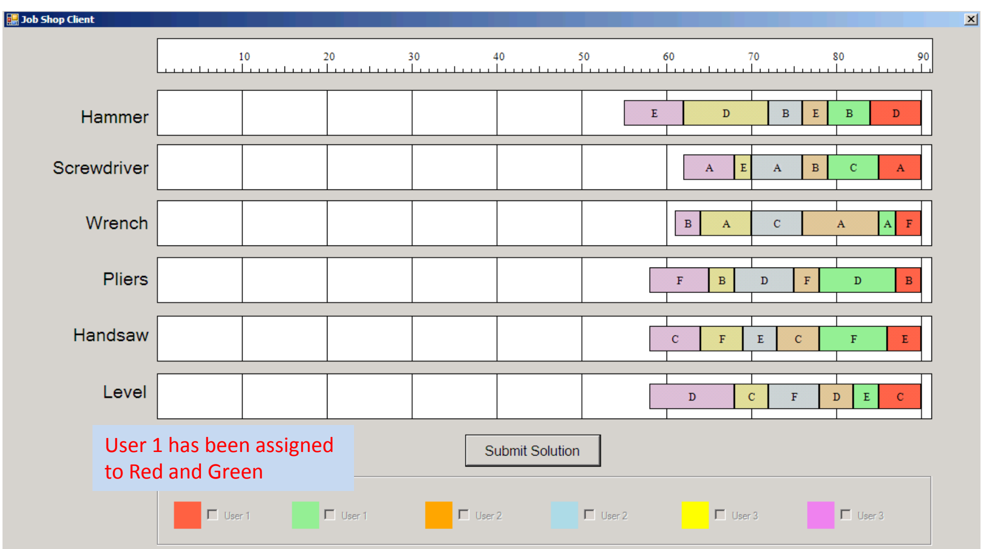
Everyone Picks Cont'd

- A final solution is again reached when all of the colours are in order from A to F with no overlapping



Everyone is Assigned Two Colours

- Each participant is assigned two colours by the system



And now for some practice…

- Remember it is a TEAM activity NOT a competition!
- For each trial you will have a 20 minute time limit, at the end of the 20 minutes you will be asked to submit your solution. You may submit your solution earlier if you wish, you may also retract your solution if you feel you can improve upon it.
- You will all submit the solution independently on your own screens when you have agreed on a solution
- Any questions?

A.5 Post-Condition Questionnaire

Subject ID: ________________ Condition: _______________

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

1. Please circle the number on the scale from 1 to 7 to indicate how much you agree with each of the following statements. A "1" indicates that you strongly **disagree** with the statement, and a "7" indicates that you strongly **agree** with the statement.

	Strongly Disagree 1	**2**	**3**	**Neutral 4**	**5**	**6**	**Strongly Agree 7**
I felt comfortable while completing the task	1	2	3	4	5	6	7
I could interact accurately with the software while completing the task	1	2	3	4	5	6	7
I was able to interpret my peers' communications.	1	2	3	4	5	6	7
I was aware of my peers' actions	1	2	3	4	5	6	7
My peers were aware of my actions.	1	2	3	4	5	6	7
I was able to communicate well with my peers	1	2	3	4	5	6	7
I was able to interpret my peers' actions	1	2	3	4	5	6	7
I felt our final solution was the best possible solution	1	2	3	4	5	6	7
I found the interface easy to use	1	2	3	4	5	6	7
I felt our group worked well together	1	2	3	4	5	6	7
I experienced conflict while completing the task	1	2	3	4	5	6	7
I felt the software interface helped in resolving group conflicts	1	2	3	4	5	6	7

2. Did you find it easy to communicate with your peers? What was the hardest thing to communicate?

3. Did the interface lack any features you would have liked? Is there any feature(s) that are not currently in the software, that you feel would make the task easier to complete?

A.6 Post-Condition Questionnaire Response Frequencies

Summary of Study I, Multi-Display and Shared Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt comfortable while completing the task	0	0	1	2	1	9	5
I could interact accurately with the software while completing the task	0	0	2	3	4	6	3
I was able to interpret my peers' communications.	0	0	1	1	4	9	3
I was aware of my peers' actions	0	0	1	5	2	7	3
My peers were aware of my actions.	0	0	1	5	5	6	1
I was able to communicate well with my peers	0	0	0	5	5	6	2
I was able to interpret my peers' actions	0	0	0	3	8	6	1
I felt our final solution was the best possible solution	0	0	2	4	7	1	4
I found the interface easy to use	0	0	2	3	4	7	2
I felt our group worked well together	0	0	0	3	4	9	2
I experienced conflict while completing the task	3	2	6	3	1	2	1
I felt the software interface helped in resolving group conflicts	0	1	4	8	1	4	0

Summary of Study I, Multi-Display and Negotiated Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt comfortable while completing the task	**0**	**0**	**0**	**0**	**2**	**8**	**8**
I could interact accurately with the software while completing the task	**0**	**0**	**1**	**1**	**6**	**6**	**4**
I was able to interpret my peers' communications.	**0**	**0**	**1**	**1**	**2**	**10**	**4**
I was aware of my peers' actions	**0**	**0**	**1**	**1**	**3**	**9**	**4**
My peers were aware of my actions.	**0**	**0**	**0**	**3**	**4**	**7**	**4**
I was able to communicate well with my peers	**0**	**0**	**2**	**1**	**4**	**7**	**4**
I was able to interpret my peers' actions	**0**	**0**	**1**	**1**	**3**	**10**	**3**
I felt our final solution was the best possible solution	**1**	**0**	**0**	**3**	**4**	**6**	**4**
I found the interface easy to use	**0**	**0**	**1**	**2**	**5**	**6**	**4**
I felt our group worked well together	**0**	**0**	**1**	**1**	**3**	**9**	**4**
I experienced conflict while completing the task	**7**	**3**	**4**	**1**	**1**	**2**	**0**
I felt the software interface helped in resolving group conflicts	**0**	**3**	**1**	**8**	**2**	**2**	**2**

Summary of Study I, Multi-Display and Fixed Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt comfortable while completing the task	**0**	**0**	**1**	**2**	**1**	**9**	**5**
I could interact accurately with the software while completing the task	**0**	**0**	**2**	**3**	**4**	**6**	**3**
I was able to interpret my peers' communications.	**0**	**0**	**1**	**1**	**4**	**9**	**3**
I was aware of my peers' actions	**0**	**0**	**1**	**5**	**2**	**7**	**3**
My peers were aware of my actions.	**0**	**0**	**1**	**5**	**5**	**6**	**1**
I was able to communicate well with my peers	**0**	**0**	**0**	**5**	**5**	**6**	**2**
I was able to interpret my peers' actions	**0**	**0**	**0**	**3**	**8**	**6**	**1**
I felt our final solution was the best possible solution	**0**	**0**	**2**	**4**	**7**	**1**	**4**
I found the interface easy to use	**0**	**0**	**2**	**3**	**4**	**7**	**2**
I felt our group worked well together	**0**	**0**	**0**	**3**	**4**	**9**	**2**
I experienced conflict while completing the task	**3**	**2**	**6**	**3**	**1**	**2**	**1**
I felt the software interface helped in resolving group conflicts	**0**	**1**	**4**	**8**	**1**	**4**	**0**

Summary of Study I, Single Display and Shared Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt comfortable while completing the task	**0**	**0**	**3**	**0**	**5**	**4**	**6**
I could interact accurately with the software while completing the task	**0**	**0**	**2**	**2**	**4**	**9**	**1**
I was able to interpret my peers' communications.	**0**	**0**	**2**	**3**	**4**	**8**	**1**
I was aware of my peers' actions	**0**	**0**	**2**	**2**	**4**	**8**	**2**
My peers were aware of my actions.	**0**	**1**	**2**	**3**	**3**	**8**	**1**
I was able to communicate well with my peers	**0**	**1**	**1**	**4**	**7**	**4**	**1**
I was able to interpret my peers' actions	**0**	**0**	**0**	**2**	**6**	**8**	**2**
I felt our final solution was the best possible solution	**0**	**2**	**0**	**2**	**5**	**5**	**4**
I found the interface easy to use	**0**	**0**	**0**	**6**	**7**	**5**	**0**
I felt our group worked well together	**0**	**1**	**1**	**1**	**6**	**7**	**2**
I experienced conflict while completing the task	**4**	**5**	**2**	**1**	**3**	**2**	**1**
I felt the software interface helped in resolving group conflicts	**1**	**2**	**3**	**9**	**2**	**1**	**0**

Summary of Study I, Single Display and Negotiated Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt comfortable while completing the task	**0**	**0**	**1**	**2**	**3**	**7**	**5**
I could interact accurately with the software while completing the task	**0**	**2**	**2**	**1**	**3**	**7**	**3**
I was able to interpret my peers' communications.	**0**	**0**	**0**	**0**	**6**	**9**	**3**
I was aware of my peers' actions	**0**	**0**	**0**	**1**	**5**	**8**	**4**
My peers were aware of my actions.	**0**	**0**	**0**	**1**	**3**	**10**	**3**
I was able to communicate well with my peers	**0**	**0**	**0**	**2**	**5**	**7**	**4**
I was able to interpret my peers' actions	**0**	**0**	**1**	**0**	**5**	**9**	**3**
I felt our final solution was the best possible solution	**0**	**0**	**2**	**1**	**4**	**5**	**6**
I found the interface easy to use	**0**	**0**	**3**	**1**	**5**	**7**	**2**
I felt our group worked well together	**0**	**0**	**0**	**2**	**5**	**8**	**3**
I experienced conflict while completing the task	**5**	**5**	**2**	**0**	**4**	**2**	**0**
I felt the software interface helped in resolving group conflicts	**0**	**1**	**1**	**8**	**3**	**4**	**1**

Summary of Study I, Single Display and Fixed Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt comfortable while completing the task	**0**	**1**	**1**	**0**	**4**	**9**	**3**
I could interact accurately with the software while completing the task	**0**	**0**	**4**	**3**	**4**	**6**	**1**
I was able to interpret my peers' communications.	**0**	**1**	**1**	**1**	**6**	**6**	**3**
I was aware of my peers' actions	**0**	**0**	**1**	**1**	**6**	**6**	**4**
My peers were aware of my actions.	**0**	**0**	**1**	**2**	**4**	**7**	**4**
I was able to communicate well with my peers	**0**	**0**	**2**	**1**	**5**	**6**	**4**
I was able to interpret my peers' actions	**0**	**0**	**1**	**1**	**8**	**4**	**4**
I felt our final solution was the best possible solution	**0**	**0**	**1**	**2**	**10**	**2**	**3**
I found the interface easy to use	**0**	**1**	**2**	**3**	**5**	**5**	**2**
I felt our group worked well together	**0**	**0**	**1**	**2**	**4**	**8**	**3**
I experienced conflict while completing the task	**6**	**3**	**2**	**3**	**2**	**2**	**0**
I felt the software interface helped in resolving group conflicts	**0**	**1**	**2**	**10**	**1**	**3**	**1**

A.7 End of Study Handout

UNIVERSITY OF WATERLOO

Characterizing Communication in Group Decision-Making Tasks in Single- and Multi Display Environments

Dear Participant,

I would like to thank you for your participation in this study. As a reminder, the purpose of this study is to establish a basic understanding of communication process and efficiency in these environments through the observation of real groups of participants completing a collaborative task in both single- and multi-display settings. The information gathered from the questionnaires, computer logs and interview questions in this study will be used to guide the design of multi-display interaction techniques that support natural collaborative behavior.

Please remember that any data pertaining to you as an individual participant will be kept confidential. Once all the data is collected and analyzed for this project, I plan on sharing this information with the research community through seminars, conferences, presentations, and journal articles. If you are interested in receiving more information contact me at either the phone number or email address listed at the bottom of the page. If you would like a summary of the results, please let me know now by providing me with your email address. When the study is completed, I will send it to you. The study is expected to be completed by April 1st, 2008.

As with all University of Waterloo projects involving human participants, this project was received by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext. 36005.

If you have any questions about participation in this study, please feel free to ask the researchers. If you have additional questions at a later date, please contact my thesis supervisor Dr. Stacey Scott at (519) 888-4567 ext. 32236 or by email at s9scott@engmail.uwaterloo.ca.

Jim Wallace
University of Waterloo
Department of Systems Design Engineering
519-616-5334
jrwallac@engmail.uwaterloo.ca

If you are interested in learning more about the topic, please see:

Biehl, J. T., Czerwinski, M., Smith, G., and Robertson, G. G. 2007. FASTDash: a visual dashboard for fostering awareness in software teams. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA, April 28 – May 03, 2007). CHI '07. ACM Press, New York, NY, 1313-1322. DOI= http://doi.acm.org/10.1145/1240624.1240823

Johanson, B., Hutchins, G., Winograd, T., and Stone, M. 2002. PointRight: experience with flexible input redirection in interactive workspaces. In Proceedings of the 15th Annual ACM Symposium on User interface Software and Technology (Paris, France, October 27 – 30, 2002). UIST '02. ACM Press, New York, NY, 227-234. DOI= http://doi.acm.org/10.1145/571985.572019

Appendix B

Study II Materials

B.1 Information Sheet

University of Waterloo

Information Sheet for Participants

Title of Project: Characterizing Communication in Group Decision-Making Tasks in Single-and Multi-Display Environments

Principal Investigator: Prof. Stacey Scott

University of Waterloo, Department of Systems Design Engineering

519-884-4567 Ext. 32236

Summary of the Project:

The overall goal of our research is to design interfaces for environments in which multiple displays are used for group work. While interactions between a single users and computer have been studied for decades, interactions within groups and with multiple devices are somewhat more difficult to study; as the number of users and devices increases, the interactions between understanding of communication process and efficiency in these environments through the observation of real groups of participants completing a collaboration task in both single- and multi-display settings. The information gathered in this study will be used to guide the design of multi-display interaction techniques that support natural collaborative behavior.

Procedure:

Your participation in this study will involve performing a group decision-making task at a computer and a group interview over two successive dates. The decision-making task will involve finding an optimal schedule for a series of jobs that need to be completed using a shared group workspace. A description of each activity follows.

In Session 1 (to be completed today) you will be asked to:

- Complete a training session on the problem solving task as a group
- Complete three problem sets using different interfaces as a group
- Complete a 5-minute questionnaire for each problem set

In session 2(to be completed on a subsequent day) you will be asked to:

- Complete three problem sets using different interfaces as a group
- Participate in a 15-minute group interview in regards to your interface preferences based on the previous two sessions
- Complete a 5-minute questionnaire for each problem set

Each session will take approximately 1.5 hours.

During each session, a researcher will observe and take notes regarding your interactions with the activity resources and tabletop, as well as your interactions with other participants in the team sessions. You will also be videotaped and any task materials produced during the session will remain with the researcher. You may decline to answer any questions, if you wish. You may to withdraw your participation in the study at any time without penalty.

Confidentiality and Anonymity:

All information you provide is considered completely confidential. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used. In these cases participants will be referred to as Participant 1, Participant 2, … (or P1, P2, …) or collectively as a group (group A, B, …). Data collected during this study will be retained in a locked office and only researchers associated with this project will have access.

You will be explicitly asked for consent for the release of photo/video/audio data captured during the study for the purpose of reporting the study's findings. If consent is granted, these data will be used only for scientific(inclusion in conference presentations, conference or journal papers) thesis' and/or teaching purposes.

All questionnaires and recordings will be kept indefinitely in a secure cabinet in a locked University of Waterloo room. Electronic data will be kept indefinitely and stored on a password protected computer and/or copied to CD.

Remuneration for your Participation:

As a participant in this study, you will receive a prorated amount at the rate of $10/hour/session to a maximum of $25. We anticipate that the study will take approximately 2.5-3 hours to complete, depending on participant skill level.

Risks and Benefits:

There are no known or anticipated risks to participation. There are no direct benefits to you, however the results of this research may contribute to the knowledge base of Human Systems Engineering research and also may lead to the development of better user interfaces.

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes at this office at 519-888-4567 Ext. 36005.

Thank you for your assistance in this project.

B.2 Informed Consent Form

UNIVERSITY OF WATERLOO

INFORMED CONSENT BY SUBJECTS TO PARTICIPATE IN A RESEARCH EXPERIMENT

Project: Towards Guidelines for the Design of Multi-Display Environments

I have read the information presented in the information letter about a study being conducted by Prof. Stacey Scott, Prof. Carolyn MacGregor and Jim Wallace of the Department of Systems Design Engineering at the University of Waterloo. 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 videotape clearly show 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 agree to allow video and/or digital images in which I appear to be used in teaching, scientific presentations and/or publications with the understanding that I will not be identified by name.

I also agree to allow excerpts from the session to be included in teaching, scientific presentations and/or publications, with the understanding that any quotations will be anonymous.

I am aware 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 by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics at 519-888-4567 ext. 36005or ssykes@uwaterloo.ca.

	Please One	**Circle**	**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 video recorded, photographed, and audio-taped.	YES	NO	_____
I agree to the use of anonymous quotations, from the session, in presentation of research results.	YES	NO	_____
I agree to let the video recordings be used for presentation of research results.	YES	NO	_____

Participant Name: ________________________ (Please print)

Participant Signature: ________________________ Date ________________________

Witness Name: ________________________ (Please print)

Witness Signature: ________________________ Date ________________________

B.3 Background Questionnaire

Background Questionnaire

Subject ID:____________

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

1. What is your sex?

Female Male

2. What is your age?

3. What is your occupation?

If student, what degree/program are you in?

4. Which hand do you primarily use when writing?

Left hand Right hand

5. When using a mouse on your home computer, which hand do you primarily use?

Left hand either/both Right hand

6. On a scale of 1-5, Please indicate how often you have used large displays over the past two years? (Computer displays mounted on a wall and larger than 20").

Never	Yearly	Monthly	Weekly	Daily
1	2	3	4	5

7. On a scale of 1-5, Please indicate how often you have used laptop computers over the past two years?

Never	Yearly	Monthly	Weekly	Daily
1	2	3	4	5

8. How well do you know group member ______ ?

Never Met				Very Well
1	2	3	4	5

9. How well do you know group member ______ ?

Never Met				Very Well
1	2	3	4	5

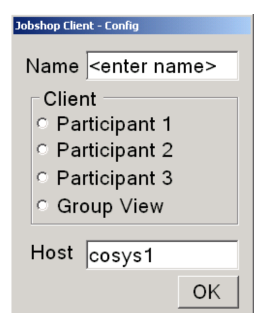
B.4 Job Shop Tutorial Materials for Negotiated Access Conditions

JOBSHOP SCHEDULING TASK

Multi-Display Tutorial

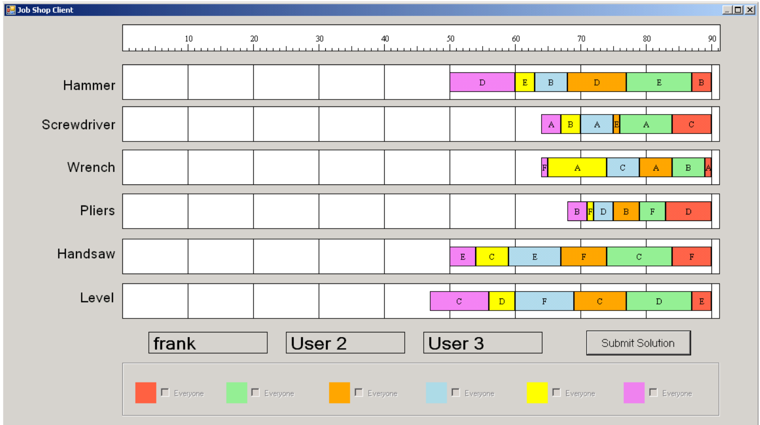
Log-in to JobShop

1. Enter **your name** in the Name field
2. Select **Group View** in the Client list
3. Click the **OK** button



Review the JobShop task screen

- The **bar** on the top of the screen represents time
- Each **row** represents a tool
- Each **colour** represent an individual worker



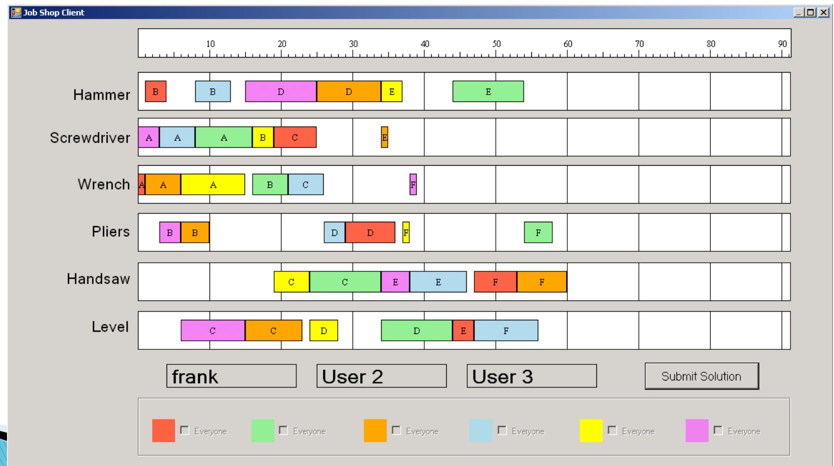
Focus on your goal

- Work as a **team** to schedule all of the blocks in the shortest amount of time
- To create the schedule, move the blocks from the right side of the screen to the left side

- Each participant works on their own laptop to move pieces
- The shared screen (this one) displays a combined view of the schedule
- Since this is a **team effort**, all three participants should **always be working together**

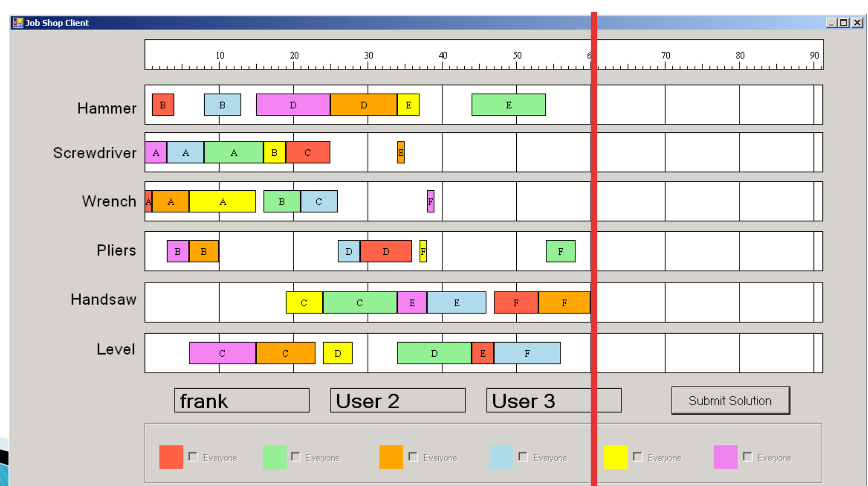
Order the coloured blocks

- Work as a **team** to
  - Order the blocks in each **row** from A to F
  - Order the blocks of each **colour** from A to F across all rows



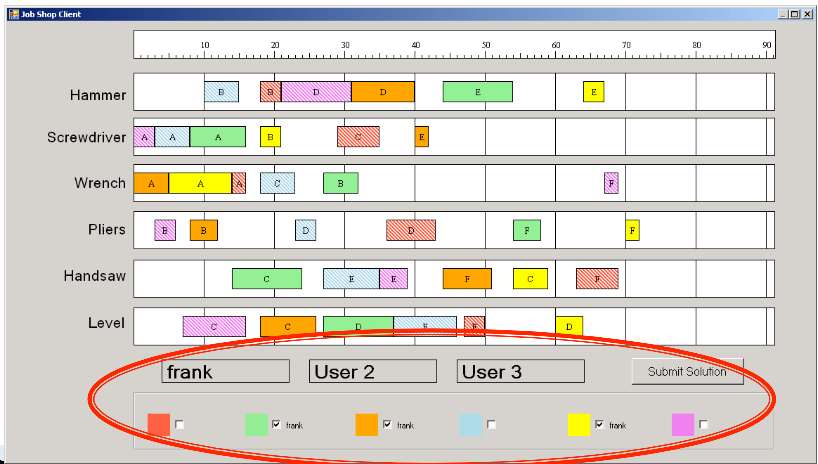
Minimize solution time

- Work as a **team** to
  - Order the blocks as tightly as possible, so that your final solution time is as short as possible
- Your final time is measured by the furthest block on the right



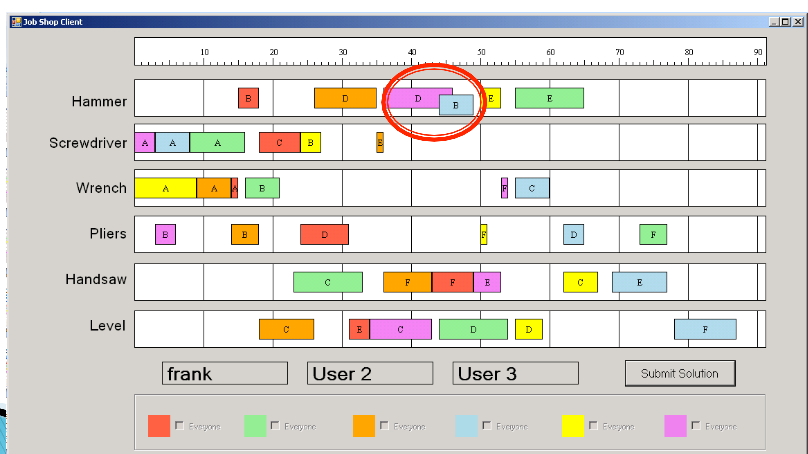
Choose colours to control

- Each team member **chooses colour(s) to control**
- Colours can be **traded** between participants at **any time**
- Only the participant who has selected the colour can move that colour's blocks



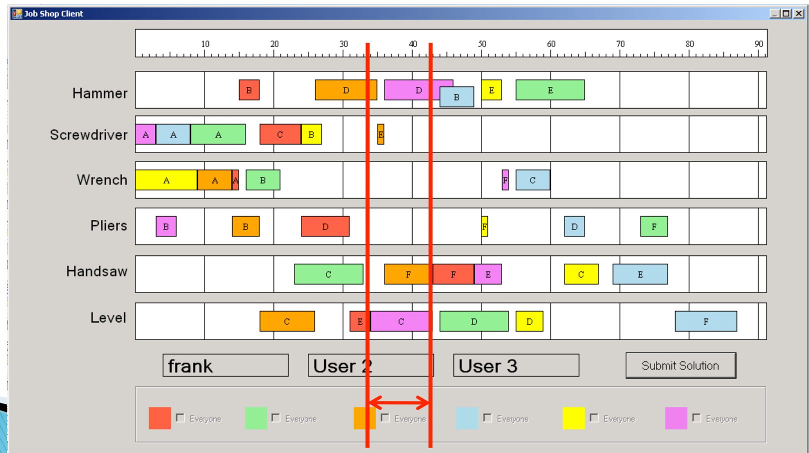
Overlap Error: Row

- Occurs when two blocks of **different colours** overlap within the **same row**
- When this happens, one of the blocks will be off-set on top of the other block



Overlap Error: Colour

- Occurs when two blocks of **the same colour** overlap on the **time indicator**
- There is no visual cue or warning when this error occurs



JobShop scheduling conditions

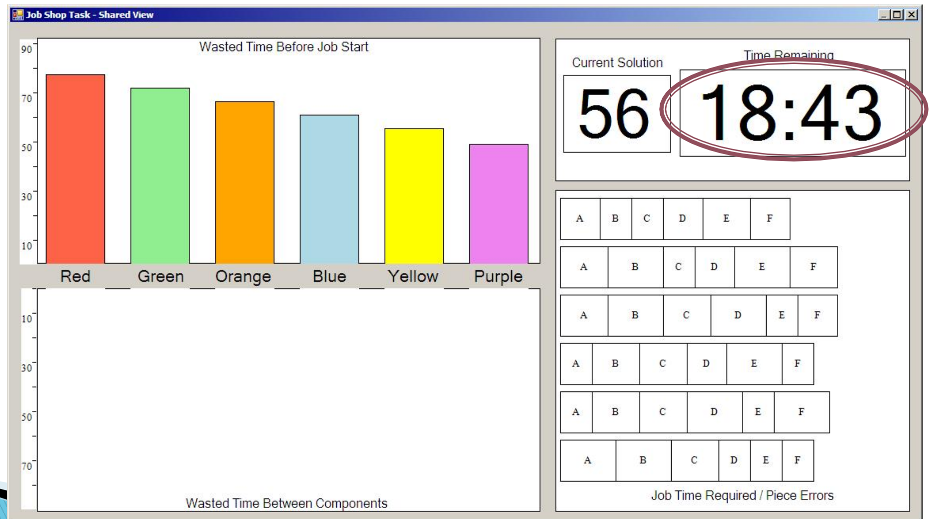
You will complete the scheduling task in **two different conditions**:

1. Shared Workspace
   - Your team can create the schedule by interacting with **both** your **personal displays** and the **shared display**
2. Status Display
   - Your team can create the schedule by interacting **only** with your **personal displays**
   - You cannot interact with the shared display
   - The large display contains status information to aid your team in completing the task

In both conditions team members choose the colours they want to control. Colours can be traded at any time.

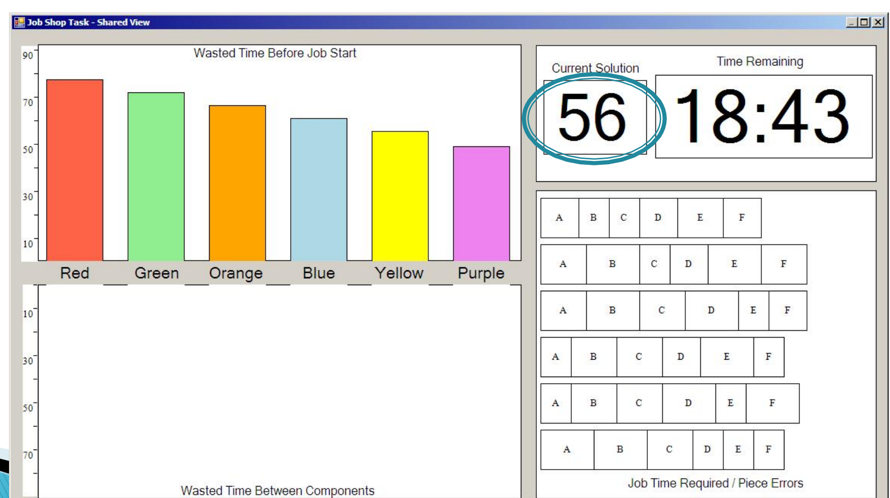
Status display: timer

- Your **timer** is on the **top right corner** of your display
- You have **20 minutes** to finish each puzzle



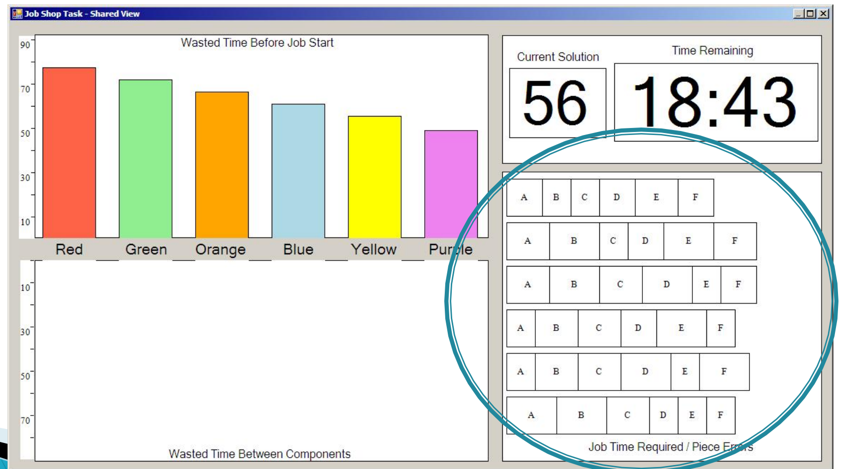
Status display: score

- Your **current solution score** is located **beside the timer** on your display
- Your score corresponds to the score on your laptop screen



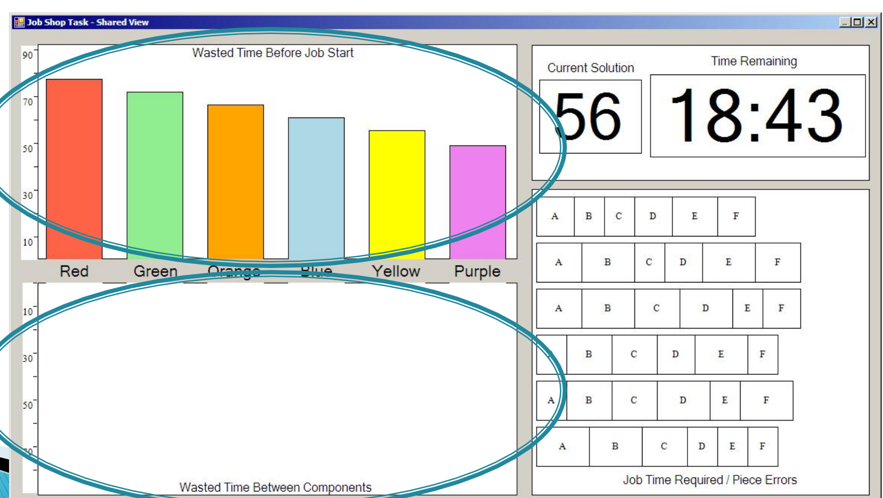
Status display: visualization

- Your **visualization** displays the **total time** it takes to complete each job
- If row or colour **overlap errors occur**, the blocks causing the error will appear in **white**



Status display: graphs

- The graph on the **top left** displays the **wasted time** between block A and the start point for **each colour**
- The graph on the **bottom left** displays the **total wasted time** between **all blocks** for **each colour**

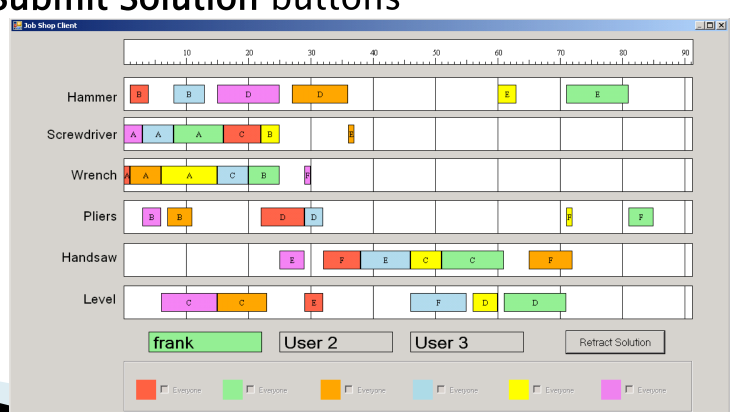


Work as a team

- You are always working as a team!
- Hint: create scheduling strategies for completing each challenge
- The different task conditions only change how the group must approach the problem, but not the problem itself

Submit your solution

- When you have finished the scheduling task, click the **Submit Solution** button
  - After clicking, the Submit Solution button will become the Retract Solution button and your name will be highlighted
- To make changes, click the **Retract Solution** button
- Your solution will not be submitted until **all team members** have clicked their **Submit Solution** buttons



Start practicing

- Remember this is a **team** activity and **NOT** a competition
- You will have **10 minutes** to complete and submit your solution in each trial
- After completing the trials, your team will complete the scheduling tasks

- **Do you have any questions?**

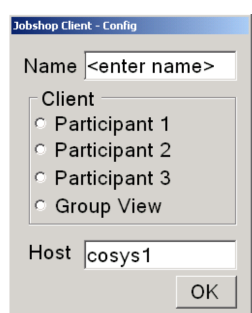
B.5 Job Shop Tutorial Materials for Shared Access Conditions

JOBSHOP SCHEDULING TASK

Multi-Display Tutorial

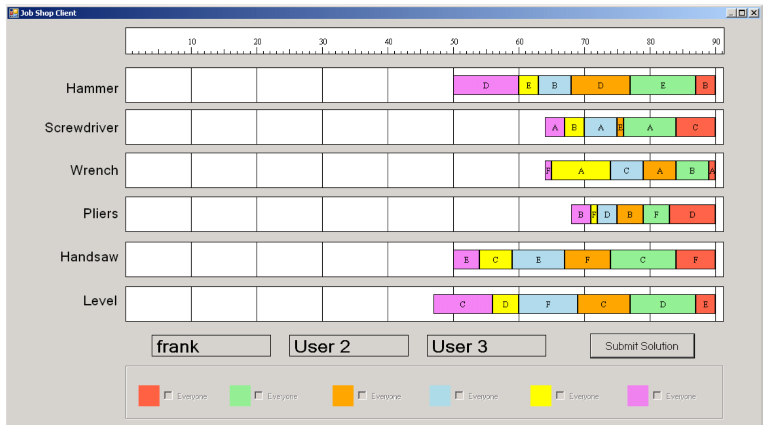
Log-in to JobShop

1. Enter **your name** in the Name field
2. Select **Group View** in the Client list
3. Click the **OK** button



Review the JobShop task screen

- The **bar** on the top of the screen represents time
- Each **row** represents a tool
- Each **colour** represent an individual worker



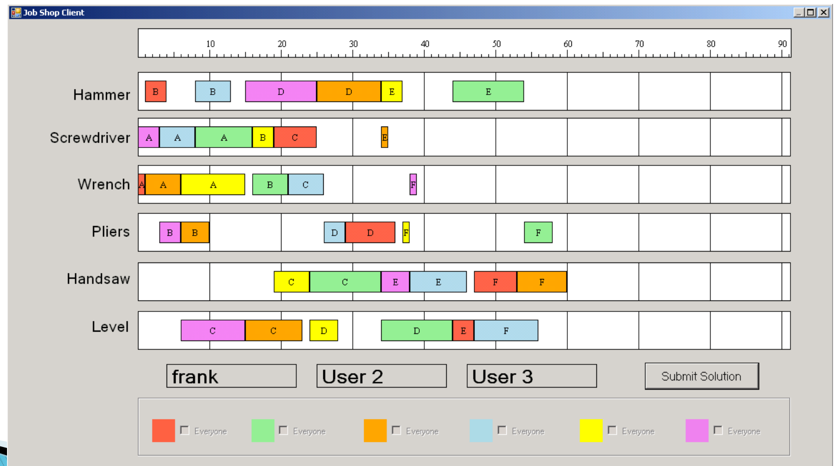
Focus on your goal

- Work as a **team** to schedule all of the blocks in the shortest amount of time
- To create the schedule, move the blocks from the right side of the screen to the left side

- Each participant works on their own laptop to move pieces
- The shared screen (this one) displays a combined view of the schedule
- Since this is a **team effort**, all three participants should **always be working together**

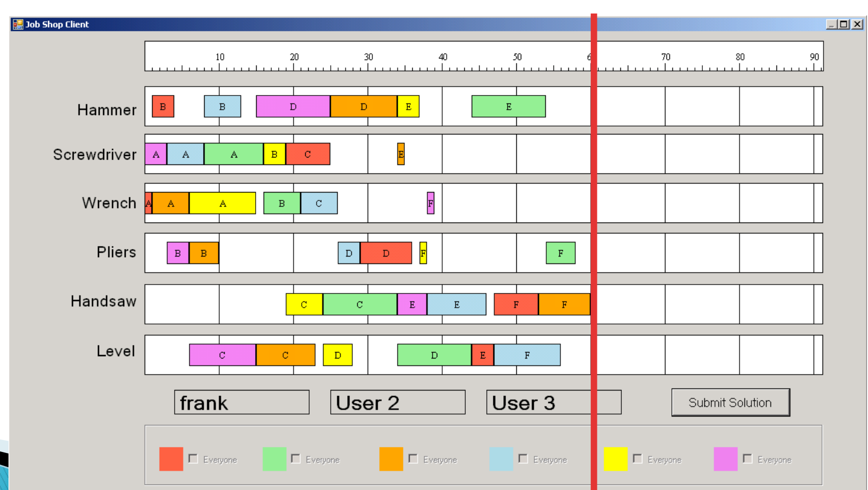
Order the coloured blocks

- Work as a **team** to
  - Order the blocks in each **row** from A to F
  - Order the blocks of each **colour** from A to F across all rows



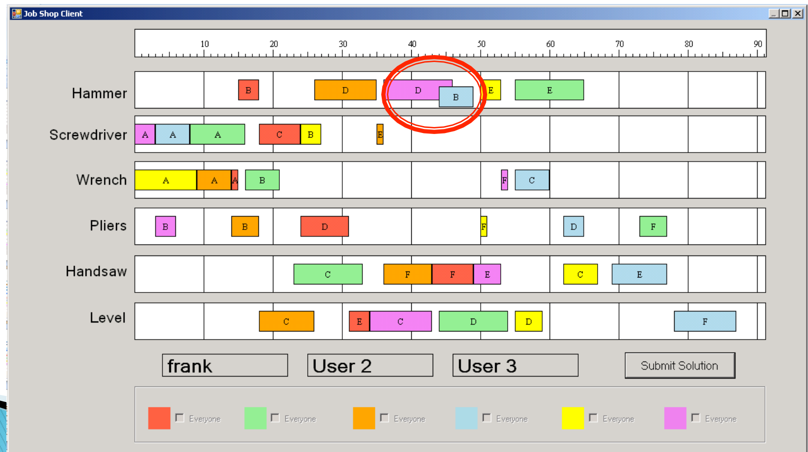
Minimize solution time

- Work as a **team** to
  - Order the blocks as tightly as possible, so that your final solution time is as short as possible
- Your final time is measured by the furthest block on the right



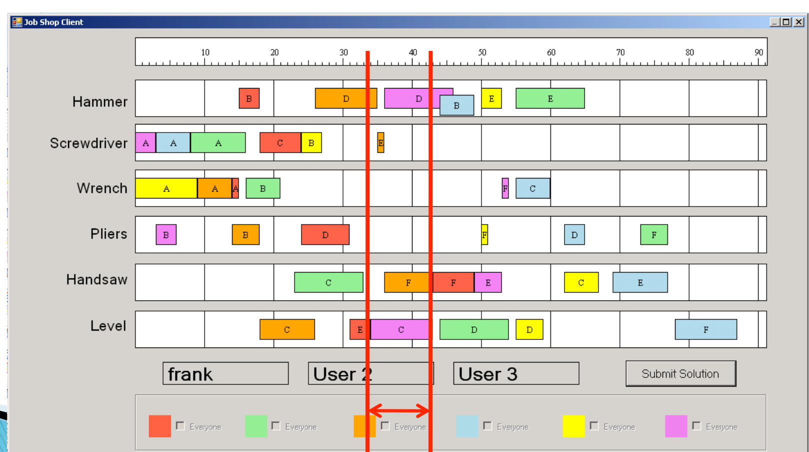
Overlap Error: Row

- Occurs when two blocks of **different colours** overlap within the **same row**
- When this happens, one of the blocks will be off-set on top of the other block



Overlap Error: Colour

- Occurs when two blocks of **the same colour** overlap on the **time indicator**
- There is no visual cue or warning when this error occurs



JobShop scheduling conditions

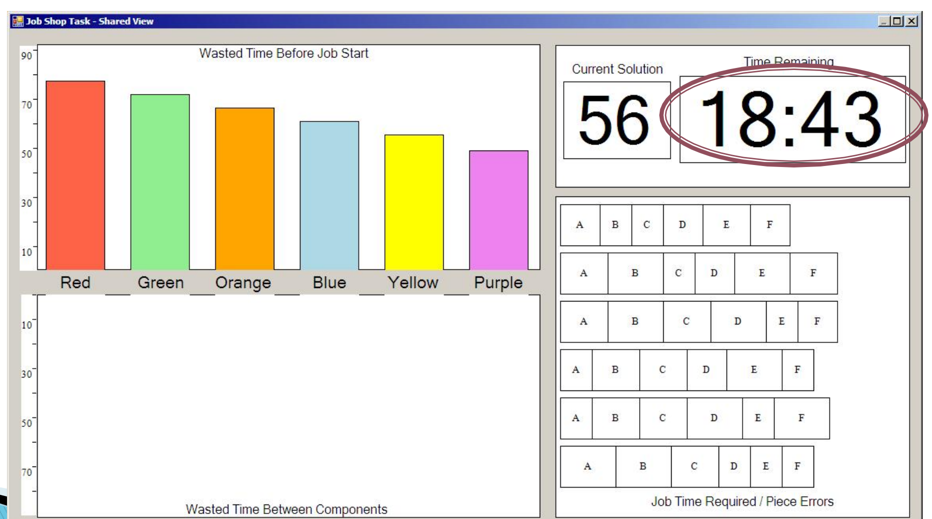
You will complete the scheduling task in **two different conditions**:

1. Shared Workspace
   - Your team can create the schedule by interacting with **both** your **personal displays** and the **shared display**
2. Status Display
   - Your team can create the schedule by interacting **only** with your **personal displays**
   - You cannot interact with the shared display
   - The large display contains status information to aid your team in completing the task

In both conditions all team members can move every block.

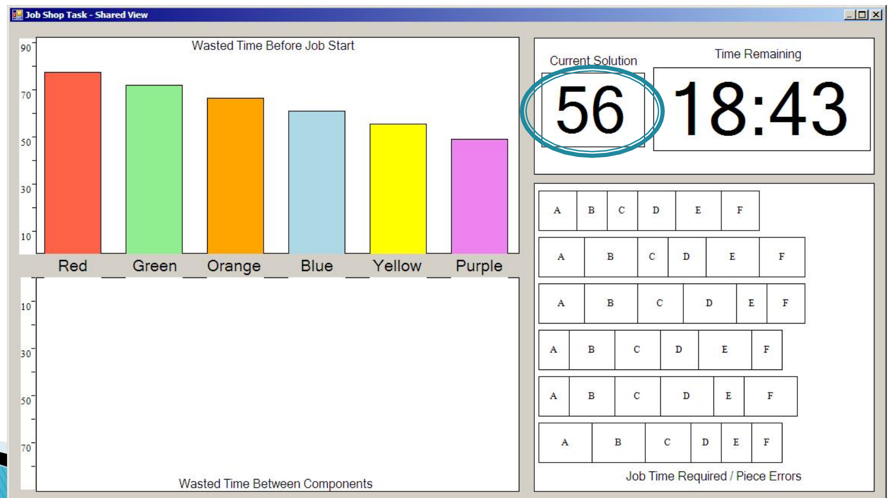
Status display: timer

- Your **timer** is on the **top right corner** of your display
- You have **20 minutes** to finish each puzzle



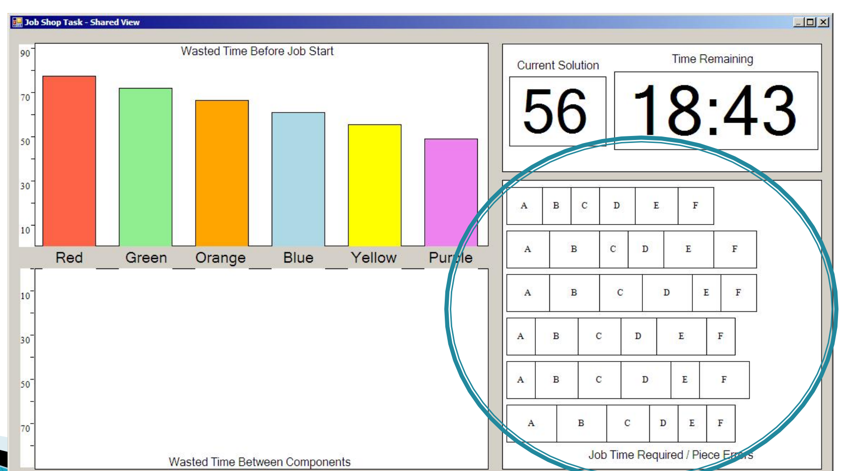
Status display: score

- Your **current solution score** is located **beside the timer** on your display
- Your score corresponds to the score on your laptop screen



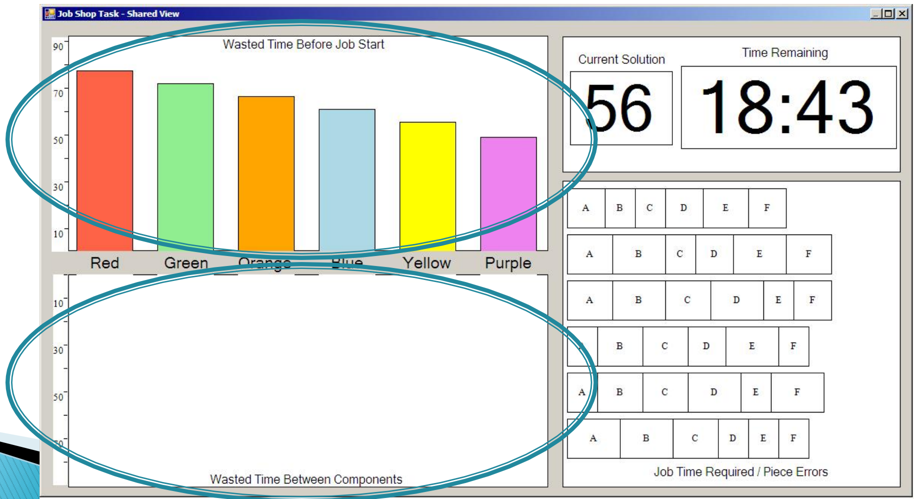
Status display: visualization

- Your **visualization** displays the **total time** it takes to complete each job
- If row or colour **overlap errors occur**, the blocks causing the error will appear in **white**



Status display: graphs

- The graph on the **top left** displays the **wasted time** between block A and the start point for **each colour**
- The graph on the **bottom left** displays the **total wasted time** between **all blocks** for **each colour**

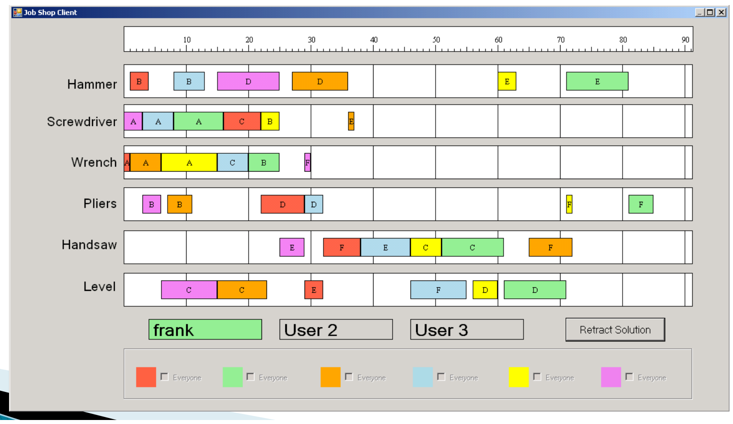


Work as a team

- You are always working as a team!
- Hint: create scheduling strategies for completing each challenge
- The different task conditions only change how the group must approach the problem, but not the problem itself

Submit your solution

- When you have finished the scheduling task, click the **Submit Solution** button
  - After clicking, the Submit Solution button will become the Retract Solution button and your name will be highlighted
- To make changes, click the **Retract Solution** button
- Your solution will not be submitted until **all team members** have clicked their **Submit Solution** buttons



Start practicing

- Remember this is a **team** activity and **NOT** a competition
- You will have **10 minutes** to complete and submit your solution in each trial
- After completing the trials, your team will complete the scheduling tasks

- **Do you have any questions?**

B.6 Post-Condition Questionnaire

Subject ID: ________________ Condition: ________________

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

1. Please circle the number on the scale from 1 to 7 to indicate how much you agree with each of the following statements. A "1" indicates that you strongly **disagree** with the statement, and a "7" indicates that you strongly **agree** with the statement.

	Strongly Disagree 1	**2**	**3**	**Neutral 4**	**5**	**6**	**Strongly Agree 7**
I felt our group worked well together.	1	2	3	4	5	6	7
I was able to interpret my peers' communications.	1	2	3	4	5	6	7
When my peers moved pieces, I was usually aware of their motivations for doing so.	1	2	3	4	5	6	7
The shared display helped us solve the puzzle.	1	2	3	4	5	6	7
I experienced conflict with my peers while completing the task.	1	2	3	4	5	6	7
I felt that it was easy to coordinate piece movements with my peers.	1	2	3	4	5	6	7
I felt it was easy to discuss new solutions with my peers.	1	2	3	4	5	6	7
I felt it was easy to suggest areas to improve on our solution with my peers.	1	2	3	4	5	6	7
I felt that solving the puzzle was mentally demanding.	1	2	3	4	5	6	7
I felt that we had enough time to solve the puzzle.	1	2	3	4	5	6	7
I felt that it took a lot of effort to solve the puzzle.	1	2	3	4	5	6	7
I felt confident that we submitted the best solution.	1	2	3	4	5	6	7
I felt that I performed well	1	2	3	4	5	6	7

Subject ID: ________________ Condition: _______________

2. Did you find the shared display useful? Why or why not?

3. Did the shared display lack any features you would have liked? Is there any feature that is not currently in the software that you feel would make the task easier to complete?

4. For the time spent during the experiment looking at the computer interfaces, please estimate what proportion of your time was spent looking at the large, shared display, how much time was spent looking at your personal laptop display, and how much time, if any, was spent looking at one of your partners' laptop display screens.

   Personal Display: Shared Display:

B.7 Post-Condition Questionnaire Response Frequencies

Summary of Study II, Shared Workspace and Negotiated Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt our group worked well together.	**0**	**1**	**1**	**3**	**4**	**8**	**1**
I was able to interpret my peers' communications.	**0**	**2**	**0**	**1**	**7**	**4**	**4**
When my peers moved pieces, I was usually aware of their motivations for doing so.	**1**	**0**	**1**	**3**	**6**	**3**	**4**
The shared display helped us solve the puzzle.	**1**	**3**	**1**	**3**	**7**	**2**	**1**
I experienced conflict with my peers while completing the task.	**2**	**6**	**2**	**0**	**2**	**5**	**1**
I felt that it was easy to coordinate piece movements with my peers.	**0**	**0**	**1**	**3**	**8**	**3**	**3**
I felt it was easy to discuss new solutions with my peers.	**0**	**1**	**0**	**3**	**6**	**4**	**4**
I felt it was easy to suggest areas to improve on our solution with my peers.	**0**	**0**	**0**	**2**	**6**	**5**	**5**
I felt that solving the puzzle was mentally demanding.	**0**	**1**	**3**	**5**	**2**	**6**	**1**
I felt that we had enough time to solve the puzzle.	**0**	**1**	**1**	**0**	**4**	**6**	**6**
I felt that it took a lot of effort to solve the puzzle.	**0**	**2**	**3**	**3**	**5**	**4**	**1**
I felt confident that we submitted the best solution.	**1**	**0**	**3**	**4**	**4**	**4**	**2**
I felt that I performed well	**0**	**0**	**2**	**4**	**4**	**5**	**3**

Summary of Study II, Status Display and Negotiated Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt our group worked well together.	**0**	**0**	**0**	**1**	**5**	**7**	**5**
I was able to interpret my peers' communications.	**0**	**0**	**1**	**1**	**7**	**5**	**4**
When my peers moved pieces, I was usually aware of their motivations for doing so.	**0**	**0**	**2**	**2**	**5**	**7**	**2**
The shared display helped us solve the puzzle.	**1**	**1**	**1**	**3**	**4**	**5**	**3**
I experienced conflict with my peers while completing the task.	**3**	**5**	**4**	**4**	**0**	**2**	**0**
I felt that it was easy to coordinate piece movements with my peers.	**0**	**0**	**1**	**3**	**7**	**3**	**4**
I felt it was easy to discuss new solutions with my peers.	**0**	**0**	**1**	**2**	**3**	**8**	**4**
I felt it was easy to suggest areas to improve on our solution with my peers.	**0**	**0**	**0**	**2**	**5**	**5**	**6**
I felt that solving the puzzle was mentally demanding.	**1**	**2**	**3**	**3**	**2**	**4**	**2**
I felt that we had enough time to solve the puzzle.	**0**	**1**	**0**	**2**	**2**	**8**	**5**
I felt that it took a lot of effort to solve the puzzle.	**1**	**1**	**4**	**4**	**3**	**2**	**3**
I felt confident that we submitted the best solution.	**0**	**1**	**3**	**5**	**4**	**3**	**2**
I felt that I performed well	**0**	**0**	**0**	**3**	**8**	**4**	**3**

Summary of Study II, Shared Workspace and Shared Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt our group worked well together.	**0**	**1**	**1**	**1**	**4**	**8**	**3**
I was able to interpret my peers' communications.	**0**	**2**	**1**	**0**	**4**	**8**	**3**
When my peers moved pieces, I was usually aware of their motivations for doing so.	**0**	**2**	**2**	**1**	**4**	**5**	**4**
The shared display helped us solve the puzzle.	**1**	**2**	**2**	**5**	**3**	**2**	**3**
I experienced conflict with my peers while completing the task.	**3**	**7**	**2**	**4**	**1**	**1**	**0**
I felt that it was easy to coordinate piece movements with my peers.	**1**	**0**	**1**	**2**	**5**	**8**	**1**
I felt it was easy to discuss new solutions with my peers.	**1**	**0**	**1**	**1**	**4**	**9**	**2**
I felt it was easy to suggest areas to improve on our solution with my peers.	**1**	**1**	**0**	**0**	**2**	**12**	**2**
I felt that solving the puzzle was mentally demanding.	**1**	**0**	**2**	**4**	**5**	**2**	**3**
I felt that we had enough time to solve the puzzle.	**0**	**0**	**1**	**3**	**3**	**5**	**6**
I felt that it took a lot of effort to solve the puzzle.	**1**	**3**	**1**	**4**	**3**	**4**	**2**
I felt confident that we submitted the best solution.	**0**	**2**	**1**	**5**	**3**	**6**	**1**
I felt that I performed well	**1**	**1**	**0**	**2**	**3**	**9**	**2**

Summary of Study II, Status Display and Shared Access Post-Condition Questionnaire Responses

	Strongly Disagree 1	2	3	Neutral 4	5	6	Strongly Agree 7
I felt our group worked well together.	**0**	**1**	**2**	**2**	**3**	**6**	**4**
I was able to interpret my peers' communications.	**0**	**2**	**2**	**1**	**4**	**5**	**4**
When my peers moved pieces, I was usually aware of their motivations for doing so.	**2**	**0**	**3**	**2**	**4**	**4**	**3**
The shared display helped us solve the puzzle.	**0**	**1**	**1**	**4**	**0**	**6**	**6**
I experienced conflict with my peers while completing the task.	**3**	**6**	**1**	**5**	**3**	**0**	**0**
I felt that it was easy to coordinate piece movements with my peers.	**1**	**1**	**3**	**3**	**4**	**5**	**1**
I felt it was easy to discuss new solutions with my peers.	**2**	**1**	**0**	**1**	**2**	**10**	**2**
I felt it was easy to suggest areas to improve on our solution with my peers.	**2**	**1**	**0**	**0**	**2**	**9**	**4**
I felt that solving the puzzle was mentally demanding.	**2**	**1**	**1**	**5**	**2**	**6**	**1**
I felt that we had enough time to solve the puzzle.	**0**	**2**	**2**	**1**	**2**	**7**	**4**
I felt that it took a lot of effort to solve the puzzle.	**2**	**1**	**3**	**3**	**5**	**3**	**1**
I felt confident that we submitted the best solution.	**2**	**1**	**2**	**0**	**2**	**8**	**3**
I felt that I performed well	**1**	**0**	**0**	**2**	**4**	**9**	**2**

B.8 End of Study Handout

UNIVERSITY OF WATERLOO

Characterizing Communication in Group Decision-Making Tasks in Single- and Multi Display Environments

Dear Participant,

I would like to thank you for your participation in this study. As a reminder, the purpose of this study is to establish a basic understanding of communication process and efficiency in these environments through the observation of real groups of participants completing a collaborative task in both single- and multi-display settings. The information gathered from the questionnaires, computer logs and interview questions in this study will be used to guide the design of multi-display interaction techniques that support natural collaborative behavior.

Please remember that any data pertaining to you as an individual participant will be kept confidential. Once all the data is collected and analyzed for this project, I plan on sharing this information with the research community through seminars, conferences, presentations, and journal articles. If you are interested in receiving more information contact me at either the phone number or email address listed at the bottom of the page. If you would like a summary of the results, please let me know now by providing me with your email address. When the study is completed, I will send it to you. The study is expected to be completed by April 1st, 2008.

As with all University of Waterloo projects involving human participants, this project was received by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext. 36005.

If you have any questions about participation in this study, please feel free to ask the researchers. If you have additional questions at a later date, please contact my thesis supervisor Dr. Stacey Scott at (519) 888-4567 ext. 32236 or by email at s9scott@engmail.uwaterloo.ca.

Jim Wallace
University of Waterloo
Department of Systems Design Engineering
519-616-5334
jrwallac@engmail.uwaterloo.ca

If you are interested in learning more about the topic, please see:

Biehl, J. T., Czerwinski, M., Smith, G., and Robertson, G. G. 2007. FASTDash: a visual dashboard for fostering awareness in software teams. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA, April 28 – May 03, 2007). CHI '07. ACM Press, New York, NY, 1313-1322. DOI= http://doi.acm.org/10.1145/1240624.1240823

Johanson, B., Hutchins, G., Winograd, T., and Stone, M. 2002. PointRight: experience with flexible input redirection in interactive workspaces. In Proceedings of the 15th Annual ACM Symposium on User interface Software and Technology (Paris, France, October 27 – 30, 2002). UIST '02. ACM Press, New York, NY, 227-234. DOI= http://doi.acm.org/10.1145/571985.572019

Appendix C

Study III Materials

C.1 Information Sheet

University of Waterloo

Information Sheet for Participants

Title of Project: An Exploration of Grounding, Monitoring, and Synchronization during Group Decision-Making Tasks

Faculty Supervisor: Prof. Stacey Scott

University of Waterloo, Department of Systems Design Engineering

519-884-4567 Ext. 32236

Faculty Supervisor: Prof. Carolyn MacGregor

University of Waterloo, Department of Systems Design Engineering

519-884-4567 Ext. 32897

Student Investigator: Jim Wallace

University of Waterloo, Department of Systems Design Engineering

Summary of the Project:

The overall goal of our research is to design interfaces that help people perform collaborative work. While interactions between a single user and computer via a mouse and keyboard have been studied for decades, interactions with new technologies such as interactive surfaces (e.g. an iPhone) are still poorly understood. The information gathered in this study will be used to further our understanding of interactive tabletops, targeted specifically at understanding how to build educational software for children's education.

Procedure:

Your participation in this study will involve a background questionnaire, a short demo of interactive tabletop software followed by a group problem solving session, and a final questionnaire.

You will be asked to:

- Complete a short background questionnaire that asks for demographic information.
- Familiarize yourself with some demo tabletop software, and then complete a group problem-solving session with that software.
- Participate in a short, post-study questionnaire that will ask you about your experiences during the problem solving session.

The session will take approximately 60 minutes.

During the session, a researcher will observe and take notes regarding your interactions with the activity resources and tabletop. You will also be audio and videotaped. You may withdraw your participation in the study at any time without penalty.

Confidentiality and Anonymity:

All information you provide is considered completely confidential. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations 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 in a locked office and only researchers associated with this project will have access.

You will be explicitly asked for consent for the release of photo/video/audio data captured during the study for the purpose of reporting the study's findings. If consent is granted, these data will be used only for scientific (inclusion in conference presentations, conference or journal papers), thesis and/or teaching purposes.

All questionnaires and recordings will be kept indefinitely in a secure cabinet in a locked University of Waterloo room. Electronic data will be kept indefinitely and stored on a password protected computer and/or copied to CD.

Remuneration for your Participation:

As a participant in this study, you be paid $10. The group that completes the problem-solving task in the shortest time while discovering the correct solution will receive a $20 per person prize. We anticipate that the study will take approximately 60 minutes to complete.

Risks and Benefits:

There are no known or anticipated risks to participation. There are no direct benefits to you, however the results of this research may contribute to the knowledge base of Human Systems Engineering research and also may lead to the development of better user interfaces.

Ethics Clearance:

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes at 519-888-4567 Ext. 36005 or ssykes@uwaterloo.ca.

Thank you for your assistance in this project.

C.2 Informed Consent Form

UNIVERSITY OF WATERLOO

INFORMED CONSENT BY SUBJECTS TO PARTICIPATE IN A RESEARCH EXPERIMENT

Project: Towards Guidelines for the Design of Multi-Display Environments

I have read the information presented in the information letter about a study being conducted by Prof. Stacey Scott, Prof. Carolyn MacGregor and Jim Wallace of the Department of Systems Design Engineering at the University of Waterloo. 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 videotape clearly show 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 agree to allow video and/or digital images in which I appear to be used in teaching, scientific presentations and/or publications with the understanding that I will not be identified by name.

I also agree to allow excerpts from the interview and discussion 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 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 by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics at 519-888-4567 ext. 36005 or ssykes@uwaterloo.ca.

	Please One	**Circle**	**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 videotaped, photographed, and audio-taped.	YES	NO	_____
I agree to let my conversation during the study be directly quoted, anonymously, in presentation of research results.	YES	NO	_____
I agree to let the videotapes/digital images/audiotapes be used for presentation of research results.	YES	NO	_____

Participant Name: __________________________ (Please print)

Participant Signature: __________________________ Date __________________________

Witness Name: __________________________ (Please print)

Witness Signature: __________________________ Date __________________________

C.3 Background Questionnaire

Background Questionnaire

Group ID:_______ Subject ID: _______

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

1. What is your gender?	Female Male
2. What is your age? (in years)	
3. What is your primary occupation? If student, what degree/program are you in?	
4. Please list any management or business courses you have taken	
5. Do you own a tablet computer? (e.g. an Apple iPad or Samsung Galaxy Tab) a. How often do you use your tablet computer? (e.g. on a daily basis?) b. How often do you use your tablet computer during class or a meeting?	
6. Please list 3 words that you would use to describe *positive* group experiences you've had:	1. 2. 3.
7. Please list 3 words that you would use to describe *negative* group experiences you've had:	1. 2. 3.

C.4 Post-Condition Questionnaire

Group ID:_______ Subject ID: _______
Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

1. Please circle the number on the scale from 1 to 7 to indicate how much you agree with each of the following statements. A "1" indicates that you strongly **disagree** with the statement, and a "7" indicates that you strongly **agree** with the statement.

	Strongly Disagree 1	**2**	**3**	**Neutral 4**	**5**	**6**	**Strongly Agree 7**
I felt our group worked well together.	1	2	3	4	5	6	7
I felt confident that we submitted the right solution.	1	2	3	4	5	6	7
I felt that the problem was mentally demanding.	1	2	3	4	5	6	7
I felt it was easy to compare data between slides	1	2	3	4	5	6	7
I felt that we had enough space to share documents	1	2	3	4	5	6	7
I felt the tools we were given to solve the problem were enough	1	2	3	4	5	6	7
I felt this experience was better than a typical group meeting	1	2	3	4	5	6	7
I felt I had a good grasp of the content of *my own* slide deck	1	2	3	4	5	6	7
I felt that I had a good grasp of the content of *my group members'* slide decks	1	2	3	4	5	6	7
I was satisfied with the process in which the group developed their solution.	1	2	3	4	5	6	7
I felt that the scenario was realistic (Do you believe that this could be an example of an actual decision-making situation within an organization?)	1	2	3	4	5	6	7
I was satisfied with the number of ideas that the group came up with.	1	2	3	4	5	6	7
I felt that I contributed to the group	1	2	3	4	5	6	7

Group ID:_______ Subject ID: _______

2. Were there any tools that you wished you had to make the group decision-making process easier?

3. Three things I *liked* about the tools that were provided to me are:

1.

2.

3.

4. Three things I *disliked* about the tools that were provided to me are:

1.

2.

3.

C.5 Post-Condition Questionnaire Response Frequencies

Study III participant response frequencies for Table Only Conditions

	Strongly Disagree 1	**2**	**3**	**Neutral 4**	**5**	**6**	**Strongly Agree 7**
I felt our group worked well together.	1	0	0	0	10	9	8
I felt confident that we submitted the right solution.	1	0	0	3	2	14	8
I felt that the problem was mentally demanding.	1	1	1	8	9	5	2
I felt it was easy to compare data between slides	1	0	0	7	9	8	2
I felt that we had enough space to share documents	1	7	7	1	5	6	1
I felt the tools we were given to solve the problem were enough	1	0	3	3	8	9	4
I felt this experience was better than a typical group meeting	1	0	0	3	5	10	9
I felt I had a good grasp of the content of *my own* slide deck	1	0	2	2	7	11	5
I felt that I had a good grasp of the content of *my group members'* slide decks	0	1	4	3	13	6	1
I was satisfied with the process in which the group developed their solution.	1	0	1	2	8	11	5
I felt that the scenario was realistic (Do you believe that this could be an example of an actual decision-making situation within an organization?)	1	1	2	2	10	5	7
I was satisfied with the number of ideas that the group came up with.	1	0	2	0	6	14	5
I felt that I contributed to the group	1	0	2	3	8	9	3

Study III participant response frequencies for Table Plus Tablets Conditions

	Strongly Disagree 1	**2**	**3**	**Neutral 4**	**5**	**6**	**Strongly Agree 7**
I felt our group worked well together.	0	1	0	1	6	8	12
I felt confident that we submitted the right solution.	1	1	0	1	4	12	9
I felt that the problem was mentally demanding.	0	2	3	4	7	8	4
I felt it was easy to compare data between slides	0	4	2	4	7	8	3
I felt that we had enough space to share documents	0	5	3	2	5	7	6
I felt the tools we were given to solve the problem were enough	0	2	1	3	10	8	4
I felt this experience was better than a typical group meeting	1	0	1	4	1	11	10
I felt I had a good grasp of the content of *my own* slide deck	2	0	2	1	8	11	4
I felt that I had a good grasp of the content of *my group members'* slide decks	1	0	2	3	14	5	3
I was satisfied with the process in which the group developed their solution.	1	0	1	3	4	11	8
I felt that the scenario was realistic (Do you believe that this could be an example of an actual decision-making situation within an organization?)	1	1	1	4	5	9	7
I was satisfied with the number of ideas that the group came up with.	0	1	2	4	6	9	6
I felt that I contributed to the group	0	1	2	2	5	8	9

Study III participant response frequencies for Tablets Only Conditions

	Strongly Disagree 1	**2**	**3**	**Neutral 4**	**5**	**6**	**Strongly Agree 7**
I felt our group worked well together.	0	0	0	0	6	10	12
I felt confident that we submitted the right solution.	0	0	1	1	3	10	13
I felt that the problem was mentally demanding.	0	2	2	10	3	6	5
I felt it was easy to compare data between slides	3	3	7	3	7	3	1
I felt that we had enough space to share documents	1	5	2	5	7	4	4
I felt the tools we were given to solve the problem were enough	2	3	3	3	8	5	3
I felt this experience was better than a typical group meeting	0	1	0	12	3	10	2
I felt I had a good grasp of the content of *my own* slide deck	0	1	4	0	8	12	3
I felt that I had a good grasp of the content of *my group members'* slide decks	0	3	4	1	12	7	1
I was satisfied with the process in which the group developed their solution.	0	1	1	1	7	8	10
I felt that the scenario was realistic (Do you believe that this could be an example of an actual decision-making situation within an organization?)	1	0	2	2	9	11	3
I was satisfied with the number of ideas that the group came up with.	0	0	0	1	6	12	9
I felt that I contributed to the group	0	0	1	2	9	9	6

C.6 Task Materials

Sales Consultant

Bonanza Paper Forms

Case Files

DIRECTIONS In this study, you are playing the role of consultants hired by Bonanza Business Forms Company. This company sells paper forms for three markets: small business, hospital, and financial institutions. During the previous three quarters, profits have steadily decreased while total sales were increasing. Bonanza's management cannot determine the cause of the declining profits, so that's why you've been brought in.

Your goal, as an individual, is to look over the information provided to you. Then, as a group, you need to make sense of the information provided to determine why Bonanza is losing money while sales are increasing.

Do not look at any slides until you are told to do so

10

Sales Consultant

Your Role:

Sales Consultant

For this meeting you will play the role of a *Sales Consultant* who has researched the company's sales force and markets. The following slides in this document provide data, charts, and figures related to the company.

When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so

11

Bonanza Sales Force

- Calls on all the three forms markets Bonanza services: health care, financial institutions, and small business.
- Compensated through a commission based on their total sales.
- Size of the sales force has not changed substantially over the past five quarters (107-persons)

Market Information

- Health Care
  - Marketed towards hospitals, clinics, and pharmacies.
  - Over the past two years, became extremely competitive and difficult to establish any product differentiation between competitors.
- Financial Institutions
  - Marketed towards banks and insurance companies
  - Competition is less fierce
  - Moderate amount of product differentiation exists amongst competitors

Sales Consultant

Customer Base

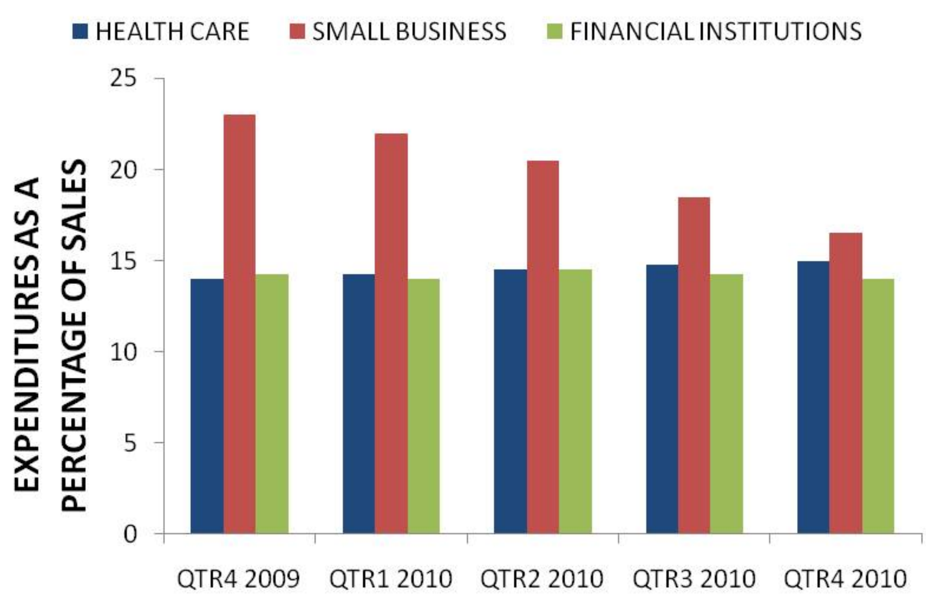
- In recent years, Bonanza has attempted to diversify its customer base.

- Expansion into the small business market.
  - Rapid growth in this segment due to proliferation of desktop and laptop computers.
  - Bonanza success in this area is mainly due to its unique product, laser-cut forms for easy tearing.

14

Sales Consultant

Fig 5. Quarterly Distribution Costs as a Percentage of Sales (in Percentages)



15

Fig 6. Bonanza Business Form's Service Level / Percentage of Orders Filled On-Time

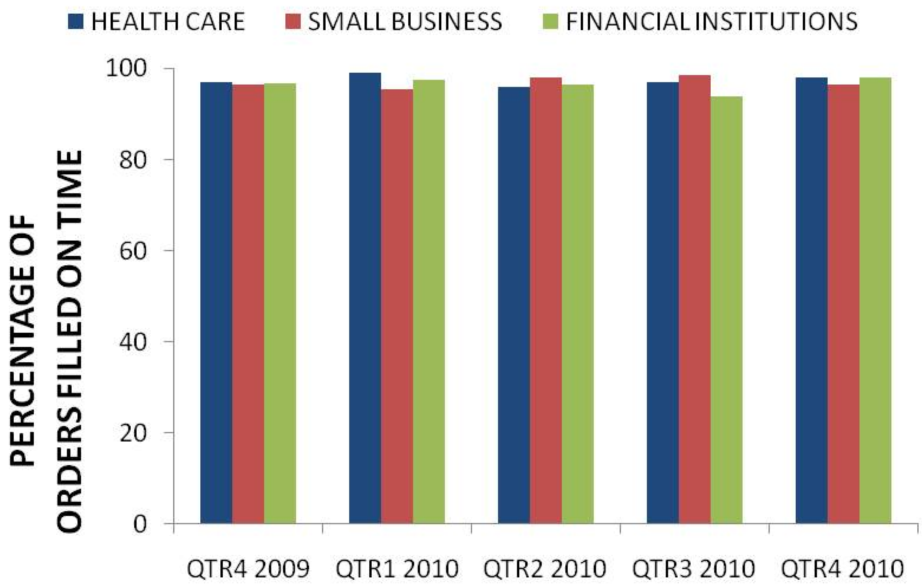


Fig 7. The Number of Sales Calls made in Three Markets as a Percentage of Total Number of Company Sales Calls

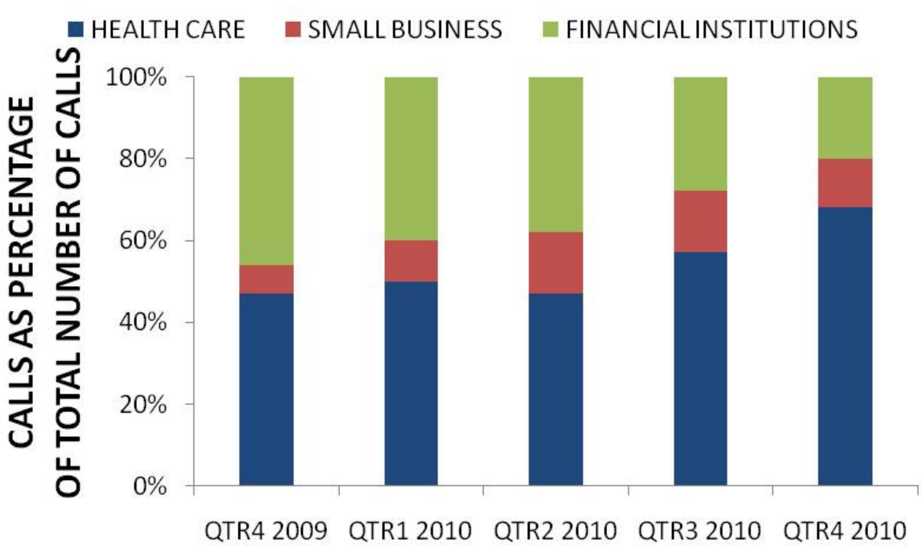


Fig 8. Bonanza Paper Company's Average Number of Accounts in Three Markets

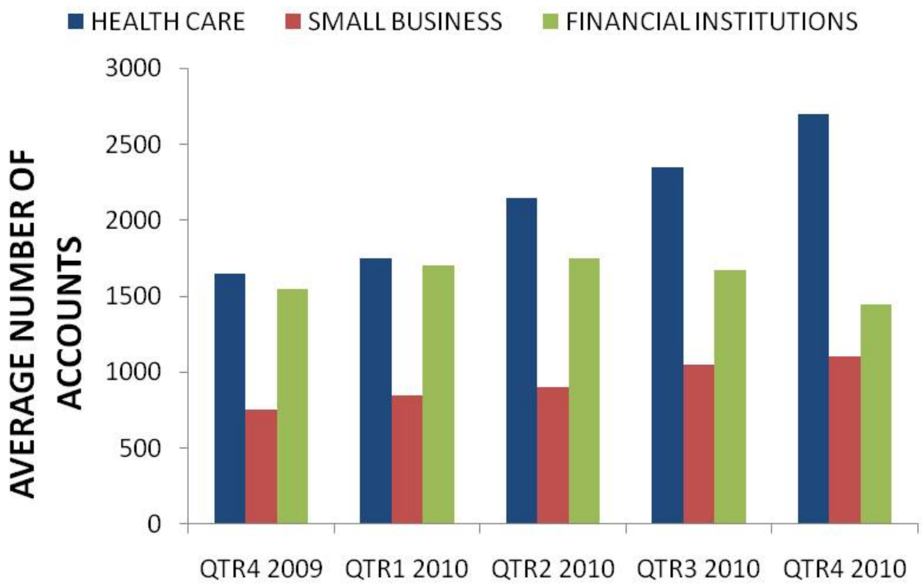
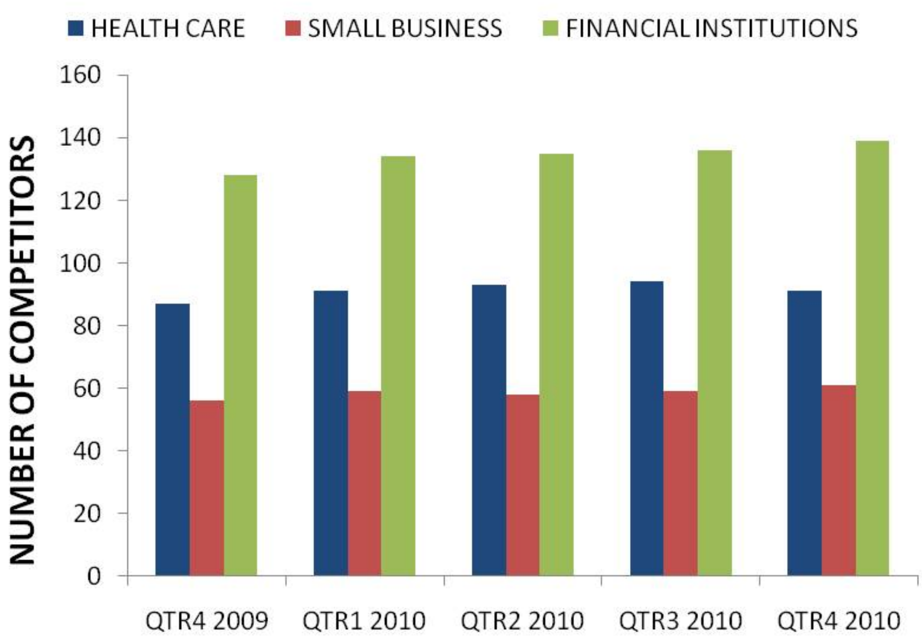


Fig 9. Number of Competitors in Market Areas



Bonanza Paper Forms

Case Files

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Do not look at any slides until you are told to do so

1

Your Role:

Domain Research Consultant

For this meeting you will play the role of a *Domain Research Consultant*. The following slides in this document provide data, charts, and figures related to the company and the paper forms industry domain.

When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so

2

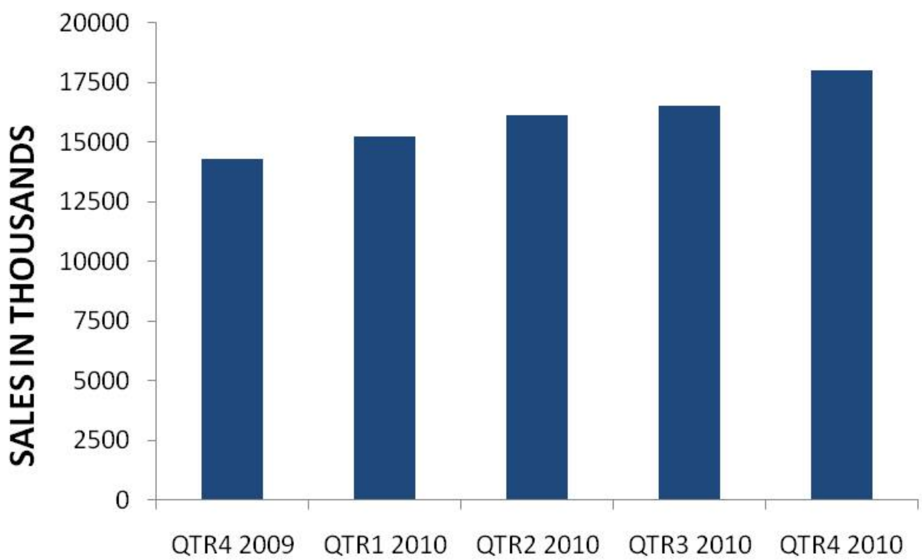
Bonanza Paper Company

- Star performer on local over-the-counter paper stock
- $70 million-a-year sales operation
- Medium-sized business with 1,225 employees, total assets of $30 million.
- Founded to manufacture and market continuous business forms.

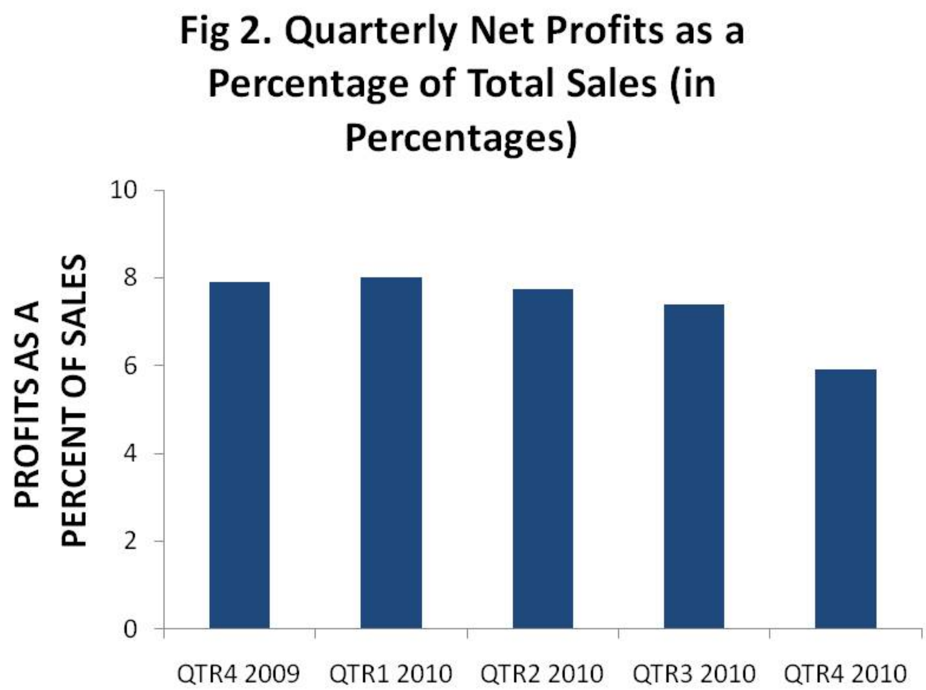
3

Domain Research Consultant

Fig 1. Total Quarterly Sales Dollars (in Thousands of Dollars)



4



5

Domain Research Consultant

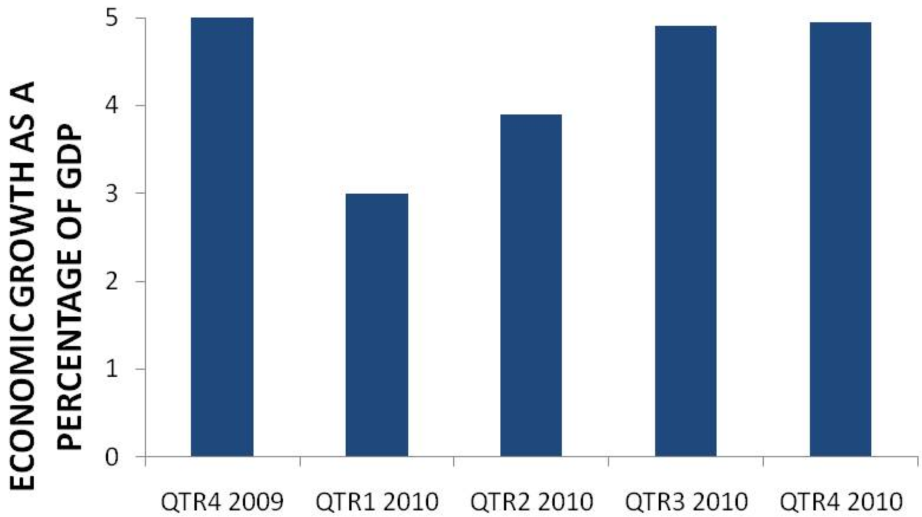
Bonanza Paper Company

- Internal investigation into decrease in profits
  - Problem is **NOT** in production
  - Evidence suggests problem is in marketing
- Demand for business forms is closely tied to leading economic indicators, trends in the computer market, and new development
  - Paperless technology is likely to increase competition in the business forms industry.

6

Domain Research Consultant

Fig 3. Annual Canadian Industrial Economic Growth as a Percentage of Real GDP



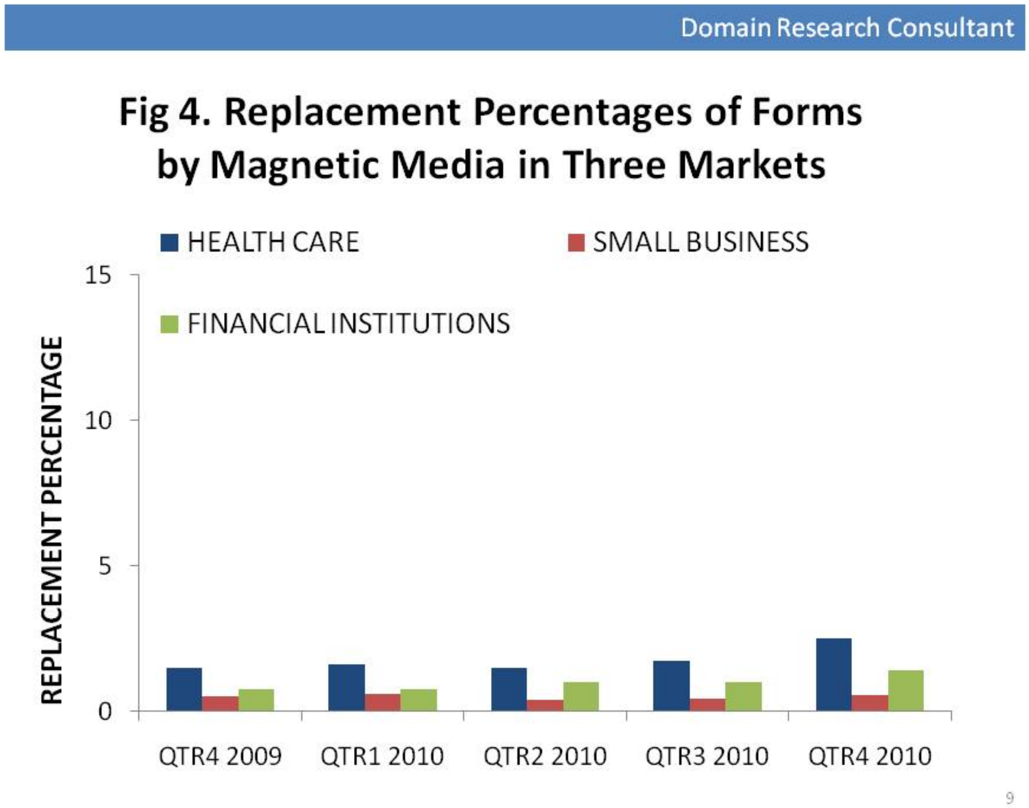
7

Domain Research Consultant

Paper Forms Distribution

- Distribution Channels:
  1. Independent Distributors
     - Approximately 2000 full-time distributors exist in the market
  2. Manufacturer's Sales Force
     - Bonanza is one of the few companies that markets directly using an internal sales force
     - Belief is strong customer loyalty is developed through personal contact by the sales force
  3. Retail, catalog/direct mail, web site, and telemarketing operations

8


Domain Research Consultant
Fig 4. Replacement Percentages of Forms by Magnetic Media in Three Markets
HEALTH CARE
SMALL BUSINESS
FINANCIAL INSTITUTIONS
REPLACEMENT PERCENTAGE
15
10
5
0
QTR4 2009
QTR1 2010
QTR2 2010
QTR3 2010
QTR4 2010
9

Bonanza Paper Forms

Case Files

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Do not look at any slides until you are told to do so

20

Your Role:

Financial Consultant

For this meeting you will play the role of a *Financial Consultant* who has researched the markets that the company sells to. The following slides in this document provide data, charts, and figures related to the company.

When you are instructed to do so, please read over the slides and familiarize yourself with the information.

Do not look at any slides until you are told to do so

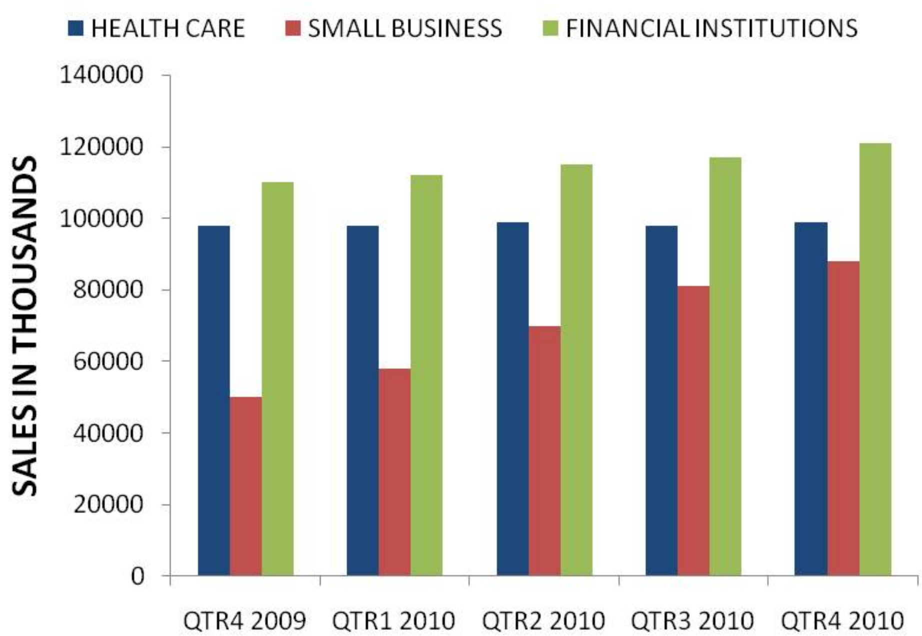
21

Internal Audit

- Research total industry sales

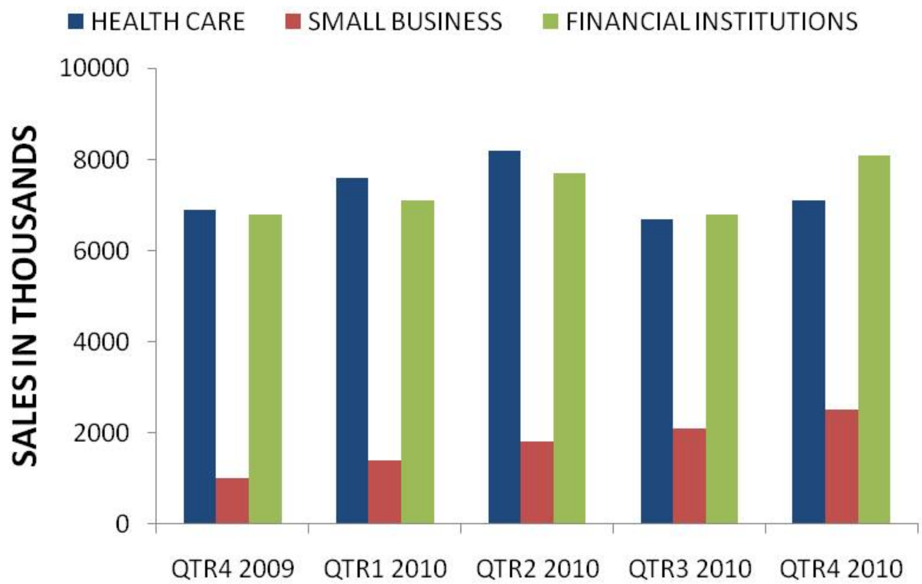
- Focus on the three markets Bonanza markets towards:
  - Total Industry Sales vs.
  - Quarterly Sales vs.
  - Quarterly Profits

Fig 10. Total Industry Sales in Markets



Financial Consultant

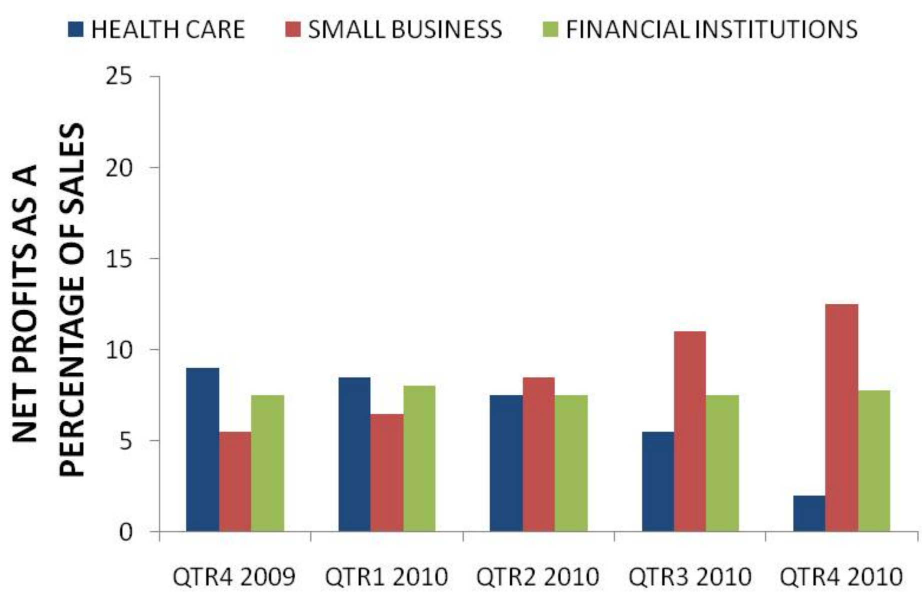
Fig 11. Quarterly Sales Dollars in Three Markets (in Thousands of Dollars)



24

Financial Consultant

Fig 12. Quarterly net Profits as Percentage of Sales in Three Markets (in Percenatges)



25

Bonanza Paper Forms

Case Files

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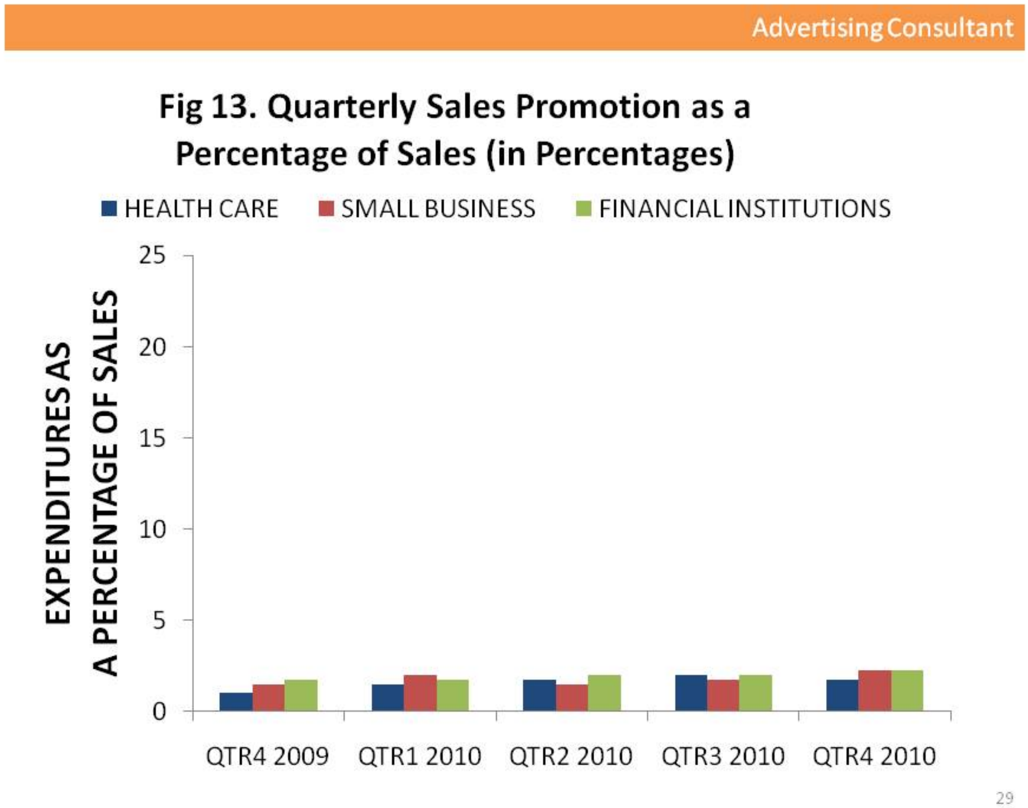
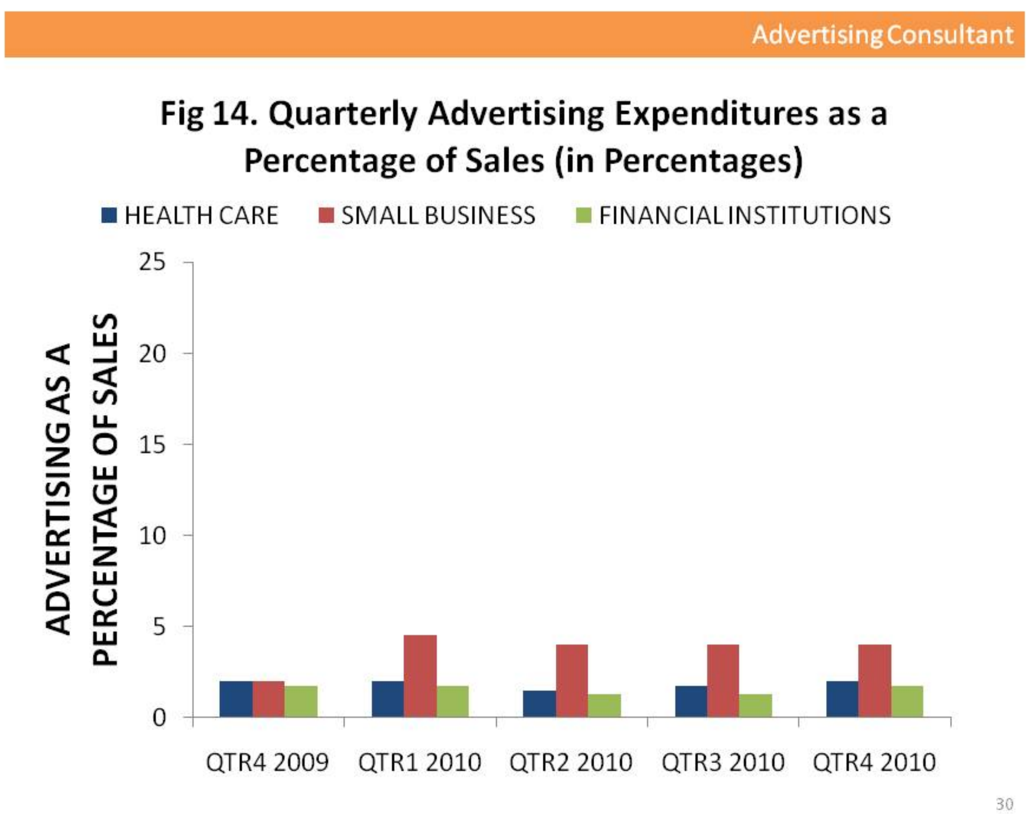
26

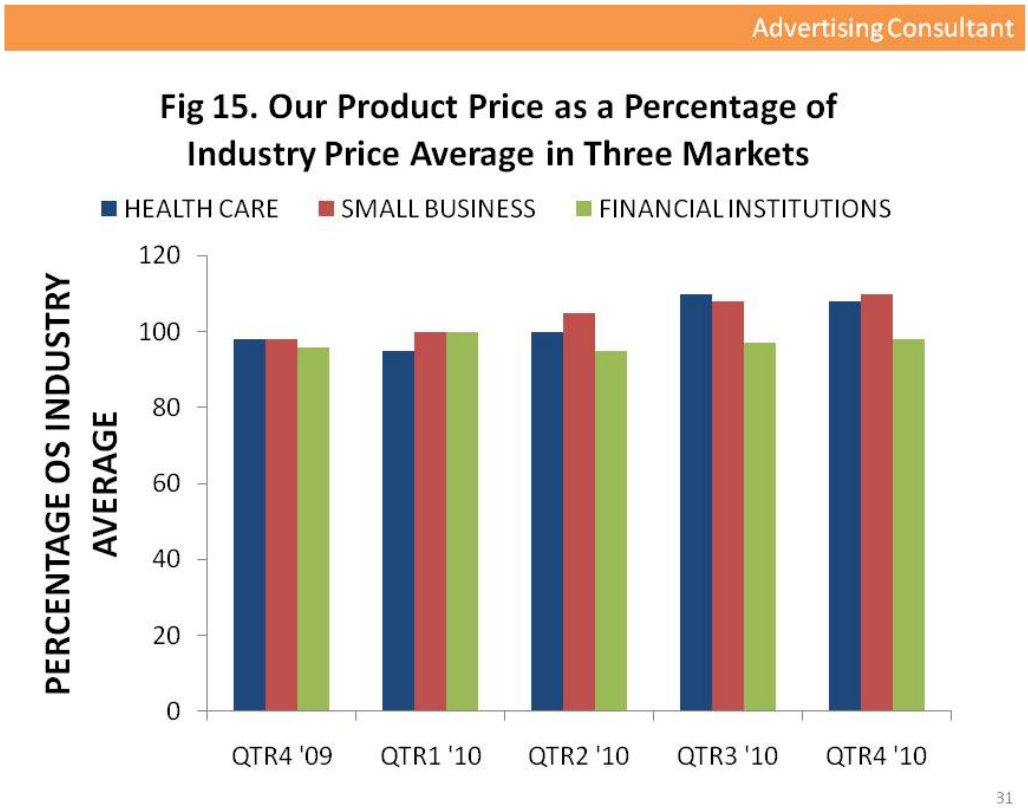
Advertising

- Advertises in health and financial community trade publications
- Sends catalogs to small businesses
- Total advertising expenses are at the industry averages
- Bonanza prides itself on maintaining quality in its products and relationships with customers
  – As a result, Bonanza can charge prices at the industry average or slightly higher in some markets

28


Advertising Consultant
Fig 13. Quarterly Sales Promotion as a Percentage of Sales (in Percentages)
HEALTH CARE
SMALL BUSINESS
FINANCIAL INSTITUTIONS
EXPENDITURES AS A PERCENTAGE OF SALES
25
20
15
10
5
0
QTR4 2009
QTR1 2010
QTR2 2010
QTR3 2010
QTR4 2010
29


Advertising Consultant
Fig 14. Quarterly Advertising Expenditures as a Percentage of Sales (in Percentages)
HEALTH CARE
SMALL BUSINESS
FINANCIAL INSTITUTIONS
ADVERTISING AS A PERCENTAGE OF SALES
25
20
15
10
5
0
QTR4 2009
QTR1 2010
QTR2 2010
QTR3 2010
QTR4 2010
30



C.7 End of Study Handout

UNIVERSITY OF WATERLOO

An Exploration of Grounding, Monitoring, and Synchronization during Group Decision-Making Tasks

Dear Participant,

I would like to thank you for your participation in this study. As a reminder, the purpose of this study is to establish a basic understanding of communication and coordination processes during group decision-making through the observation of real groups of participants completing a decision-making task. The information gathered from the recorded video and interview questions in this study will be used to guide the study of interactive tabletop software that supports natural collaborative behavior.

Please remember that any data pertaining to you as an individual participant will be kept confidential. Once all the data is collected and analyzed for this project, I plan on sharing this information with the research community through seminars, conferences, presentations, and journal articles. If you are interested in receiving more information contact me at either the phone number or email address listed at the bottom of the page. If you would like a summary of the results, please let me know now by providing me with your email address. When the study is completed, I will send it to you. The study is expected to be completed by August 1st, 2012.

As with all University of Waterloo projects involving human participants, this project was reviewed and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext. 36005.

If you have any questions about participation in this study, please feel free to ask the researchers. If you have additional questions at a later date, please contact my thesis supervisor Dr. Stacey Scott at (519) 888-4567 ext. 32236 or by email at s9scott@engmail.uwaterloo.ca.

Jim Wallace
University of Waterloo
Department of Systems Design Engineering
519-888-4567 ext. 33677
jrwallac@engmail.uwaterloo.ca

If you are interested in learning more about the topic, please see:

Plaue, C. and Stasko, J., Presence & Plancement: Exploring the Benefits of Multiple Shared Displays on an Interactive Sensemaking Task. in *Proceedings of the ACM 2009 International Conference on Supporting Group Work (GROUP '09)*, (Sanibel Island, FL, USA, 2009), ACM Press, 179-188.

Wallace, J.R., Scott, S.D., Stutz, T., Enns, T. and Inkpen, K. Investigating teamwork and taskwork in single- and multi-display groupware systems. *Personal and Ubiquitous Computing*, *18* (8). 569-581.