Do You Know What I Know?

Situational Awareness of Co-located Teams in Multidisplay Environments

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IN MULTIDISPLAY ENVIRONMENTS

DISSERTATION

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Chapter 1

Introduction

> *"A vision without a task is but a dream, a task without a vision is a drudgery, a vision and a task is the hope of the world."*
> *–from the church in Sussex, England, ca. 1730*

1.1 *Display-mania*

Remember the good old days when people used to go to a meeting with a paper notebook and a pen in a room with only a table, a couple of chairs and a blackboard? Can you believe that, twenty years ago, people used to travel without a mobile phone and an MP3 player or going to a meeting without a laptop?

Today, we live in a world of screens. People are surrounded with all kinds of screens [Beale and Edmondson, 2007; Borchers, 2006; Paek et al., 2004] on personal devices such as mobile phones, PDA's, MP3 players, digital cameras, laptops and PC monitors, navigation systems and so on. Public large displays are also constantly present in urban environments [Jacucci et al., 2009; Morrison and Salovaara, 2008]. Think of the advertisement billboards, touch screens to buy tickets at train stations and airports, projectors and wall-size information displays in public and work spaces, and even in our homes [Markopoulos et al., 2005]. For many people it is no longer enough to check emails only from their office desk. Nowadays, people feel the need and are provided with simple affordable ways to constantly be 'online' wherever they go. Emailing, synchronizing diaries, updating a Facebook status or talking via skype has become part of our daily routine. As the price of the large displays decreases fast, people and especially companies tend to buy wall-size displays for a home cinema or a modern meeting room. When it comes to the size and the number of displays, people often assume 'the more and the bigger – the better', and 'cooler'. And as you can imagine, as well as multitasking individually, more and more modern meeting rooms are equipped with projectors, digital whiteboards, touch screens, tablet PCs, etcetera.

Let me give you an example. Imagine a modern city traffic control room (Figure 1.1). If you have ever seen one in a movie or in real life, you can picture a large number of monitors and a wall-size display with a city map. How does an operator stay on top of everything that is going on in the control room? It takes a trained team of professionals to monitor what is going on, constantly communicate the state of events to each other and to react to the unexpected events. Well, pretend you happen to be invited to experience working in the control room for a day. A chief operator gives you a task to monitor all displays in the room and report any changes or unexpected events. Here is a million dollar question: *Do you think you could manage?*

Figure 1.1: Traffic control room example.

1.2 Problem Statement

Modern collaborative environments often provide an overwhelming amount of visual information on multiple displays [Borchers, 2006; Kulyk et al., 2007a]. The complexity of the collaborative situation and the vast amount of expertise in a team lead to lack of awareness of team members on ongoing activities, and awareness of who is in control of shared artefacts. This thesis addresses the *situational awareness* (SA) [Banbury and Tremblay, 2004] support of multidisciplinary teams in co-located multidisplay environments. *Situational awareness* concerns "knowing what is (and has been) going on", basically being aware of what is happening around you in the environment and having a shared understanding of the information. This work aims at getting insights into design and evaluation of shared display visualisations that afford situational awareness and group decision making.

The research reported in this thesis is conducted has been the framework of the BioRange[1] project; a large, national project aimed at strengthening the bioinformatics infrastructure in the Netherlands. The subproject 4.2.1 *User Interfaces for Scientific Collaboration* at the Human Media Interaction Group in the University of Twente is devoted to the user-centred design and evaluation of visualisations and enriched interactions in order to enhance the exploration of diverse information resources by multidisciplinary teams of scientists. Understanding users in their context of work,

[1] http://www.nbic.nl/research/biorange/, last retrieved: Dec 5, 2009

their working practices with different information resources and tools, is essential to provide information technology to facilitate team decision making.

1.3 Co-located collaboration

The diversity of multiple disciplines in teams stimulates the processes of creative thinking and reasoning and positively impacts collaborative problem solving [Coughlan and Johnson, 2006; Dunbar, 1997; Mumford et al., 2001; Shalley and Gilson, 2004]. Creativity plays an important role in collaborative practices of multidisciplinary teams [Coughlan and Johnson, 2006; Paulus, 2000; Pirola-Merlo and Mann, 2004]. On the other hand, the vast amount of expertise in a team might also lead to the lack of understanding of the representations in different disciplines. It is essential to analyse how such collaboration takes place in daily work practices.

As the literature confirms, team collaboration and creativity can be supported by providing an appropriate environment and a certain context [Coughlan and Johnson, 2006; Sundholm et al., 2004]. However, introducing a new environment and new technologies - for example, presenting multiple visualisations on a large display - may increase team members' cognitive load and influence the way they collaborate [Varakin et al., 2004]. Awareness of what is going on in such shared environments is required to coordinate team activities [Dourish and Bellotti, 1992]. Thus, the complex project settings, the amount of visual information on multiple displays, and the multitude of personal and shared interaction devices in new multidisplay environments, can reduce the awareness of team members on ongoing activities, the understanding of shared visualisations, and the awareness of who is in control of shared artefacts. The focus of this research is on the situational awareness support of co-located teams in multidisplay environments.

1.4 Multidisplay Environments (MDEs)

Awareness and awareness support systems for collaboration have been a topic of research in Human-Computer Interaction (HCI) since the mid-1980s. Although in the last few years awareness concepts have become increasingly complex, knowledge of what awareness in collaboration actually means has not progressed as well. Various classifications were introduced in the early years, such as synchronous versus asynchronous and social vs. task awareness and so on, but no single one of them covers all the aspects of awareness research in computer-supported collaborative work (CSCW). Despite the popularity of awareness topics in research, there are only a few overviews of the existing research and awareness classifications summarised in a structured manner [Gross et al., 2005; Schmidt, 2002]. Thus, in order to understand what situational awareness means in our research and to identify the research questions, we first take the challenge to conceptualize the notion of awareness and give an overview of the existing types of awareness in relation to team collaboration practices. Next, various types of awareness are discussed, followed by examples of various awareness classifications from computer-supported collaborative work (CSCW) and social studies.

1.5 Awareness Classification

According to the general definition of Chalmers [2002], *awareness* is the ongoing interpretation of current representations of human activity and of artifacts. Importantly, the definition above focuses on the awareness of people, rather than on systems or their environment. We find that *past* activities are missing in the definition of Chalmers [2002]. Namely, awareness of the current situation should be combined with a memory of the interpretation of recent human activities and of artifacts. For example: "I see someone's bag in my office, and I remember that Courtney is in on Wednesdays". We will explain this further, along with our own definition of situational awareness in chapter 2.

Various types of awareness are described in human-computer interaction research, computer-supported collaborative work and social studies [Bardram et al., 2006; Gross et al., 2005; Gutwin and Greenberg, 2002; Markopoulos et al., 2009]. Importantly, the definition above focuses on awareness of people, rather than on systems or their environment. This can be contrasted to the concept of *context-awareness* that has also been studied extensively in CSCW research [Hallnass and Redstrom, 2002]. We will not consider the awareness of the environment as studied in context-awareness research on sensor-based smart environments. Instead, we will focus on what types of awareness characterize a person who is trying to stay aware of the surrounding environment.

Gross et al. [2005] proposed a classification that distinguishes between: (1) *spatial*, (2) *temporal*, and (3) *social awareness*:

(1) Designing for *spatial awareness* aims at providing people with an awareness of distinctive features of a specific location [Bardram et al., 2006], for example, providing the level of activity in the operating room, what kind of operation is taking place there, status of the operation, the kind of professionals in the room and so on.

(2) Designing for *temporal awareness* aims at providing an awareness of past, present, and future activities and events which may be relevant for the experts or team members working in a shared control or team room. In the medical domain, for instance, temporal awareness information would include activities and events that are relevant for the medical staff in the operating ward, such as operating schedule for each operating room [Bardram et al., 2006]. This type of awareness resembles the definition of situational awareness [Endsley, 1995a].

(3) The goal of designing for *social awareness* is to provide people with general awareness of their team members and colleagues, what they are doing and where they are [Bardram et al., 2006; Markopoulos et al., 2005]. It is less important to show exactly what the other people are doing. Instead, providing relevant cues can help to form an overview of what other people are most likely doing. Such relevant contextual cues can be, for instance, location, status, activity, and future plans.

Social awareness is not the focus of this thesis. Social awareness becomes most relevant for informal social interactions in non co-located situations [Markopoulos et al., 2009], whereas we focus on the formal interactions between individuals that have to collaborate and communicate in a team to solve a complex problem in a co-located shared workspace. This typically includes a team decision-making process, for example during a meeting.

A relevant distinction is also made between *individual awareness* of other *people* (e.g. social awareness) and *individual awareness* of the availability of shared artifacts (e.g. awareness of who is in control of the shared display). Another type of awareness is *workspace awareness* of various individual activities in a shared workspace [Gutwin and Greenberg, 2002].

Gutwin and Greenberg [2002] introduce *workspace awareness* which they define as the up-to-the-moment understanding of another person's interaction with a shared workspace. Workspace awareness relates to the categories (1) and (2) of Gross et al.'s classification of awareness [Gross et al., 2005], and involves knowledge about where others are working, what they are doing, and what they are going to do next.

In the framework of the research reported in this thesis, we will further refer to *awareness* as: an agent (e.g. a person, a system, a group) is *aware* of X (of smth.) if he/she considers the relevant state or existence of X in his/her plans, actions, observations, and/or interpretations. As an example of an agent: a person can be aware of who is currently present in the room, who has just entered the room, what the person sitting next to them is doing, and who is planning to leave.

In this thesis research, we only look at the awareness of *individual* people. Thus, the focus of this work is on the awareness of an individual person of other people, the environment or systems. We define *team* as a group of individuals that require shared awareness to be able to collaborate and coordinate. We further restrict our analysis to situations where the collaborating team is *co-located*. A detailed overview of the related studies on team coordination and awareness support in different domains is presented in chapter 2.

1.6 Situational Awareness

Situational awareness is expected to be an important determinant of team performance [Bolstad et al., 2005; Endsley, 1995a]. SA provides the *"primary basis for subsequent decision making and performance in the operation of complex, dynamic systems..."* [Endsley, 1995a]. At its lowest level the team member needs to perceive relevant information (in the environment, system, self, etcetera), next integrate the data in conjunction with task goals, and, at its highest level, predict future events and system states based on this understanding [Endsley, 1995a].

Situation Awareness theory primarily focuses on how visual information influences the ability of groups to formulate a common representation of the state of the task, which in turn allows them to plan and act accordingly [Endsley, 1995b, 1993]. Visual information helps team members assess the current state of the task and plan future actions [Endsley, 1995b; Whittaker, 2003]. This awareness supports low-level coordination for tightly-coupled interactions.

The most commonly cited definition of SA is one suggested by Endsley [1995b] who states that situational awareness *"...is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* (p. 36, more elaborated 3-levels definition of SA is presented in chapter 2). Despite the frequency of its citation, many researchers do not accept this definition of SA. For example, Wickens [1992] suggests that SA is not limited to the contents of working memory, but it is the ability to mentally access relevant information about the evolving circumstances of the environment. Crane [1992] provides a very different conceptualization of situational awareness by focusing on inadequate performance and suggests that SA is synonymous with expert-level performance.

In this research, we define situational awareness as: (1) *detection* and *comprehension* of the relevant perceptual cues and information from the environment; (2) *understanding* of the situation, based on individual *previous knowledge*; and (3) *interpretation* of these and reconfiguration of understanding and knowledge in a continuous process during the *group collaboration effort*. This allows *awareness of changes in the environment*, knowing what team members are doing and have done regarding current events in the environment, and keeping track of work progress. An elaborated motivation and the definition of the situational awareness that is used in this thesis is presented in chapter 2.

Especially in multidisciplinary settings situational awareness information is affected by the abilities of individual members, their interaction with other team members, and the environment in which they collaborate [Bolstad et al., 2005]. Various factors affect individual situational awareness formation: environmental (physical location, display arrangement and size, etcetera) and group aspects (communication, use of collaboration tools, team processes, etcetera). In order to assess SA during evaluation of collaborative interfaces or awareness displays, specific factors need to be identified relevant to a particular domain. Applying an iterative user-centered design approach, we need to analyse the actual work context in order to design technology that supports team members in their primary task. Thus, this leads teams to communicate and interact in a collaborative environment with prolonged involvement and, hopefully, better results. It will also help us to find out how new technology in collaborative environments, such as large shared displays, influences daily work and team coordination [Hallnass and Redstrom, 2002]. This and other aspects of situational awareness theory are further addressed in chapter 2.

1.7 Related Theories

Besides the theory of situational awareness, activity theory, distributed cognition, common ground and situated action are the other relevant theories from cognitive sciences that we find important to mention in this thesis. Below, we present a comparison of these four theories to the theory of situational awareness, thus giving a motivation for choosing the situational awareness theory as the main approach and the design inspiration in this research.

1.7.1 Distributed Cognition

Distributed cognition is a theoretical approach that is concerned with the interactions between people, artifacts and both internal and external representations. It was developed by Hutchins [1995] in the mid to late 80s as a new paradigm for conceptualising cognition. The theoretical and methodological bases of the distributed cognition approach are derived from the cognitive sciences, cognitive anthropology and the social sciences. A unit of analysis in the distributed cognition approach is a cognitive system composed of individuals and the artifacts they use [Flor and Hutchins, 1991; Hutchins, 1995]. As such, the distributed cognition approach does not claim, that people are aware of a current situation, just that knowledge is available in the situation.

Nardi [1996] notes that distributed cognition is concerned with structure – representations inside and outside the mind – and the transformations these structures go through. Because of this focus on internal and external representations, much attention is paid to studying these representations. This may take the form of finely detailed analyses of particular artifacts [Norman, 1988; Hutchins, 1995].

Distributed cognition holds to the notion that artifacts are cognizing entities [Nardi, 1996]. As Flor and Hutchins [1991] state, what happens is *"the propagation of knowledge between different individuals and artifacts"*. However, we agree with Nardi [1996] that an artifact serves as a medium of knowledge for a human and cannot know anything. Unlike an unpredictable, self-initiated act of a human on a piece of information according to socially or personally defined motives, a system's use of information is always programmatic.

A distributed cognition analysis usually begins with the positing of a system goal, which is similar to the activity theory notion of object, except that a system goal is an abstract concept that does not involve individual consciousness. A system-oriented approach to distributed cognition does not suit our human-centered perspective. Instead of focusing on the use of artifacts in different situations, we believe that prior to designing or redesigning artifacts or tools, it is important to first determine what human *agents* perform which *roles* (see section 4.2) in a current work practice. Whereas some distributed cognition studies focus on the collaboration in distributed teams (e.g., Rogers and Brignull. [2003]), our research is focused on the co-located team collaboration. We do, however, apply methods for data gathering and analysis used in distributed cognition studies, such as in situ observations and analysis of the real work settings (e.g., see chapter 4.1).

1.7.2 Activity Theory

Activity Theory is an expansive framework for describing human behaviour, where an activity is described as specified by a subject, an object, actions, and operations [Halverson, 2002; Nardi, 1996]. A *subject* is a person or a group engaged in an activity. An *object* (or *objective*) is held by the subject and motivates activity, giving it a specific direction. *Actions* are similar to what are often referred to in the HCI and task analysis literature as tasks [Nielsen, 1994; Preece et al., 2002; van Welie and van der Veer, 2003]. Operations become routinized and unconscious with practice. For example, when driving a car the changing gear routine becomes operational. Operations depend on the conditions under which the action is being carried out.

A key idea of activity theory is that people's interaction with the world is mediated by physical and psychological tools [Leont'ev, 1978]. Tools are artifacts that enable people to act on the objects of their activities. In other words, these tools allow humans to accomplish, understand, motivate, or see the future transformations of their activities. According to activity theory, context is the activity itself. What takes place in an activity system composed of objects, actions, and operations, is the context. Context is constituted through the enactment of an activity involving people and artifacts.

An overview of Nardi [1996] compares three theoretical approaches to the study of context – activity theory, situated action models, and the distributed cognition approach. According to Nardi [1996], activity theory seems to be the richest framework for studies of context in its comprehensiveness and engagement with difficult issues of consciousness, intentionality, and history. However, Nardi [1996] also states that the situated action perspective *"...provides a much-needed corrective to the rationalistic accounts of human behavior from traditional cognitive science"*. Whereas in activity theory, activity is shaped first and foremost by an object, the situated action approach emphasizes the importance of focussing on what people are actually doing in the course of *real* activity. Though situated action theory has a different origin [Lave, 1988, 1993], it is closer to the situational awareness approach in terms of being the closest to the analysis of the real practice. We will continue with the discussion on the relation between the situated action and the situational awareness in section 1.7.4 below.

1.7.3 Common ground

Common ground is a key concept in conversation. Clark and Schaefer [1989] define *common ground* as mutual knowledge, mutual beliefs and mutual assumptions between two or more conversational partners. Collaborators construct and maintain common ground through a process known as *grounding*. During conversational activity, grounding occurs between speakers when one of them makes a statement indicating a misunderstanding about knowledge that should be common and that is critical for further conversation. Clark and Brennan [1991] argue that common ground is necessary for effective coordination of all joint activities.

Even though common ground theory is a compelling theory on grounding mechanisms during conversational activity, grounding needs to be developed further as a general collaborative concept. In particular, collaborators can rely on more than just conversation to help them detect and repair misunderstandings. This is particularly true for collaborators engaged in information-intensive group tasks such as software programming. Such collaborators have multiple media available to them that can signal problems with common ground. For example, a group member may draw a design diagram on paper or type code onto a computer screen that signals a violation of common ground. The paper and computer screen are examples of non-verbal explicit media that can be used to either detect or help repair problems with common ground. For the latter, instead of verbally repairing a misunderstanding, a co-worker could, for example, simply reach over and erase the incorrect part of the diagram or retype the correct code on the computer.

While grounding theory predicts that people will ground with whatever media are available, process details, such as how and when collaborators ground, are not explicit. Given the example of two collaborating software programmers, examples of such details would include making explicit: the different ways a programmer can use a computer screen to repair a co-worker's misunderstandings, or under what working conditions a programmer would detect misunderstandings in a co-worker's computer screen. Representational details need to be made explicit as well.

Common ground theory is focused only on analysis of the conversational behaviour, whereas situational awareness theory takes a more broad perspective allowing the analysis of various factors of group collaboration and the environment (chapter 2). In the study of [Flor, 1998] on discourse and collaboration across workspaces, the author states that common ground and grounding activities are not specific to conversations and theoretically all collaborations require constructing and maintaining some kind of common ground. However, Flor [1998] also reports the lack of models of the grounding process which would help to construct better collaborative tools. The common ground approach seems to focus on sharing conceptual (semantic) knowledge, not on actual shared understanding of a complex and dynamic situation.

1.7.4 Situated Action, Situational Awareness and Our Focus

In our research, *awareness*, shared *visual information* and *real work context* are the main requirements for studying co-located group collaboration. In addition, an important requirement for the theoretical framework in this research is the focus on the individuals that have to collaborate and coordinate as a group in a specific domain.

In parallel to the developments in situational awareness research [Endsley, 1989, 1993; Fracker, 1988], situated action [Lave, 1988, 1993; Lueg and Pfeifer, 1997; Suchman, 1987; Winograd and Flores, 1986] approach emerged: an alternative approach, according to Vera and Herbert [1993] in artificial intelligence, to explain human cognition based on the notion of 'situatedness'. According to situated action concept, human cognition is considered to be emergent from the interaction of the human with the environment, for example, the current situation the human is involved in. Lueg and Pfeifer [1997] proposed a 'situated design' methodology capitalizing on the notion of the human as a situated agent.

Situated action concept views action as not just the execution of plans, but as modified by surrounding circumstances. In this view, the situation is whatever relates to the action that is not in the plan. This is the first concept that could possibly be used to explain the effect of shared visual information on group collaboration, because it views interaction between a person and system apart from the information being transmitted. Unfortunately, situated action does not provide an account of mechanisms nor specifications of elements. The concept of situational awareness, on the other hand, tries to account for group performance in various practical domains (e.g., [Blandford and Wong, 2004; Manser et al., 2006]) by explaining certain crucial human processes. These processes include perception, comprehension, and projection (prediction of near-term future) [Endsley, 1995b]. The situation in SA approach is that to which these processes are applied. This model is keyed to particular features of each domain – features that do not generalize and must be exhaustively studied for each domain of interest. This concept is useful for well-understood, but complicated tasks involving group collaboration, or where experts are available for requirements elicitation.

Studies of Heath and Luff [1992] on underground control rooms and of Kostiuk et al. [1998] on air traffic management are the examples of studies that were not based on a particular theoretical framework, also never related to the parallel developments in situational awareness. These studies, on the other hand, played an important role in human-computer interaction research by informing the community about the importance of capturing how the human tasks and their performance are connected to the social interaction between human actors that manage the awareness of each others and their own.

The focus of this thesis is on the awareness of the collaborating group members of other members' working activities, work progress and changes in real working environments. The situational awareness approach is the most practical approach in studying group collaboration practices in real situations [Blandford and Wong, 2004; Heath and Luff, 1992; Kostiuk et al., 1998; Manser et al., 2006; Wilson et al., 2006]. Although distributed cognition, activity theory, common ground, and situated action are relevant approaches to study collaborative work, situational awareness theory is the most suited approach for this research that meets our main requirements stated above. Therefore, we have chosen for the situational awareness [Banbury and Tremblay, 2004] approach as a conceptual framework for further study and inspiration for design (see section 4.3.1).

1.8 Research Questions

The main research question of this thesis is defined as follows:

How can we support situational awareness in collaborative working environments?

This question is addressed in this thesis by answering three concrete questions, that are explained in detail below:

RQ 1 — Does situational awareness positively affect team decision making and collaboration mechanisms?

RQ 2 — How can we support situational awareness in co-located multidisplay environments in practice?

RQ 3 — How can we evaluate empirically the introduced situational awareness support to demonstrate that it affords situational awareness and positively affects team decision making in co-located multidisplay environments?

Before answering the research questions, a scientific background of this research on team coordination and situational awareness support is presented (section 1.9.1). An extensive requirements elicitation study was performed in a real-life context to answer the second question (section 1.9.2). Answering the first and the third research question involves the analysis of some existing situational awareness support techniques and evaluation methods for accessing the influence of SA support systems on team decision making and collaboration mechanisms (section 1.9.3).

This research aims at informing HCI theory and collaborative design practice on situational awareness support in shared workspaces, by presenting: (1) results of practical case studies on SA support in three different domains demonstrating that SA has effect on group process and group decision making; (2) an alternative approach to study situational awareness support for shared displays in relation to the group decision making; and (3) implications for the design of supportive SA visualisations for multidisplay environments.

1.9 Thesis Chapters Overview

The start of the introduction presented a problem statement and a motivation for this research. Then, co-located team collaboration and multidisplay environments were introduced, as they are in the focus of this thesis. Based on the extensive overview of various types and definitions of awareness, we presented our own definition of awareness. After introducing the situational awareness approach, we discussed four related theories from cognitive science: activity theory, distributed cognition, common ground and situated action. We compared each approach to the theory of situational awareness, thus giving a motivation for choosing the last theory as the main approach in this research. Finally, we presented the main focus of this thesis and research questions.

The rest of the chapters in this thesis are organized in three parts as follows:

1.9.1 *Part I: Situational Awareness and Collaboration*

Part I starts with an overview of the related studies on team coordination and situational awareness support (chapter 2). First, we discuss the theory of situational awareness and present our own definition of SA (section 2.1). After giving an overview of related studies on team coordination and situational awareness support, we discuss various approaches for measuring situational awareness. We argue why scientific collaboration has not been studied enough and discuss the role of shared visualisations in affording situational awareness in team collaboration (section 2.5). In section 2.6, we give an overview of related studies on evaluation of visualisations in multidisplay environments. Finally, the practical challenges are discussed for design and evaluation of group support systems for shared working environments. Part I provides a scientific background of this research on team coordination, situational awareness support and the role of shared visualisations in affording situational awareness in order to support group decision making in real working environments.

1.9.2 *Part II: Team Collaboration*

Part II starts with an introduction of the three domains (chapter 3) in which we performed empirical user studies presented in Part III. Chapter 4 presents the results of an exploratory user study and requirements elicitation in the first, life science experimentation domain (section 3.1). In situ observations, questionnaires and interviews with life scientists of different levels of expertise and various backgrounds were carried out in order to gain insight into their needs and working practices (section 4.1). The analyzed results are presented as a user profile description and user requirements for designing user interfaces that support situational awareness and group decision making in co-located multidisplay environments (section 4.1.4). Life sciences is used as an example domain in this study.

Section 4.2 presents the results of the task analysis study which aims at describing the current collaboration and work practices in a complex multidisciplinary situation. For this purpose, we have chosen an example domain of life science experimentation.

The outcome of the requirements elicitation and the task analysis studies leads to the discussion of three new concepts for SA support in section 4.3.1, namely (**1**) *Highlighting-on-Demand*, (**2**) *Chain-of-Thoughts*, and (**3**) *Control Interface*. The purpose of these concepts is to explore various alternative solutions for SA support in multidisplay environments to enhance group decision making and to facilitate co-located group discussions.

1.9.3 *Part III: Empirical Results*

Part III presents the results of the three empirical user studies in three different domains, aimed at fostering situational awareness and accessing the effect of situational awareness support on team decision making and group process in co-located multidisplay environments.

Chapter 5 presents the results of the first empirical user study on the effect of the Highlighting-on-Demand concept on situational awareness and satisfaction with the group decision-making process in a real multidisplay environment. The Highlighting-on-Demand interface enables a team member who is currently controlling the shared display to draw the attention of the other team members by highlighting a certain visualisation via a touch display.

Next, chapter 6 discusses the results of the second empirical user study on evaluation of the Chain-of-Thoughts concept that enables group members to capture, summarise and visualise the history of ideas on a shared display, providing an awareness of the group decision-making progress and status.

Chapter 7 presents the results of the design and evaluation of the large display visualisation to support situational awareness of software teams' activities and project progress in co-located team workspaces.

1.9.4 *Generic Implications*

Chapter 8 presents general conclusions, implications for the design of supportive SA visualisations and awareness displays for multidisplay environments. We also discuss challenges in the evaluation of merging collaborative workspaces (section 8.4). The thesis ends with a general summary.

Part I

Situational Awareness and Collaboration

Chapter 2

Supporting Situational Awareness

"Discovery is seeing what everyone has seen, and thinking what nobody else has thought."
–Albert Szent-Gyorgyi

This chapter[1] addresses awareness support to enhance teamwork in co-located collaborative environments. In particular, we focus on the concept of situational awareness which is essential for successful team collaboration.

Understanding who you are working with, what is being worked on, and how your actions affect others, is essential for effective team collaboration [Dourish and Bellotti, 1992]. Such shared awareness helps teams to achieve goals that are unreachable by a single expert. *Situational awareness* (SA) [Banbury and Tremblay, 2004] concerns "knowing what is (and has been) going on", basically being aware of what is happening around you in the environment and having a shared understanding of the information. Moreover, as various studies we discuss in section 2.2 confirm, shared situational awareness leads to the development of shared working cultures which, in turn, are essential aspects of group cohesion. Before giving the extensive definition, we will first explain the importance of SA for team collaboration.

This chapter focused the following aspects of situational awareness, such as: the relation between situational awareness, team collaboration and shared visual information; the criteria and methods for measuring situational awareness; the relation between situational awareness and decision making. Next, we discuss the theory of situational awareness and present our own definition of SA. As we will try to address different aspects of situational awareness related to the team collaboration, various categories from our definition of SA will be elaborated with respect to the specific domain and work environment. After giving an overview of related studies on team coordination and situational awareness support, we present a review of various approaches for measuring situational awareness. Then, we discuss the role of shared visualisations in affording situational awareness in team collaboration. Finally, an overview

[1]Adapted from: Kulyk, O., van Dijk, E.M.A.G., van der Vet, P.E., Nijholt, A., van der Veer, G. Situational Awareness in Collaborative Working Environments. In: *Handbook on Socio-Technical Design and Social Networking Systems*, B. Whitworth and A. de Moor, editors, pages 635–649. Hershey PA: Information Science Reference, 2009.

of case studies on evaluation of visualisations is presented, along with practical challenges for designing supportive visualisations and awareness displays for multidisplay environments.

2.1 Situational Awareness and Teamwork

Situational awareness is expected to be an important determinant of team performance [Bolstad et al., 2005; Endsley, 1995a]. Especially in multidisciplinary settings, situational awareness information is affecting the abilities of individual members, their interaction with other team members, and the environment in which they collaborate [Bolstad et al., 2005]. Various factors affect individual situational awareness formation: environmental (physical location, display arrangement and size, etc.) and group aspects (communication, use of collaboration tools, team processes, etc.). Additional factors, such as fatigue or an emotional state, might also influence the SA of a person, depending on the specific case.

Situational awareness becomes even more critical in complex multidisplay environments which change rapidly and provide a lot of detailed data. Recent studies [Borchers, 2006; Brad et al., 2002; Huang, 2006; Rogers and Lindley, 2004] point out that people are less aware of their visual surroundings than they think they are. Data overload, fatigue and other stressors can undermine the development and maintenance of the situational awareness [Bolstad et al., 2006]. The phenomenon of *change blindness* shows that even if people have an accurate representation, they may still fail to notice changes [Martens, 2007; Varakin et al., 2004]. Actively capturing people's attention at the location of the change by means of spatial cues improves the detection of the information and detection of changes. Therefore, it is important to design systems that support situational awareness and sharing of SA among team members to ensure efficient and effective team coordination and decision making.

Of the many SA models presented in the literature (e.g. Endsley 1995a, Smith and Hancock 1995, Bedny and Meister 1999, Hourizi and Johnson 2003, Banbury et al. 2004), Endsley's information-processing-based three-level model is the most popular. Endsley's theory of situational awareness suggests that SA can be achieved by linking an objective state of the world to its mental analogue on three main levels: *perception*, *comprehension* and *projection* [Endsley, 1993, 1995a]. **Level 1** of SA – is *perception* of relevant elements in the environment. It is an active process whereby individuals extract salient cues from the environment. **Level 2** – embraces *comprehension* of the meaning of these cues and requires abstraction of irrelevant information. This level involves integration of information in the working memory [Salas et al., 1995] to understand how the information will impact upon the individual's goals and objectives. In this way an individual develops a comprehensive picture of the world or of that part of the world of concern to the individual. **Level 3** – *projection*, consists of extrapolating this information forward in time to determine how it will affect future states of the operating environment [Endsley, 1993]. The third level of SA combines what the individual knows about the current situation with his or her mental model of similar events from previous experience, to be prepared for what might happen next.

Despite its popularity, Endsley's model is not accepted by all in the area and even a cursory look at the SA literature reveals that the construct, both in relation to its description and measurement, remains highly contentious [Salmon et al., 2008]. Klein [2000] states that Endsley's model of SA needs to be extended to cover decision making. Further, some researchers (e.g., Bell and Lyon [2000]) have even questioned the extent to which SA represents a unique psychological construct in its own rather than merely being a popular term encompassing various elements of human cognition, such as perception and working memory. In developing a working definition of SA, it is important to realise that, much like other constructs (attention, workload, stress, etc.), SA has no absolute, or 'correct' definition. We will return to this discussion in section 2.4 on various approaches for measuring situational awareness.

In this research, we define SA as:

(1) *Detection* and *comprehension* of the relevant perceptual cues and information from the environment, which supports comprehending visualisations in their context;

(2) *Understanding* of the situation, based on individual *previous knowledge* and which contributes to identifying the source and nature of issues and problems;

(3) *Interpretation* of these and reconfiguration of understanding and knowledge in a continuous process during the *group collaboration effort*. This allows *awareness of changes in the environment*, knowing what team members are doing and have done regarding current events in the environment, and keeping track of work progress.

Henceforward we refer to *shared situational awareness* as to the amount of communality of the individual SA of team members on the three aspects defined above. We define *team* as a group of individuals that require shared awareness to be able to collaborate and coordinate in a complex domain. Whereas Endlsey's definition of situational awareness is more generic, our definition is more extensive in regard to group collaboration in a shared working environment.

According to the model of team SA [Bolstad and Endsley, 2000], the process of the shared SA development involves four main factors: (1) shared SA requirements – the degree to which team members understand which information is needed by other team members; (2) shared SA devices – including communications, shared displays and a shared environment; (3) shared SA mechanisms – such as shared mental models [van der Veer and del Carmen Puerta Melguizo, 2002]; and (4) shared SA processes – effective team processes for sharing relevant information. Several barriers and problems can occur for shared SA of teams in dynamic collaborative environments [Kaber and Endsley, 1998], including: unavailable process resources, unavailable information and information of poor quality, a lack of information sharing, a lack of teamwork and interpersonal conflicts, and poor information system design. Lack of information sharing is addressed in chapter 6.

Shared SA can be built through various devices, such as shared displays, shared communications, and/or shared environments [Bolstad and Endsley, 2000]. Shared situational awareness and performance in team collaboration can be enhanced by the development of the shared displays that are based on the shared information requirements of team members in realistic field conditions [Bolstad and Endsley, 2000]. The design and evaluation of shared awareness display for software teams is discussed in chapter 7.

The next section gives an overview of the state of the art of research on group process and coordination in real working environments.

2.2 Group Process and Coordination

There have been a series of studies [Blandford and Wong, 2004; Manser et al., 2006; Wilson et al., 2006] investigating group processes in real world situations, mainly in domains such as: military, medical or crisis management. These empirical studies, although conducted in real work environments, focus only on team coordination in operation control or emergency dispatch. Operation control refers to collaboration within war room environments (chapter 3.2), also refereed to as operating control rooms, where teams work together synchronously in all phases using a variety of computer technologies to maximize communication and information flow. For instance, Manser et al. [2006] investigate coordination needs of cardiac anaesthesia teams in an operating room environment. The result of their study is a conceptual framework for the analysis of multidisciplinary team collaboration in complex work environments. A qualitative study by Wilson et al. [2006] reports the impact of a shared display on small group work in a medical setting.

However, these studies did not address non-emergency teams. Still, collaboration in scientific domains such as life science and drug design can be just as complex as a crisis situation, and one can be just as creative in science as in any other domain [Johnson and Carruthers, 2006]. A recent empirical study by Johnson and Carruthers provides a good overview of the relevant theories on creative group processes.

Applying a human-centered approach, we need to analyse the actual context in which the collaborative system will be deployed [Carroll et al., 2006; Varakin et al., 2004]. An understanding of the work context will help us to design technology that supports team members in their primary task, and thus leads them to communicate and interact in a collaborative environment with prolonged involvement and, hopefully, better results. It will also help us to find out how new computing technology in collaborative environments, such as large shared displays, influences scientists' work and team coordination [Hallnass and Redstrom, 2002].

2.3 Visual Information in Support of Situational Awareness

Visual information helps team members to assess the current state of the environment and plan future actions [Endsley, 1995a; Endsley and Garland, 2000]. Situational awareness theory helps to understand how visual information influences the ability of groups to formulate a common representation of the state of the environment and of the current task, which in turn allows them to plan and act accordingly. This awareness supports group coordination in dynamic working environments.

According to the situational awareness theory, visual information is primarily valuable for coordinating the task itself. In order for collaboration to be successful, group members need to maintain an ongoing awareness of one another's activities, the status of relevant task objects, and the overall state of the collaborative task [Endsley, 1995a; Endsley and Garland, 2000]. This awareness allows accurate planning of future activities and can serve as a mechanism to coordinate group activities.

For example, the study of Gergle et al. [2006] demonstrates how delayed visual feedback impact the collaborative task performance. The authors describe how parameters of the task, such as the dynamics of the visual environment, reduce the amount of delay that can be tolerated [Gergle et al., 2006]. In a similar fashion, Gutwin et al. [2004a] discuss how task coordination is supported by the availability of visual information during a dynamic collaborative activity in which two persons need to quickly move computational objects within a shared 2D workspace. When the shared visual information is delayed, the pairs have difficulty assessing the state of their partner and the state of the task, and there is an increase in the number of errors they make during the task.

At a micro-level, situational awareness of what is currently happening likely influences the next move or action engaged in. When groups are performing dynamic decision-making tasks in a multidisplay environment, a lack of of the shared visual information may disrupt the formation and maintenance of such awareness, ultimately yielding coordination difficulties.

Although immediately available shared visual information generally improves collaborative task performance by supporting situational awareness, the benefits it provides in any given situation will likely depend on both the accuracy of the visual information (e.g., whether the information is up-to-date) along with the requirements for coordination imposed by the task structure.

Next section presents a review of various approaches for measuring situational awareness to provide a better understanding of the SA construct and evaluation criteria. After this general review is presented, SA will be discussed as it relates more specifically to co-located team collaboration and decision making in multidisplay environments. Later, in section 2.6 we give an overview of case studies on evaluation of visualisations and practical challenges for designing supportive visualisations and awareness displays for multidisplay environments .

2.4 Situational Awareness Measures and Decision Making

Depending on the different ways of conceptualizing situational awareness, various approaches are used in assessing SA. This section provides a review of these approaches and techniques. Some of the measures reviewed here are specifically associated with the theoretical approaches and methods for measuring situational awareness in real collaboration situations [Gergle et al., 2006; Banbury and Tremblay, 2004].

Salmon et al. [2006] distinguish seven categories of SA measurement techniques: (1) SA requirements analysis (interviews, task analysis and questionnaires [Endsley and Robertson, 1996]); (2) freeze-probe techniques – involve the administration of SA related queries during 'freezes' in the task (e.g., SAGAT [Endsley, 1995a], SALSA [Hauss and Eyferth, 2003], SACRI [Hogg et al., 1995], etc.); (3) real-time probe techniques – SA related queries administrated on-line during task performance, measuring answer concent and response time (e.g., SPAM [Durso et al., 1998]); (4) self-rating techniques (e.g., SART [Taylor, 1989]); (5) observer-rating techniques [Biehl et al., 2007; Salmon et al., 2006]; (6) performance measures – indirect assessment of SA [Gugerty, 1997]; and (7) process indices (e.g., eye tracking [Smolensky, 1993]). In addition, retrospective memory technique [Klein, 2000] is used to analyze the documented previous incidents in command and emergency control using task analysis.

Some researchers (e.g., [Fracker, 1988; Vidulich and Hughes, 1991; Wickens, 1992]) divide the measures of SA into three broad categories: (a) explicit, (b) implicit, and (c) subjective measures. Table 2.1 shows the categories and techniques of SA measures mentioned above. The potential advantages and disadvantages associated with various measures are discussed further, and, where applicable, examples of each measure are provided, along with related work.

Table 2.1: Categories and techniques of SA measurements.

Categories	**Techniques**
Explicit Measures	• Retrospective Memory: [Klein, 2000] • Freeze-Probe Techniques: SAGAT [Endsley, 1995a], SALSA [Hauss and Eyferth, 2003], SACRI [Hogg et al., 1995] • Real-time Probe Techniques: SPAM [Durso et al., 1998] • Process indices: eye tracking [Smolensky, 1993]
Implicit Measures	• Performance Measures [Gugerty, 1997] • Perceived Performance [Fracker, 1988] • Task Measures: Workload [Wickens, 1992]
Subjective Measures	• Self-Rating Techniques: SART [Taylor, 1989] • Observer Rating Techniques [Biehl et al., 2007; Salmon et al., 2006]

The methods review demonstrates that (aside from the SA requirements analysis procedure which would be required prior to any form of SA analysis), in their current form existing measurement approaches are inadequate for the measurement of SA in multidisplay environments. There are two main reasons for this conclusion. First of all, the SA measurement techniques reviewed all focus upon the assessment of individual SA and this is problematic when considering the measurement of team or shared SA. Kaber and Endsley [1998] distinguish between individual SA measures and team SA measures. However, as the authors state themselves [Kaber and Endsley, 1998], very few measurements have been specified for assessing shared SA of teams. In fact, the only technique for assessing shared SA is to define SA requirements of team members for decision making through task analysis, field observations and interviews with experts [Endsley and Robertson, 1996]. Blandford and Wong [2004] used observations and the contextual inquiry technique to analyze situational awareness in emergency medical dispatch. In this thesis, we presents the results of an exploratory SA requirements study, applying task analysis, in situ observations and interviews in the domain of life science experimentation resulting in the design of three SA support concepts for large displays (see chapter 4.2).

Each of the different SA measurement approaches contain distinct flaws that could potentially influence the SA data obtained. Freeze-probe techniques, such as (SAGAT) [Endsley, 1995a], are intrusive and cannot be applied in the field whilst real-time probe techniques are difficult to apply and are still intrusive to primary task performance. Self-rating techniques correlate to performance and participants may experience difficulties rating SA during low performance [Salmon et al., 2006]. Situation Awareness Rating Technique (SART) is a widely used self-rating technique that involves an individual subjective assessment of system designs in terms of demands placed on attentional resources and understanding of system states [Taylor, 1989]. The observer rating technique can only be used in the field which is often not practical. The commonly used process index technique is eye-tracking, which can be used to assess which situational elements the participant(s) fixated upon during task performance. However, the eye-tracking device in a group and/or field setting is difficult if not impossible. Furthermore, eye-tracking data can point to which elements in the environment the participant is fixated on, but there is no assurance that the element in question was accurately perceived.

Moreover, most of these techniques are developed for military aviation or emergency control and are difficult to apply in other domains. SART self-rating and observer rating techniques are the exceptions and has been applied in assessing SA of software teams [Biehl et al., 2007]. We adopt these two techniques in our empirical study in the domain of agile software development (chapter 7).

Returning to the discussion about the independence of the SA construct, some studies note (e.g., Klein [2000]) that SA construct is used by researchers and Human Factors practitioners to describe psychological theories or concepts that cannot be assessed or measured directly. The problem lies in the fact that anyone can choose to label their particular theory or concept as SA, which is demonstrated by the large variety of definitions in the state of the art [Crane, 1992; Endsley and Garland, 2000; Wickens, 1992].

Many approaches for measuring SA rely on the cognitive types of measures, such as workload [Bolstad and Endsley, 2000; Wickens, 1992]. As we discussed earlier in

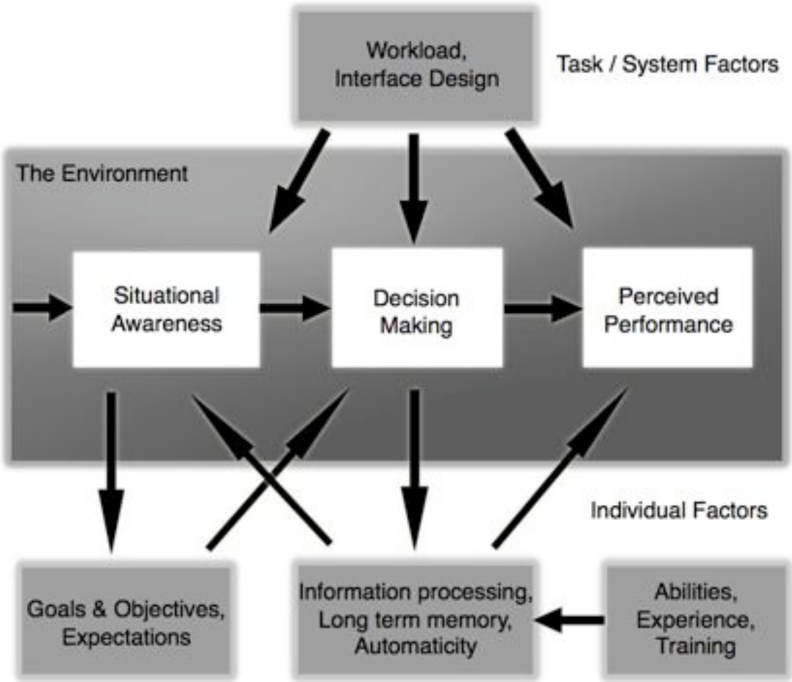


Figure 2.1: A model of the mechanisms involved in SA, partially adapted from [Endsley, 1995a].

section 2.1, situational awareness is a determinant of successful group coordination and decision making [Klein, 2000]. However, rarely has such a link been made between the situational awareness measures and decision making. As Klein [2000] states, one way to study and measure shared SA is within the context of real tasks that involve decision making. Practitioner and researchers in team SA point out that the real challenge in today's group support systems is the ability of the decision maker to locate, integrate and share needed information from the variety of alternatives [Klein, 2000; Wickens, 1992]. According to Wickens [1992], accurate decisions are typically based upon accurate probabilistic diagnosis (situational awareness), coupled with the assigned values of different outcomes (see ranking game in chapter 6.5). The study of Fjermestad [2004] shows how perceived quality of group decisions and level of consensus results in more efficient communication in groups working on a decision-making task. In this thesis, we explore the relation of situational awareness to the decision-making process and perceived agreement with the final group decision in two empirical studies (chapter 5 and chapter 6).

Figure 2.1 shows a model of the mechanisms involved in SA, demonstrating the relationship between individual, environmental and task (system) factors, such as workload, decision making and perceived performance. The main goal of this research is to design and evaluate the supportive SA visualisations for multidisplay environments. Our sub-goal is to establish the relation of situational awareness to the decision-making process, workload, and to the perceived quality of group decisions through the empirical user studies in various domains (see chapter 5 – chapter 7).

Further, we discuss the role of shared visualisations in affording situational awareness in scientific team collaboration.

2.5 Affording Situational Awareness in Scientific Teams

The importance of visualisation tools in life sciences and biomedical research has grown tremendously over the past years and is expected to do so for years to come. Various experts have to collaborate and to work with shared knowledge. They are forced to use complex scientific applications that require expertise they often do not have. Currently used life science interfaces are designed for expert bioinformaticians, cheminformaticians and computational biologists. They are too complex for novice users such as bench biologists [GenomeWeb, 2005]. The users' cognitive load is overstretched by huge amounts of heterogeneous data, mutually inconsistent representations, and the complexity of and limited interaction with the user interfaces of bioinformatics tools. A new generation of interactive visualisation interfaces has to meet user requirements as well as to improve the exploration of large amounts of heterogeneous data and to enhance knowledge construction [Koua and Kraak, 2004]. Therefore, there is a need for user-centred interface design and evaluation in order to improve the effectiveness and efficiency of both visualisation systems and life science interfaces.

Previous studies on creative and complex thinking of life scientists have shown that multidisciplinarity in research teams stimulates the process of creative thinking and reasoning [Dunbar, 1995, 1997]. Collaborative creativity involves both individual and group working practices, which introduces a new level of complexity in understanding the target users and in designing for their needs [Coughlan and Johnson, 2006]. Creativity may be supported by providing an interactive environment and an appropriate context to scientists (Figure 2.2) [Sundholm et al., 2004].

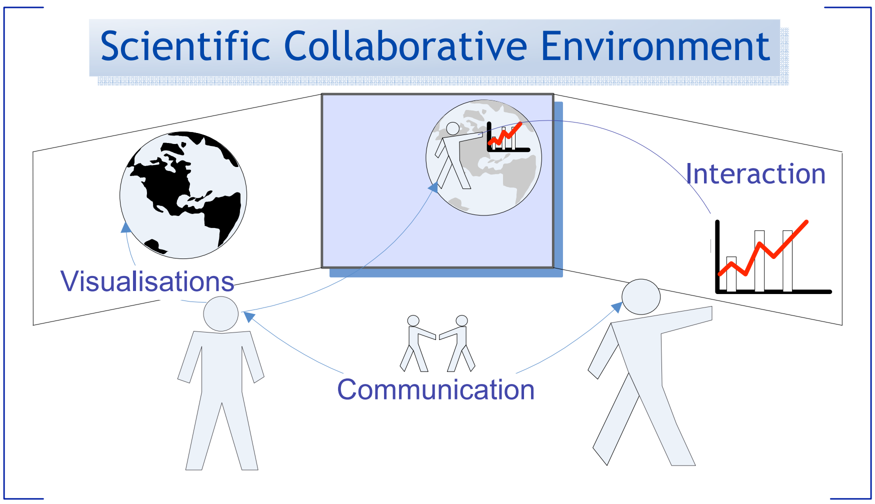


Figure 2.2: Concept: Multidisplay Environment for Scientific Collaboration

According to the creative thinking theory, there are three stages of creative problem solving: preparation, production and judgement [Ware, 1999]. Visualisations and tentative interactions can support creativity in all three stages. However, they are especially important in the production stage to support the generation of multiple hypotheses. The challenge at the judgement stage is to design visualization for an optimal perception of the information [Ware, 1999]. User interfaces and visualisations are part of the problem solving process. We will need to test and optimise the visualisation designs and interaction styles by performing user analysis and iterative evaluations [Saraiya et al., 2004; Faisal et al., 2005].

Figure 2.3: Scientists interacting with various visualizations on multiple displays in *e*-BioLab, MicroArray Department/Integrative Bioinformatics Unit, University of Amsterdam.

Presenting visualisations on a shared display in a collaborative working environment can support group discussions [Borchers, 2006; Huang, 2006; Rogers and Lindley, 2004]. Looking at the statistical representations of the same data on a shared large display enables scientists to assess the quality of the entire omics experiment at a glance [Kulyk et al., 2008a] (see Figure 2.3). The visualisations on the various parts of the display are implicitly related, in the sense that they refer to the same experiment, but currently it is not always evident what the precise relation is. To prevent team members from getting lost and to support situational awareness, the relations between various statistical representations have to be explicitly visualised. In order to afford detection of changes in visualisations and to avoid change blindness, it is important to draw team members' attention to current changes without distracting them from the discussion.

Multiple visualisations can be closely related, and therefore a change in a visualisation on one display will have to be related to visualisations on other displays, for example, in a manner pioneered by the Spotfire[2] system [Ahlberg, 1996; Ahlberg et al., 1992; Shneiderman, 1994]. As Shneiderman [1994] wrote in 1999: *'The old days of command line interfaces and submitting queries to databases are passing quickly'*. Life scientists, however, still run their hand-made scripts through a command line interface while performing statistical analysis and daily use the database interfaces, such as

[2]http://www.cs.umd.edu/hcil/spotfire/, last retrieved: Dec 5, 2009

WU-BLAST2[3] and ClustalW2[4] (Figure 2.4), that remain very primitive, inconsistent and far from being user friendly [Kulyk and Wassink, 2006] (chapter 4.1.2). In our case, the situation is more complex. Scientists in multidisciplinary omics teams use discipline-related visualisations. For example, in microarray experimentation, spotting the outliers and abnormal patterns in the large data set can be done only by an expert in both statistics and in molecular biology, by analysing a combination of various statistical representations and microarray scans. Another example is when, at the microarray experiment design stage, a statistician needs to establish confidence intervals and statistical power of an analysis. However, only molecular biologists and microarray experts can assess whether it is experimentally possible in the wet-lab to increase statistical power or to avoid invalid statistical results by choosing a different experimental setup.

In view that shared visualisations are in scope of the design applications of this thesis, next section presents an overview of the state of the art in evaluation of visualisations, as well as and challenges in designing supportive visualisations and awareness displays for multidisplay environments.

2.6 Evaluation of Visualisations in Collaborative Environments

This section[5] gives an overview of the state of the art and challenges in evaluation of visualisations in collaborative environments.

New generations of interactive visualisations not only have to meet user requirements but also have to enhance exploration of large heterogeneous data sets and provide domain-relevant insight into the data [Koua and Kraak, 2004; Saraiya et al., 2004]. This raises challenges in the evaluation of visualisations. Innovative and complex designs need to be tested in order to check whether they meet user requirements. Existing evaluation methods are not fully applicable to new visualisation spaces and related advanced user interfaces [Koua and Kraak, 2004]. Evaluation of any visualisation technique has to include an assessment of both visual representation and interaction styles [Winckler et al., 2004].

Kobsa [2001] compares three different commercial information visualisation systems. In this experiment, each of the participants performed a set of predefined tasks. Mean task completion time was measured in combination with observations to measure ease of use. He found that users achieved only 68-75 percent accuracy on simple tasks. In this study, the success of visualisation systems was found to depend on the following factors: flexibility of visualisation properties, freedom of operating the visualisation, visualisation paradigm and visualisation-independent usability problems.

[3] WU-Blast2, EBI, http://www.ebi.ac.uk/blast2/, last retrieved: Dec 5, 2009

[4] ClustalW2, EBI, http://www.ebi.ac.uk/Tools/clustalw2/, last retrieved: Dec 5, 2009

[5] Partially adapted from: Wassink, I., Kulyk, O., van Dijk, E.M.A.G., van der Veer, G., van der Vet, P.E., Applying a User-Centered Approach to Interactive Visualisation Design. In: *Trends in Interactive Visualisation*, E.V. Zudilova-Seinstra, T. Adriaansen, and R. van Liere, editors, Advanced Information and Knowledge Processing series, pages 175–201. Springer Verlag, London, UK, 2008.

Figure 2.4: Search options in ClustalW2, multiple sequence alignment program for DNA or proteins (EBI, http://www.ebi.ac.uk/Tools/clustalw2/, last retrieved: Dec 5, 2009).

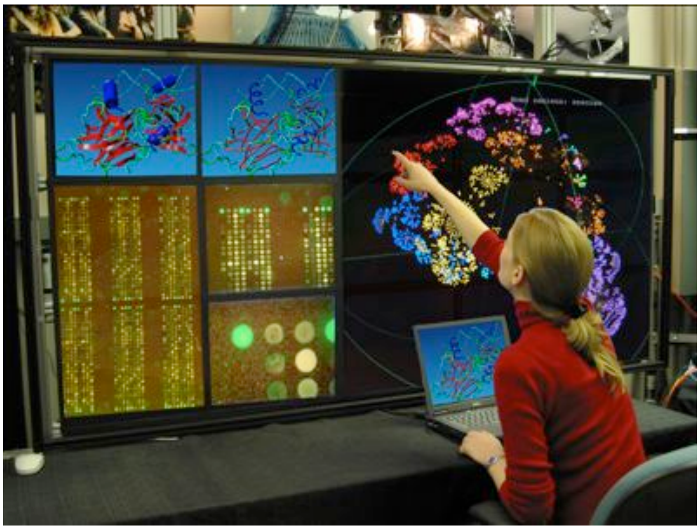


Figure 2.5: A scenario in which a life scientist is interacting with multiple visualisations.

Kobsa [2001] concludes that there is room for improvement in effectiveness of visualisations.

The lack of a generic framework is a common problem in the evaluation of visualisations. Very few studies are devoted to frameworks for design and evaluation of information visualisation techniques [Amar and Stasko, 2004; Figueroa et al., 2005; Koua and Kraak, 2004; Winckler et al., 2004]. Such models can help researchers to perform evaluations in a structured way. For example, Figueroa et al. [2005] introduce a methodology for the design and exploration of interactive virtual reality (VR) visualisations. They evaluated performance and user preference with several design alternatives during the early stage of development of a VR application. Alternative interaction techniques were presented to users in order to choose the technique they prefer most [Figueroa et al., 2005].

Koua and Kraak [2004] developed a framework for the design and evaluation of exploratory geovisualisations for knowledge discovery. This study addresses the lack of evaluation methodologies and task specifications for user evaluations of geovisualizations. In contrast, Amar and Stasko [2004] presented a knowledge task-based framework to support decision making and learning. Their study classifies limitations in current visualisation systems into two analytic gaps. First, the *worldview gap* between what is shown to a user and what actually needs to be shown to make a decision. Second, the *rationale gap* between perceiving a relationship and expressing confidence in the correctness and utility of that relationship. In order to diminish these gaps, new task forms are presented for systematic design and heuristic evaluation. For example, an interactive visualization system can bridge the rationale gap by clearly presenting what comprises the representation of a relationship, and presenting concrete outcomes where appropriate. A similar study by Winckler et al. [2004] proposes a task-based model to construct abstract visual tasks and generate test scenarios for more effective and structured evaluations.

A number of studies also demonstrate the practical use of various methods for the evaluation of visualisations. For example, Tory and Moeller [2005] report on heuristic evaluation [Nielsen, 1994] of two visualisation applications by experts in human-computer interaction. They conclude that expert reviews provide valuable feedback on visualisation tools. They recommend the inclusion of both experts and users in the evaluation process and stress the need for development of visualisation heuristics based on design guidelines.

Allendoerfer et al. [2005] use the cognitive walkthrough [Nielsen, 1994] method to assess the usability of CiteSpace, a knowledge domain visualisation tool to create visualisations of scientific literature. The cognitive walkthrough method is typically suitable for the evaluation of systems with structured tasks for which action sequences can be scripted. In CiteSpace tasks are exploratory and open-ended. Allendörfer et al. adapted the cognitive walkthrough method to be fit for the evaluation of knowledge domain visualisation systems [Allendoerfer et al., 2005]. This study confirms that each evaluation method has to be adjusted for the specific domain, the intended users and the evaluation purpose.

Focus groups, combined with interviews and questionnaires, are also common techiques in evaluation practice used during the analysis phase to generate ideas for the visualisation designs. Figueroa et al. [2005] demonstrate the evaluation of interactive visualisations using the focus group method. The main purpose of using focus groups in this study [Figueroa et al., 2005] was to establish users' attitudes, feelings, beliefs, experiences, and reactions in a better way than with interviews or questionnaires.

Usability testing is the most widely used method later in the design process [Preece et al., 2002]. In usability testing, performance is measured of typical users interacting with a high-fidelity prototype or an actual implementation of a system. Usability testing is typically done in artificial, controlled settings with tasks defined by the evaluator. Users are observed and their interactions with the system are recorded and logged. These data can be used to calculate performance times and to identify errors. In addition to these performance measures, user opinions are elicited by query techniques (interviews, questionnaires) [Preece et al., 2002]. In addition to traditional performance measurements, several studies illustrate that visual and spacial perception, for example the users' ability to see important patterns, should be also included in the evaluation measures of the interactive visualisations [House et al., 2005]. North and Shneiderman [2000] evaluate users' capability to coordinate and operate multiple visualisations in spatial information representations. The study of Westerman and Cribbin [2000] reports evaluation of the effect of spatial and associative memory abilities of users in virtual information spaces. Other important evaluation aspects are, among other things, influence of shared visualisations on multidisciplinary collaboration, cognitive abilities and cognitive load, peripheral attention, awareness, and engagement.

2.6.1 Controlled Laboratory Evaluation versus Field Studies

In addition to the controlled evaluation studies that are usually performed in the laboratory, it is necessary to evaluate an interactive system in the real context of use [Dunbar, 1995]. Unfortunately, there are very few studies in which the evaluation of visualisations is done in the real context of use. One example is a field study by Trafton et al. [2000] on how complex visualisations are comprehended and used by experts in the weather forecasting domain.

Another example is a longitudinal field study performed by Seo and Shneiderman [2002], including participatory observations and interviews. This study focused on the evaluation of an interactive knowledge discovery tool for multiple multi-dimensional genomics data. This contextual evaluation aimed at understanding the exploratory strategies of molecular biologists. While exploring the interactive visualisation, biologists were excited to discover genes with certain functions without, however, knowing how the correlations between a gene and its function are established.

In another study [Graham et al., 2000], it was found that traditional evaluation methods are not suited for multi-dimensional interactive visualisations. Therefore, the authors focused on initial testing by observing users trying out the prototypes using representative tasks. A combination of techniques was used in this study for data capturing, namely logging software, video recordings, note taking, and verbal protocol, which helped to disambiguate detailed interactions.

The field studies described here were aimed to understand the actual use of visualisation tools by real users in the real use context. Although constraints like time and budget often tend to limit evaluation to the controlled laboratory settings, field studies are needed to find out what people do in their daily environment.

2.7 Collaborative Visualisations and Awareness Displays

Most published evaluation studies focus on 'single user - single visualisation system' interaction. Another challenge for the visualisation designer is collaborative exploration of information. This requires new and advanced collaborative visualisations. Special evaluation methods are needed in order to adequately address the aspects of collaborative work with such visualisations [Ramage, 1999]. Refined methodologies and reliable measures are required to assess aspects such as, for example, knowledge discovery and decision-making quality. Evaluation practices could be adopted from fields like computer supported cooperative work (CSCW) and ubiquitous services [Iqbal et al., 2005; Neale et al., 2004; Poppe et al., 2007].

New systems for collaborative use of visualisation are emerging. Figure 2.6 illustrates I-Space (right) [Stolk et al., 2002] an example of a visualisation environment for multidisciplinary exploration of the human genome. MacEachren et al. [2004] present a collaborative geovisualisation environment (left) for knowledge construction and decision support.

One more demonstration of multiple visualisations design is the multidisplay environment designed by Mitsubishi Research Lab [Dietz et al., 2004]. Such environments may include *peripheral awareness displays* – an important class of applications that allow a person to be aware of information from multiple aspects of one or more activities, helping to build up a model of a certain activity or domain with low effort and

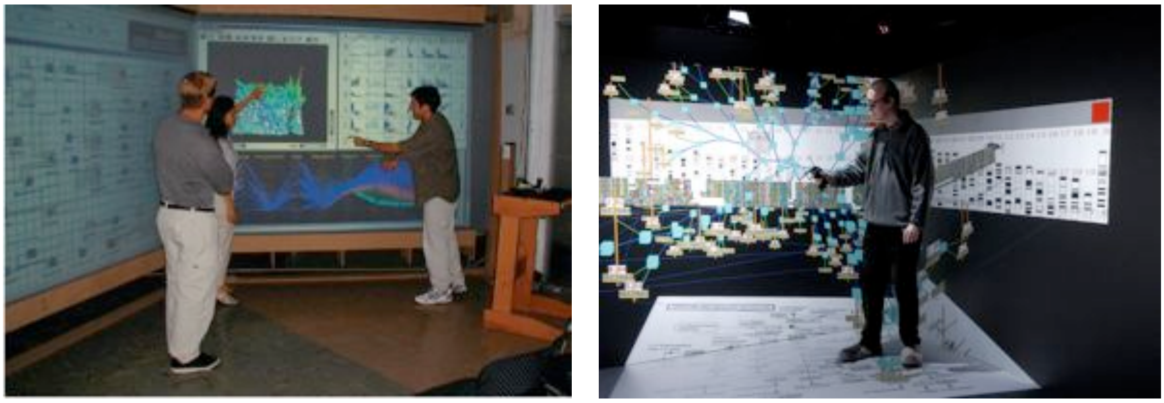


Figure 2.6: Collaboration in a Geovisualization Environment (left), Pennsylvania State University [MacEachren et al., 2004], ©2004 IEEE; I-Space (right), Visualization Environment for discovering human genome [Stolk et al., 2002].

without requiring focused attention [Matthews et al., 2007; Markopoulos et al., 2007; Plaue et al., 2004]. In such a ubiquitous computing environment involving more than one display, some displays cab be peripheral to a person's main focus of attention and remain useful when a user focuses on the other display or devices. Ubiquitous computing services allow feedback to the users throughout the supporting awareness signs that can be generated from multi-modal cues sensed by the perceptive services embedded in the environment [Iqbal et al., 2005]. The evaluation of awareness displays focuses on effectiveness and unobtrusiveness and the ability of visual representation to communicate information at a glance without overloading the user [Iqbal et al., 2005; Matthews et al., 2007; Plaue et al., 2004].

The complexity of multiple displays showing often complex visualisations can, as mentioned earlier, be reduced by employing attentive and proactive interfaces, also called notification services [Crowley, 2006]. Such interfaces have to anticipate the context and provide an appropriate feedback without distracting the users from their main task. An example of such an interface for awareness and collaboration support is the persuasive displays environment designed by Mitsubishi Research Lab [Dietz et al., 2004]. Such an environment can include a peripheral awareness display: an information system or a graphical representation that resides in the user's environment and provides information within the periphery of users' attention [Plaue et al., 2004]. Monitoring the peripheral display should cause minimal shift from the userÕs current focus of attention, allowing users to acquire information without being distracted from their primary task. Current peripheral display approaches use visual [Kulyk et al., 2006; Nikolic and Sarter, 2001] and other modalities, such as auditory [Graham, 2008; Graham et al., 2007] and tactile [Donmez et al., 2008], for conveying the information. Our primary focus for this thesis is on the visual modality, since visualisations is the main source of information for co-located teams in state of the art multidisplay environments. The evaluation of such an awareness display is mainly focused on effectiveness and unobtrusiveness: the ability of the visual representation to communicate information at a glance without overloading the user [Plaue et al., 2004; Kulyk et al., 2006]. We will further elaborate on the design and evaluation of a peripheral awareness display in chapter 7.

2.7.1 Conclusion

Visualisation systems are often designed for specific user groups which have specific goals and work in specific environments. The last section presented an overview of evaluation studies and has illustrated a need for design of interactive visualisations for group collaboration, based on the specific domain requirements, types of users tasks and different contexts to achieve different goals. Both controlled laboratory studies and field studies are needed to provide the necessary knowledge of how users interact with visualisations and of how visualisation tools affect their working practices.

We argued that emerging multidisplay environments pose new challenges for the design and evaluation of visualisations for collaborative use. Current evaluation techniques for single-user visualisations need substantial adjustments for multi-user settings. Essential insights in a wider range of disciplines such as human visual perception, cognitive science, and social psychology in combination with traditional user-centered design methods can guide us towards the most promising venues of investigation.

2.8 Summary

In this chapter, we have reported on the scientific background of this research on team collaboration and situational awareness support. The theory of situational awareness (SA) was discussed along with our own definition of SA. We reviewed various approaches for measuring situational awareness and their relation to the decision making. Then, we addressed the role of shared visualisations in affording situational awareness in scientific teams. Finally, an overview of case studies on evaluation of visualisations was presented, along with practical challenges for designing supportive visualisations and awareness displays for multidisplay environments.

The next part of the thesis presents three domains in which we performed empirical user studies, as well as the results of an exploratory user study and ask analysis in the first, life science experimentation domain. Three situational awareness support concepts for large displays are presented, based the generalized findings of the exploratory user study and task analysis.

Part II

Team Collaboration

Chapter 3

Teamwork in Multidisplay Environments: Case Studies

"An idealist believes the short run doesn't count. A cynic believes the long run doesn't matter. A realist believes that what is done or left undone in the short run determines the long run."
–Sidney J. Harris

In this chapter, we present three different domains: life science experimentation, decision making in brainstorming teams, and agile software development. In Part III of this thesis, we present the results of the empirical user studies performed in these three domains. Our main three requirements in terms of choosing a domain for the further empirical studies are: (1) co-located teams collaborating in a real working environment, (2) importance of shared visualisations in teams' work, and (3) a domain outside the scope of the common SA domains, such as operation control, air-traffic control or crisis management.

In contrast to domains such as aircraft or plant operation control, emergency dispatch or crisis management [Mark, 2002; Sharma et al., 2003], scientific teams are not working in life-threatening situations and are not under constant strong time pressure. However, long-term scientific projects involve high costs and therefore it is hard to recover from errors. Shared visualisations on large displays have proven to be helpful to support group discussions because they support situational awareness [Borchers, 2006; Huang, 2006; Rogers and Lindley, 2004]. Other examples of teams using a large display to enhance awareness of their activities are brainstorming teams and software development teams [Biehl et al., 2007].

3.1 Life Science Experimentation Teams

Evolving technologies in life sciences produce vast amounts of data. Scientists in this domain are confronted with the problem of applying methods from different disciplines when analyzing and interpreting their data, such as statistical, mathematical and machine learning techniques. Moreover, integration of the results from heterogeneous information sources is a difficult but essential part of the analysis of experimental results. Current omics experimentation in molecular biology, for example in drug discovery and cancer research, is a complex, highly dynamic and multidisciplinary task that requires teamwork [Rauwerda et al., 2006; van der Vet et al., 2007]. It is essential for life scientists to design the experiment precisely and accurately to ensure the statistical validity of the data. Timely spotting of outliers and abnormal patterns in a huge amount of data is crucial for experimentation.

In life science experimentation, there is a strong need for visualising the large genomics datasets during multidisciplinary collaborative discussions for comparing and sharing data [Kulyk et al., 2008a; Li et al., 2005] (see Figure 3.1). Designing awareness visualisations for collaborative use will enhance exploration of heterogeneous information and enable information sharing, which is one of the common barriers in gaining shared situational awareness [Kaber and Endsley, 1998].

Figure 3.1: Scientists discussing various visualisations in *e*-BioLab, MicroArray Department/Integrative Bioinformatics Unit, University of Amsterdam.

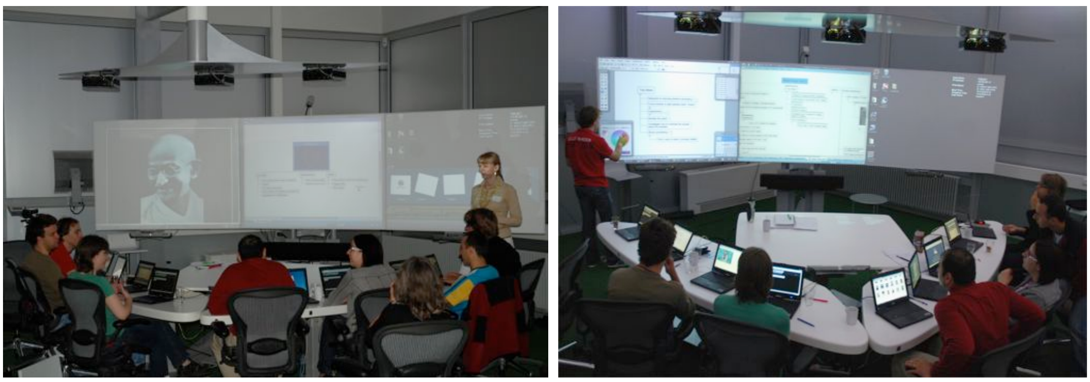


Figure 3.2: Brainstorm sessions: T-Xchange lab, Enschede, The Netherlands (T-Xchange, part of Thales Nederland: http://www.t-xchange.nl/, last retrieved: Dec 5, 2009.)

Much of the work on situational awareness and visualisation support presented in chapter 2 is relevant but has to be adapted to the specific needs of the multi-disciplinary teams in life science experimentation: molecular biologists, microarray experts, bioinformatic experts, and statistics experts. The practitioners of the various disciplines bring with them rich and often implicit background knowledge, as was found for scientists in general by Dunbar [1995].

Life science domain fulfills the requirements of our research, namely, the focus on the co-located team collaboration and the importance of shared visual information. Inspired by how unexplored this domain is in situational awareness and CSCW research, we chose the life science experimentation as an example domain to explore the need for situational awareness outside the most common SA studies within crisis management or emergency dispatch. We aim to thoroughly analyze and use the new domain as an inspiration for designing various concepts for SA support in multidisplay environments. First, we need to explore the new domain by to get insight into the existing collaborative practices and needs of the real life scientists and experimentation teams.

In chapter 4 we present the results of an exploratory user and task analysis study that provides insight into the daily working practices and needs of life scientists and life science teams in omics experimentation.

3.2 Enhanced Decision Making in Brainstorm Teams

The group research provides information about the potential effectiveness of meetings in which ideas are being exchanged [Dunbar, 1997; Paulus et al., 2005; Paulus and Dzindolet, 2008]. Brainstorming – the process of idea generation in groups – should be more beneficial in an environment in which there are few constraints on sharing the ideas. Information exchange in various modalities (for example, verbally and visually) is important in brainstorming [Paulus et al., 2005; Thompson and Choi, 2006]. Performance in brainstorming declines over short periods of time, and shifting from one mode of brainstorm to another may help maintain task motivation as well as provide cognitive benefits for situational awareness (e.g., individual idea generation versus generating ideas in a group, oral versus written presentation of ideas, etc.) [Paulus et al., 2005].

Many studies in HCI research address interaction techniques to facilitate brainstorming. For example, the Tivoli project by Pedersen et al. [1993] presented Liveboard: one of the first large interactive pen-based whiteboard interface used to support brainstorming meetings. The Idea-Collector concept [van Turnhout et al., 2002] is designed to support creative group discussions. The prototype applied a pick and drop technique via a tangible input device that is used to organize information displayed on an electronic whiteboard [van Turnhout et al., 2002]. The study concludes that fast organization of materials during a brainstorm session does not interfere with social relationships within the group. Authors acknowledge that the Idea-Collector concept needs to be further evaluated in more realistic setting [van Turnhout et al., 2002].

Although a wide range of technologies for smart boards and brainstorming have been addressed in human-computer interaction design (e.g., finger-pointing touch interfaces [Crowley et al., 2000], multi-touch [Fikkert et al., 2009], using tangibles [van Turnhout et al., 2002], etc.), there has been little work done on supporting group collaboration and decision making for brainstorming.

In visions of future computing, humans are surrounded and supported by smart environments and smart objects that are attentive and proactive. Ubiquitous computing, ambient intelligence, and pervasive computing are among the names that are used in the literature to refer to this vision. Such environments use their sensors to observe and their intelligence to interpret the activities of their inhabitants and provide support. The environment itself is called by different names, depending on the aspect one wants to emphasise: for example, war room (enabling extreme collaboration [Mark, 2002] or for managing crisis situations [Sharma et al., 2003]), collaborative interactive environment [Borchers, 2006], ubiquitous computing room [Brad et al., 2002], multi-sensor meeting room [McCowan et al., 2003], among many others. The use of large displays to support meeting participants has itself been the subject of a strand in the literature [Borchers, 2006; DiMicco et al., 2004; Fitzmaurice et al., 2005; Huang, 2006; Rogers and Lindley, 2004]. Much of this work is relevant to us but has to be adapted to the specific needs of the users of the brainstorming teams.

Some of the collaborative environments have developed into so-called *future workspaces* [Fernando et al., 2003]. This development is due to the ability to capture more aspects of human verbal and nonverbal communication behaviour and due to advancements in artificial intelligence, allowing us not only to represent and use domain knowledge, but also to reason about domain knowledge. Apart from supporting, in a global way, design practices and brainstorming sessions of collaborating teams, these 'spaces' or environments are meant to provide team members with mixed reality cooperation and support. That is, virtual environments are created in which various experts cooperate, in our case co-located in the same physical environment, and manipulate objects and tools that are both virtual and physical (Figure 3.2).

Team collaboration and desision making in multi-stakeholder settings typically involves experts in various disciplines: product life-cycle engineering, automotive simulation, landscape planning, industrial design, military training, war gaming, serious gaming, etcetera. Chapter 6 elaborates further on the results of the empirical user study performed in this domain with enhanced brainstorming teams.

3.3 Agile Software Engineering Teams

Team collaboration and coordination in software development is complex [Cadiz et al., 2002; Sarma et al., 2008] as it requires frequent coordination to plan and review the progress of a team. For example, it is not trivial to find the right person to assign to a task or to determine how many tasks a team member can complete in a week [Jakobsen et al., 2009; Ko et al., 2007]. A team member may become pressed for time if assigned tasks take longer to complete than estimated. In addition, completing a task often involves team collaboration because knowledge is divided between team members who have different roles or own different parts of the software system. Team members may also work on multiple task items at a time, or belong to more than one team, adding to the challenge of coordination. Thus, team members need to be aware of what others on the team are doing.

Many organizations adopt agile software development methodologies that promote shorter iterations and daily stand-up meetings to improve coordination [Schwaber and Beedle, 2002]. Also, collocation of a team in a shared team space may improve productivity [Teasley et al., 2000] (see Figure 3.3). Yet, software teams are still challenged with maintaining awareness of ongoing activity [Ko et al., 2007].

Figure 3.3: Shared workspaces of software teams

Software teams typically store information about work items (e.g., tasks and bugs) in software repositories, such as Microsoft Team Foundation Server (TFS), to support coordination of the teams' collaborative efforts. However, such repository systems are not designed to give an overview of the state of a project or to keep team members constantly aware of the current activities of the team. Developers can find it burdensome to continuously update work items in the repository and may not feel that they get a proper return on the time they invest in doing so. While information shared on whiteboards and sticky notes on the walls of the team room is often visible to team members, it is not easy for them to see changes to work items in a software repository. The software repositories available today frequently use textual list views for work items. Team members sometimes find it difficult to visually scan for changes or work items that they care about. Also, the status of the work item is often not up to date, as team members do forget to change it.

Chapter 7 presents the results of the design and evaluation of the large display visualisation to support situational awareness of agile software teams of each others' activities and project health in co-located team workspaces.

3.4 Conclusion

This chapter introduced three domains: life science experimentation, enhanced decision making in brainstorming teams, and agile software development. We agree with Heath and Luff [1992], who recognize the need to study the situated character of collaborative work in real world, in everyday work settings. All three domains presented above answer our main three requirements for further empirical studies: *co-located teams* collaborating in a *real working environment* using *shared visualisations* in non-crisis situations. Choosing three different domains ensures representativeness of the cases for each of the domains, their diversity and practical applicability of the results. The limitation of such diversity is the generalizability of the overall findings. We will come back to this discussion later in chapter 8. In Part III, we present the results of the empirical user studies performed in these three domains.

The next chapter presents the results of an exploratory user study and requirements elicitation in the first, life science experimentation domain. In situ observations, questionnaires and interviews with life scientists of different levels of expertise and various backgrounds were performed in order to gain insight into their needs and working practices. The analyzed results are presented as a user profile description and user requirements for designing user interfaces that support situational awareness and group decision making in co-located multidisplay environments. Life sciences is used as an example domain in this study. We discuss the outcome of the task analysis in life science experimentation teams, resulting in three SA concepts. The purpose of these concepts is to explore various alternative solutions for SA support in multidisplay environments and to evaluate them in different domains (see Part III).

Chapter 4

Exploratory User Study and Requirements Elicitation

"Men of lofty genius when they are doing the least work are the most active."
–Leonardo da Vinci

The focus of this chapter is on the first domain presented in chapter 3: the team collaboration in life science experimentation (section 3.1). An extensive requirements elicitation study was performed to gain insight into the existing work practices, potential awareness problems and the support for effective and satisfactory group decision making. Life sciences is used as an example domain in this study. The outcome of this study are the generic user requirements and SA support concepts (section 4.3.1).

Although the life science domain is the focus of the requirements elicitation study, the main goal is not only understanding existing life science experimentation practices, but rather understanding collaboration in a real media-rich working environment. Colocated collaboration in life sciences provides a context for studying how collaborators behave and gain shared situational awareness in a multidisplay environment, where they have easy visual and manual access to one another's resources. By observing the real scientific teams we hope to understand their working style, ways of using the technology, visualisations and preferred interactions styles.

4.1 Team Collaboration in Life Sciences

This section[1] presents the results of an exploratory user study that aims to gain insight into the current working practices and needs of life scientists and life science experimentation teams. This exploratory study is part of the user requirements and domain

[1]Partially adapted from: Kulyk, O., Kosara, R., Urquiza J., Wassink, I. Human-Centered Aspects. In: *Human-Centered Visualization Environments*, A. Kerren, A. Ebert and J. Meyer, editors, Lecture Notes in Computer Science, volume 4417, pages 13–76. Springer Verlag, Berlin, 2007; this study was carried out in collaboration with Ingo Wassink and is partially reported in the dissertation of Wassink [2010].

analysis to design support situational awareness visualisations for co-located teams. Contextual field observations, questionnaires and interviews with bioinformatics researchers of different levels of expertise and various backgrounds were performed in order to gain insight into their needs and working practices [Kulyk and Wassink, 2006; Kulyk et al., 2007b]. The analysed results are presented as a user profile description and user requirements for designing user interfaces that support the collaboration of multidisciplinary research teams in scientific collaborative environments.

4.1.1 Introduction

The purpose of this empirical user study is to explore the working practices and experiences of users from different life sciences sub-domains and disciplines, such as bioinformatics, with various levels of expertise in real-life settings. We also aimed to identify the key aspects and user requirements in the context of scientific collaborative environments. Such an environment contains high tech devices, such as large displays for interactive visualisations and digital whiteboards. Therefore, we started to analyse the current working style of multidisciplinary project teams in real-life contexts in order to better understand the needs and practices of our target user group.

The remainder of this section is organized as follows. The next subsection contains a brief review of the related formative user studies in bioinformatics. Then we describe the method and three main target groups. Finally, the incorporated results presented as user profile descriptions and design implications are discussed, followed by the conclusion and discussion.

4.1.2 User Analysis in Life Science Domain

The process of designing visualisations is a specific type of Human-Computer Interaction (HCI) design. User analysis is essential to identify the users, and more in particular their general tasks and needs before one can start to design visualisation techniques [Kulyk et al., 2007b]. Most published studies, for example [Saraiya et al., 2004], focus on the evaluation of the existing tools but not on user analysis to formulate the requirements. There are very few user analysis studies available in the literature, and none concentrating on multidisciplinary collaboration in life sciences. Dunbar performed ethnographic observations and interviews in molecular biology to study cognitive mechanisms and complex thinking [Dunbar, 1995].The only user analysis study in the life science domain we are currently aware of is the study reported by Bartlett and Topms [2005]. They proposed an information behaviour framework integrated with task analysis for studying patterns among bioinformatics experts. Their work is based on 20 interviews with bioinformatics analysts working on functional analysis of a gene [Bartlett and Topms, 2005]. However, this framework is not unique as it presents the results in a detailed hierarchical task model without further implications or design solutions. In section 4.2, we describe the results of the task analysis method to study collaboration practices in life science experimentation teams.

4.1.3 Target Groups and Methods

A user analysis study was conducted to gain insight into the needs and working practices of researchers from different sub-domains of life sciences. These studies included a questionnaire, in situ observations and interviews. Different target groups were chosen for the study in order to get different perspectives on users in the life science world. For each user group, a different method of study was chosen. The selection of the methods was based on both the goal of the analysis and the characteristics of the target users.

Questionnaire

The first target group were *novice* users of the life science tools, since we wanted to understand what problems do users, experienced in their disciplines, experience using diverse life science resources that are new to them. The aim of this part of our study was to get more insight into how novice users deal with bioinformatics problems and how they use bioinformatics resources: What is their working strategy? How do they use various life science tools and resources for getting from the target question towards a conclusion? A multidisciplinary group of 47 students taking an introductory bioinformatics course participated in the questionnaire part of this user study. They had no prior experience with bioinformatics and life science tools and therefore had no formed opinion about the usefulness of various tools. A discussion of the results translated into user profiles can be found in section 4.1.4. The questionnaire results are presented in Appendix B.

First we wanted to gain insight into the daily practice of the novice users while they learn to use different bioinformatics tools and deal with the real-life problems. Unobtrusive observations of students from different backgrounds were collected, prior to a questionnaire, during a 9 weeks introductory bioinformatics course at the Bachelor's level offered by the CMBI, Radboud University in Nijmegen in the Netherlands. The environment where students followed a weekly practical course consisted of multiple rows of tables with PCs were students often worked in pairs during practical assignments (see Figure 4.1).

The collected observations were translated into simple statements about the way in which novice users deal with practical bioinformatics problems using different on-line web resources, both data and tools. Based on these statements, a questionnaire was designed to check and refine the statements. In order to correlate the questions with students' recent practice, 3D visualisations of a familiar protein from the tool Yasara[2] were included (Figure 4.2). Students had to apply knowledge from the whole course and use different bioinformatics databanks and tools for this assignment. The screenshots of familiar proteins used during the course were included in the questionnaire to correlate the questions to the students' recent practice.

Participants

[2]Yasara, IMBM, IPC, CMBI, http://www.yasara.org/, last retrieved: Dec 5, 2009

Figure 4.1: Observations of the novice users, practical bioinformatics course room at the Radboud University in Nijmegen

In total 47 (21 female and 26 male) students took part in the user study: the average age was 21,5 years. The participants were mainly Dutch and German students from different disciplinary backgrounds (molecular science, chemistry and general natural science) of the Radboud University in Nijmegen. Based on the user profile questions it became clear that students' level of experience with software tools is generally quite high. The majority of students used the Windows platform and multiple mail programs, web browsers, search engines, text editors, spreadsheets and instant messengers.

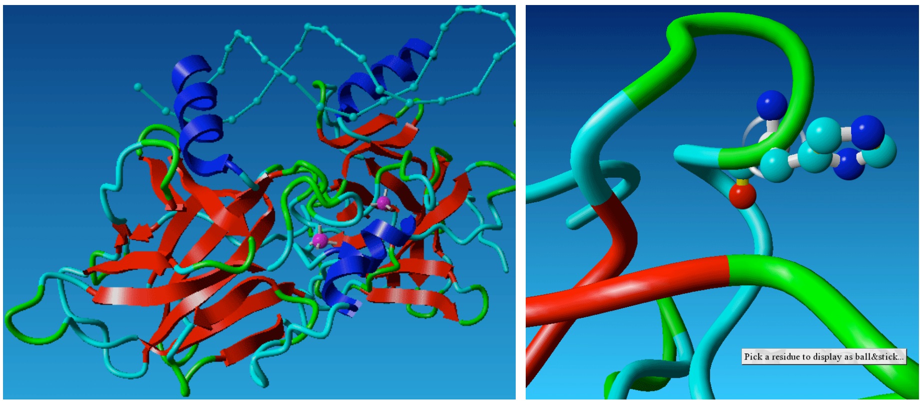


Figure 4.2: Different views for a complete protein visualization tool Yasara: 'Ribbon' (*left*), 'Sticks' (*right*)

Procedure

A pilot test with two course assistants was conducted. Based on their feedback, the necessary adjustments to the questions and the layout were made.

Students were asked to fill the questionnaire at the end of the course day. A course assistant explained the purpose of the study and emphasised that participation was anonymous and voluntary. Students were given an introduction on how the questionnaire was constructed. It took 15-20 minutes for the students to answer the questions. The questionnaire consisted of three parts: 1) background information and general software usage questions; 2) questions on 3D visualization tools; 3) questions on the web-based databanks to obtain protein sequences data. Additional space was left for extra comments after the second and third parts. Fourteen out of twenty-one questions used a 5-point Likert-scale, where '1' was presented as 'Agree strongly' and '5' as 'Disagree strongly'. All questions were multiple choice, but some were single-response and some multiple-response questions. The last two were ranking questions, where users had to rank the options by importance on a scale from 1 to 3. The results were kept anonymous. The response of the questionnaire was about 90%. The full questionnaire can be found in Appendix A. Section 4.1.4 discusses the results.

In situ Observation of Multidisciplinary Teams

The second target group were multidisciplinary teams collaborating on a joint scientific experiment. Such a team normally consists of scientists from different domains related to bioinformatics, for example, molecular biology, chemistry and statistics. Teams of scientists are of special interest for our further studies, since it is known from creative cognition and complex thinking theory that creativity of scientific thinking occurs in groups rather than individuals [Dunbar, 1995]. We have observed a multidisciplinary user group consisting of biologists, statisticians and bioinformaticians with the aim of finding out how they collaborate and how they use technologies provided in the meeting room. A multidisciplinary team, consisting of 3 biologists, 2 statisticians and 2 bioinformaticians from different research institutes, was observed during one of their regular project meetings at a Dutch university. The subject was the interpretation of the results of a microarray experiment. Details and findings are presented in section 4.1.4.

Novice users have little or no experience in collaboration with other researchers. Therefore, a multidisciplinary team of experts was chosen for an ethnographic observation. The goal of the observation was to gain more insight into how researchers from different disciplines collaborate while solving biological problems and how they use technologies supported by the simple meeting room with a single projector and a whiteboard. The regular meeting of a project team was audio recorded with participants' permission. The observations were made at the University of Amsterdam. The meeting room contained:

- Large table, with seats around it
- Data projector, remote control with a laser pointer
- Paperboard
- A wooden stick used as pointer
- Whiteboard

See Figure 4.3 for the layout of the room.

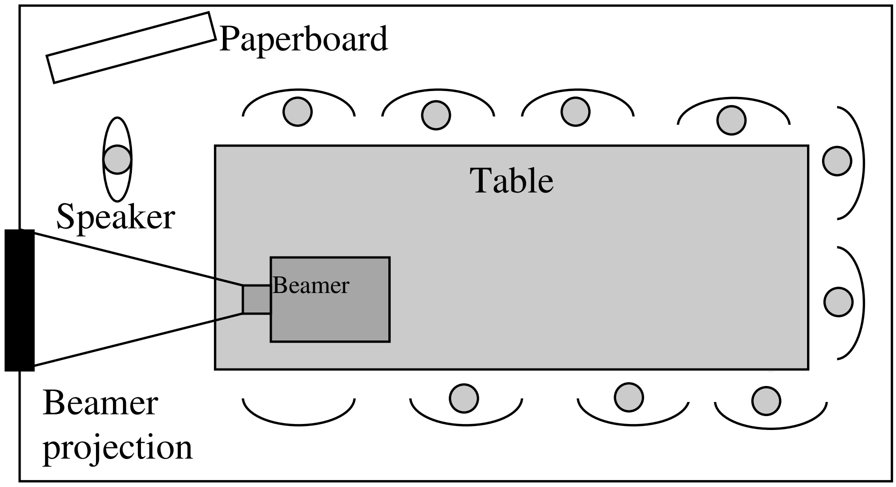


Figure 4.3: Layout of the meeting room

Interviews

The third target group were expert users familiar with bioinformatics applications. Participants of this study were researchers from different disciplines working in bioinformatics. Observation showed that collaboration is essential in bioinformatics research. Therefore, we decided to conduct interviews with experts from different areas of bioinformatics, biology and biomedical technology. Bioinformaticians were selected in order to gain insight into their experiences in collaboration with researchers from other areas and their use of different tools.

Interview questions were focused on their work practices and on the use of bioinformatics tools. We also asked about experts collaboration experience and opinion on how future technology in collaborative environments, such as large wall displays, might influence collaboration.

Semi-structured interviews were carried in the context of the experts' work. So far, three researchers were interviewed at a Dutch bioinformatics group at the Radboud University, Nijmegen: two PhD students and one postdoc. Scientists with biology, molecular biology, bioinformatics and statistics backgrounds work together on various projects in this research group. All participants were male and aged between 25 and 30 years, and had been active in the bioinformatics domain for at least 2.5 years. The full transcripts of interviews with these researchers are omitted here for privacy reasons. The sessions were audio recorded with the participants' permission. Details and findings are presented in section 4.1.4.

4.1.4 Results: User Profile

The completed questionnaires, observations and interview results were analyzed and translated into a user profile description and into user requirements for a mulidisplay collaborative environment. These results will be an input for the design of situational awareness interfaces to support co-located collaboration of multidisciplinary research teams. Full reports on the results of the questionnaire, observations and interviews are available in the Technical report[3] [Kulyk et al., 2008b].

Our target groups consist of two types of life scientists: biologists and bioinformaticians. Bioinformaticians can be seen as *domain experts* in this case: they know their way around in the vast (and growing) space of online bioinformatics resources, and they know about data handling and the operation of bioinformatics databases [Rauwerda et al., 2006]. They move between the two worlds of biology and computer science. Unlike computer scientists, they have the necessary biology background required to collaborate with biologists. Unlike bioinformaticians, biologists are mostly *novice users* of life science resources. They are experts in doing wet-lab experiments, but lack the programming skills bioinformaticians have.

Novice users

Novice users of life science tools, such as biologists lack the programming skills that expert bioinformaticians have. They often do not directly understand how programs work. As a result, they are often discouraged from experimenting with these tools. One of the interviewees stated that, for this reason, biologists only use default parameters most of the time. The questionnaire results show that less than 22% of the novice users changed parameters to assess parameter influence on the result of an experiment.

The novice users, however, were quite skilled and advanced in using general software tools. More than 68% of the participants often use cross references for getting more details about experimental results. It is essential to provide an option to make the desired information visible on demand. In addition, each bioinformatics database needs to clearly inform the users about what type of data it provides. The novice users got confused by many unstructured configuration options. They also missed a history function if they were redirected to a different web application.

Domain experts

The interviewees, who are domain experts themselves, explained that bioinformaticians create and use bioinformatics tools to collect huge amounts of data from databases. They collaborate with statisticians to analyse these huge amounts of data using various methods such as statistics.

Domain experts use diverse databases and tools to compare huge amounts of data and to draw conclusions from them. To do the statistical analysis, they use software such as Matlab[4] and R[5]. Specialized software such as ClustalW[6], WU-Blast2[7] and Yasara[8] are used for respectively, protein sequence comparison, sequence similarity search, and the visualisation of protein 3D structures.

[3] Accessible at: http://eprints.eemcs.utwente.nl/14622, last retrieved: Dec 5, 2009
[4] Matlab, MathWorks, http://www.mathworks.com/, last retrieved: Dec 5, 2009
[5] R, R-project, http://www.r-project.org/, last retrieved: Dec 5, 2009
[6] ClustalW, EBI, http://www.ebi.ac.uk/clustalw/, last retrieved: Dec 5, 2009
[7] WU-Blast2, EBI, http://www.ebi.ac.uk/blast2/, last retrieved: Dec 5, 2009
[8] Yasara, IMBM, IPC, CMBI, http://www.yasara.org/, last retrieved: Dec 5, 2009

Bioinformaticians have programming skills, and consequently, they understand how programs and tools work and they often know how to extend them. This makes them less afraid to experiment with different tools and with parameter settings. Their work style can be roughly characterised as follows: they first try things out to verify their hypotheses using the default parameters. When the hypothesis is more or less confirmed, they fine-tune the parameters to optimise the results. Bioinformaticians prefer command line applications over web-based interfaces, since command line tools allow them to customize all parameters. They also claim a command line gives them more insight into how the tool works.

When the interviewees were asked how they become aware of the existence of new tools, they mentioned that colleagues are important sources of information for learning how to use new bioinformatics tools. If they find a new tool by themselves, they test the tool and compare the results with those of familiar tools in order to establish a quality measure. Experience with, trust in, and perceived quality of tools are exchanged among bioinformaticians.

Multidisciplinary teams

In the biomedical domain, researchers very often work in *multidisciplinary teams*. These teams consist of researchers with backgrounds in biology, bioinformatics, (bio)-chemistry, mathematics and statistics. The interviewees told that industries are often involved in research projects. In the cases with which our interviewees were familiar this included the food and milk industries which provide abstract research questions. These questions are translated into concrete research questions by the team leader.

4.1.5 Results: User Requirements

The results of the questionnaire, the observation and the interview provide useful initial input for designing interfaces to support co-located collaboration. The combined information from the three methods is translated into a set of requirements for visualisations, collaboration and multidisciplinary teamwork support in a scientific collaborative environment. These aspects will be discussed next.

Visualisations

Visualisations are very important in the bioinformatics area. Researchers in this area use different types of visualisations for different types and different amounts of data. During the observation, students were searching for active sites (usually hydrophobic pockets in proteins that involve sidechain atoms of a particular protein [Campbell and Laurie, 2006]). They used 3D visualisations of the protein for searching for amino acids which could possibly be involved in the protein's function (see Figure 4.4.A). This activity requires intensive interaction with the 3D model of a protein, consisting of zooming and selecting different levels of detail for the whole 3D model or just parts of it. Therefore, *easy switching between views* and *feedback about current selection* are essential. More than 67% of the participants of the questionnaire agreed with this statement.

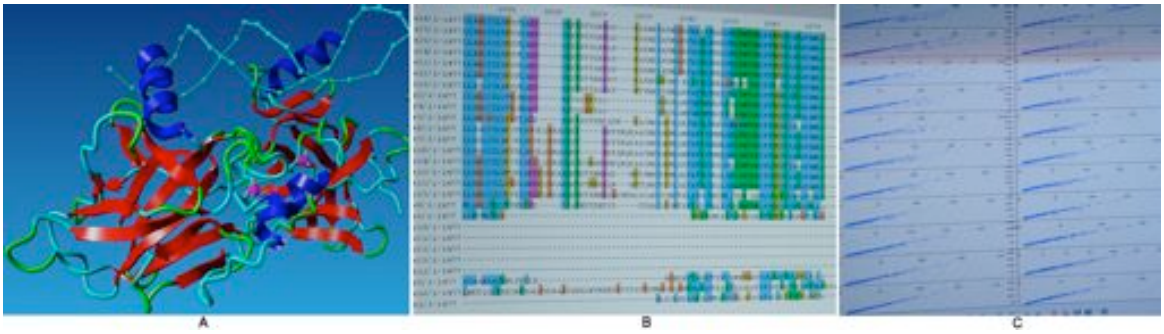


Figure 4.4: Visualisation used for: A) protein structure, B) sequence alignment, C) micro-array analysis

Another frequently used visualisation is a sequence alignment visualisation (Figure 4.4.B). In alignment visualisation, the similarity of two or more proteins or DNA sequences is depicted by means of a colour-coded map that shows a number of strings (amino acids in the case of proteins, nucleotides in the case of DNA) which are aligned to achieve optimum similarity over the entire string (see Figure 4.4.B).

The multidisciplinary team was discussing a micro-array analysis during a regular project meeting. Micro-array analysis is a quantitative method to study the simultaneous activity of thousands of genes at a certain point in time. There are two types of micro-array studies: in one, absolute gene activity is measured for a particular cell while in the other, gene activity of cells under different conditions (in other words, from sick and from healthy tissue) is compared. Because the raw data from a microarray experiment are normally marred by a lot of noise, statistical analysis is used. Graphical plots of the results are used to aid the analysis (see Figure 4.4.C).

Visualisations are very important in bioinformatics. One of the interviewees mentioned that visualisations are often underestimated in biology and suggested that they should also be used for showing active and inactive parts of biological networks.

Collaboration and multidisciplinary teamwork

The interviewees agree that collaboration is essential in bioinformatics. Collaboration can be achieved in different ways, ranging from working together in the same physical place to working distantly to publish their work. The interviewees highly valued the collaboration in the same working space, but reject the idea of distance collaboration based on virtual meetings.

Bioinformatics researchers have to work with people from other fields of expertise, such as biology and statistics, because bioinformaticians do not have these skills themselves. This was not only found from the observation of a multidisciplinary team, but also confirmed by the interviewees.

Collaborative environments

New technologies offer the opportunity to enhance meetings of the multidisciplinary teams by means of a scientific collaborative environment, such as large interactive displays [Rauwerda et al., 2006]. These large interactive displays can be used for discussing the setup of an experiment and for sharing and joining interpretation of experimental results, among other uses. A large display can show multiple views of the same datasets or the same type of view of different datasets for comparing experimental results. The interviewees thought that this could enhance creativity and stimulate discussion, although such displays should not overload users with a lot of results shown at the same time.

It is difficult to perform experiments during project meetings because experiments often take too much time. Therefore the collaboration environments are mainly used for the *discussion of (intermediate) experiment results* and of the *project progress*. It was clear from our observations that the project team could not remember what was agreed at previous meetings. Therefore, it is important to *assist the project teams during group discussions* to keep track of their decisions, action points and ideas.

Although researchers can access their data for presentation during the meeting, one interviewee mentioned that preparation of a meeting still remains important. In addition, a moderator should lead the discussion to prevent the meeting from becoming chaotic.

4.1.6 Conclusion and Discussion

Most life science and bioinformatics tools are very complex, even for domain experts, due to the number of parameters that can be set and the lack of documentation to assist users in understanding the interface. The detailed results of the questionnaire, including user preferences and usability problems with commonly used visualisation tools and web-based databanks can be found in the appendices. The results of the observations and the interviews on collaboration in multidisciplinary teams show that bioinformaticians work together with biologists and statisticians for initiating, executing and discussing experiments. The first results confirm that multidisciplinary collaboration is an essential part of bioinformatics research.

Visualisation of biological data is very important in life sciences. Visualisation is used for discussing the design of an experiment and/or (intermediate) results and for assessing the progress of an experiment. However, domain experts think that the use of visualisations is currently underestimated particularly in bioinformatics.

A lot of research is done on virtual collaboration, where the scope is on distance collaboration. Life scientists themselves are sceptical about the idea of virtual collaboration. They expect people to be more dynamic in a joint physical space, than in virtual space. Our focus is however on co-located collaboration in a multidisplay environment. The target group for this environment will consist of multidisciplinary scientific teams. Such an environment will contain large interactive displays for presenting experimental results or project progress in order to improve collaboration. Domain experts believe that such an environment can help collaboration, although facilitating the discussion by a moderator is essential.

4.2 Task Analysis of Microarray Experimentation

Design of a new interactive system is often triggered by an existing task situation. For example, a current way of performing tasks is not considered optimal, or the availability of new technology is expected to allow improvement over current work methods. A systematic analysis of the current work situation may help to formulate design requirements, and at the same time may later allow evaluation of the new designs and concepts. When studying the current task situation, a domain-specific analysis is of great importance for the design of a new system. Specific methods are needed for studying a complex scientific domain in order to envision the future task situation where multiple users interact with a system or an interactive environment. Groupware Task Analysis (GTA) [van Welie and van der Veer, 2003] combines classical HCI techniques such as contextual interviews, field observations, such as ethnographic studies and video analysis [Jordan, 1996; Jordan and Henderson, 1994].

This section presents the results of the extensive taks analysis study which aims at describing the current collaboration and work practices in a complex multidisciplinary situation. For this purpose, we have chosen an example domain of omics experimentation. Namely, multidisciplinary work in spotted microarray experimentation. The results of this task analysis study can also aid designers and developers in understanding the target domain and therefore designing more effective and useful tools and visualisations to enable more effective coordination between various domain experts. Please refer to the glossary of terms (Appendix F) for the detailed definitions of the terms in the context of task analysis, such as *agents*, *roles*, *tasks*, *goals*, *events*, *objects*, and so on.

4.2.1 Microarray Experimentation in Life sciences

Life science has been the subject of a famous ethnographic study by Latour and Woolgar [1979]. Life scientists, namely molecular biologists, study the chemistry of life or, more precisely, chemical interactions in and of living cells. They experiment with living organisms (*in-vivo*) and with living cells or material that has been extracted from cells or synthesised (*in-vitro*). Since the time of Latour and Woolgar [1979], the explosion of digital resources (databases and programs) has made a third type of experiment possible, nicknamed *in-silico* or dry-lab. For contrast, the in-vivo and in-vitro experiments are now also collectively known as wet-lab experiments. A large part of the life scientists' work consists of designing experiments and interpreting their results, in both cases heavily aided by the published literature. Living cells are incredibly complex [Papin et al., 2005] and with the emerging *'omics'* technologies that allow large scale experimentation, the biologist's task would be infeasible without appropriate software tools and visualisations.

Roughly, the scientific activity of molecular biologists takes place in three different contexts: in the lab, at the desk, and in meetings. The typical life scientist has a computer with high-speed connections to local servers and the Internet. These systems are still very much classical desktop PCs with some scientific software installed that, however, still falls short of the vision of computer-supported discovery environment that De Jong and Rip [1997] already proposed some ten years ago. The current desktop machines are ill-equipped for high-definition visualisations, and afford only poor interaction with visualisations, and limited multimedia tasks. It requires near-prohibitive overhead to operate such machines. A desktop PC is, in fact, the wrong tool for much scientific work of life scientists because of the limited screen space.

The goal of a microarray experiment is to simultaneously examine the expression level of all genes of a specific organism, in a cell type in a specific growth or stress condition. Microarray technology is currently one of the most important methods in genomics and is usually applied to unravel complex cellular mechanisms or discover transcriptomics biomarkers: genes whose expression profile can be used for diagnostic purposes or to monitor and predict cellular processes [Campbell and Laurie, 2006; Stekel, 2003]. Spotted microarray analysis is usually applied to understand complex cellular mechanisms or/and to discover biomarkers.

MA experiments involve many sources of noise and the interpretation of the results is far from straightforward [Stekel, 2003]. Nevertheless, there are stakes involved. For example, breast cancer treatment can currently be based on the result of a microarray experiment. In the experiment itself and its interpretation, practitioners from various disciplines are involved: microarray experts, biologists, bioinformatics experts and statistics experts. Microarray experiment itself is complex, as are the procedures to clean the data and to validate the results. A new challenge for molecular biologists is to find biological meaning in the diverse, multidimensional and huge (whole-genome) datasets. Methodology for inference of biological models from 'omics' data is still in its infancy.

4.2.2 User Group

User groups have to be defined during a task analysis. Different stakeholders may influence the requirements for the quality of work or may define certain roles, conditions and relations in a task model [van Welie and van der Veer, 2003]. We will further define the most important roles in a microarray experiment, indicate agents to whom certain subsets of tasks are allocated (see Table 4.2). More than one agent may perform the same role, and a single agent may have several roles at the same time.

The target user group for this study is a multidisciplinary research team collaborating on a joint scientific project in life sciences. Such a team often includes scientists from different domains related to life sciences, for example, molecular biology, chemistry and statistics. Various experts from a multidisciplinary team, consisting of bioinformatics researchers, lab-technicians, biologists and statisticians from different research institutes, were observed and interviewed in their working environment. The elaborated results of the conducted exploratory user study with a detailed description of this user group are presented in section 4.1.3.

Roles and Agents

After the first phase of the task analysis validation it became clear that microarray experiments are rather driven by individual expertise of various experts on the team (expertise-driven), than driven by one or more specific tasks (task-driven). This implies that the life science team is often shaped by the various Therefore it is important to clearly define individual characteristics of *agents* and *roles* that they perform to achieve a certain objective. Roles will be described as the packages of tasks that have a common goal and are performed by one or several agents (see Figure 4.5 for an illustration of relations in the Task ontology).

Goals:

1. Identify *agents* (see Table 4.2), what *tasks* (see Table 4.1) they perform, *roles*, and *objects* used (input and output results of each task, which are essential as input for other tasks, e.g. a statistical plot, see the Glossary of Terms in Appendix F for the detailed definitions).

2. Describe the current working practices, validate with microarray experts via in situ observations and semi-structured interviews.

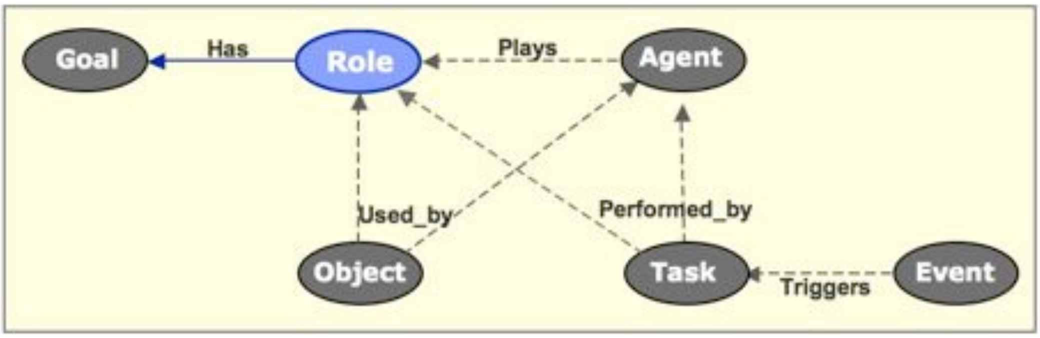


Figure 4.5: Role-centered task world ontology, based on van Welie and van der Veer [2003]

4.2.3 Method

Task Analysis is based on contextual interviews and observations conducted with researchers at the MicroArray Department (MAD)/Integrative Bioinformatics Unit (IBU) at the University of Amsterdam (UVA) (section 4.1.3). The Groupware Task Analysis (GTA) [van Welie and van der Veer, 2003] method was applied in this study. This entails two phases of the study: (1) analyzing the *current* work situation and (2) envisioning the *future* work situation, including conceptual design. The focus of the analysis reported in this section are the current working practices in microarray experimentation. Semi-structured interviews with microarray experts were conducted during the first phase to elicit the user requirements.

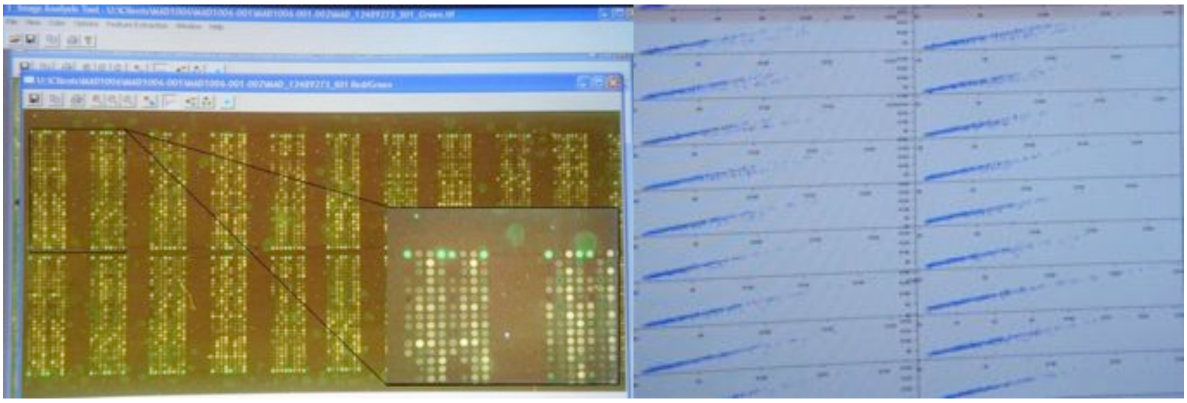


Figure 4.6: Raw image data (scans of microarrays) used by MA expert and lab technician during the visual inspection of arrays - Phase III (*left*); visualizations of the statistical analysis used during data validation in Phase IV: Dry lab (*right*)

4.2.4 Results

After analysis of the interviews and observations (section 4.1.3) [Kulyk and Wassink, 2006], the current work situation could be described, also referred to as the current task model [van Welie and van der Veer, 2003] .

A spotted microarray (MA) experiment can be divided into four major phases: problem statement, biological part, wet lab part, and dry lab part (see Table 4.1). Table 4.1 presents an overview of the tasks involved in various stages of a microarray experiment and which experts (agents) are involved in which tasks. Specifically, we focus on the situational awareness and team collaboration support during the dry lab phase, the interpretation of microarray experiments (Table 4.1).

Research questions are defined by biologists or by medical researchers. Examples of research areas: cancer research; food conservation; neurology; dental medicine, etcetera. Experimental design is usually created by the biologists, who define the requirements and restrictions from the biological experimentation, the microarray specialists, who define the requirements and restrictions related to the microarray technology, and bioinformaticians/statisticians, who define the requirements and restrictions aimed at data analysis. A team normally defines the experimental design in collaboration with various experts during one of the first project meetings.

The other important decisions concerning the project and the whole experiment are taken during regular face-to-face meetings with project members, sometimes during telephone conversations, via e-mail or during discussion between colleagues. The people involved could be spread over several locations within one or several countries.

Figure 4.6 demonstrates the examples of visualizations used by various experts in different phases of a microarray analysis. The tasks are performed by agents who perform a specific role (roles), consisting of a package of tasks in the different phases of the experiment.

Table 4.1: Phases of a microarray experiment and agents involved.

Phase	**I. Problem statement**	**II. Biological experiment**	**III. Wet lab part**	**IV. Dry lab part**
Tasks:	• Defining a research question and experiment design • Sample randomization (statistician)	• Execution of biological experiment & sample preparation	• Sample preparation: RNA extraction • Conversion into cDNA • Labeling • QC: quality checks (RNA, labeled cDNA). • Microarray experiment • Scanning • Visual inspection of arrays • Feature extraction • Basic QC testing parameters	• Data storage in DB • Data extraction (from DB) • Data transformation & normalization. • Data validation • Data analysis: making biological models, images
Agents:	Project team A: • Molecular biologist • Bioinformatics expert • MA Statistics specialist • MA expert	Biological lab agents: • Molecular biologist • Lab technician	Wet lab agents: • Lab technician • MA expert	Project team B: • Molecular biologist • Bioinformatics expert • MA Statistics specialist

4.2.5 Validation

A validation of the task analysis description is required to list criteria for making decisions and to define the roles and expertise of the agents at each phase of a microarray experiment. We performed validation with microarray experts through in situ observations and interviews.

After validating the description of roles and agents (see Appendix F for the definition) with the experts, it has been verified and adjusted. The next step is to describe the future work situation, focusing specifically on the part where agents collaborate during the regular co-located meeting discussions. In this case, microarray analysis (MA) in a Scientific Collaborative Environment (see Figure 4.7) is the future work situation [Rauwerda et al., 2006]. To acquire data about the future work situation, new design concepts will be described based on the results of the requirements elici-

Table 4.2: Agents involved in different tasks of a microarray experiment.

Phase	**Task**	**Agents**				
		Molecular biologist	MA expert	Bioinf. expert	MA Stat. specialist	Lab technician
I	Defining a research problem & experiment design	•	•	•	•	
II	Execution of biological experiment & sample preparation	•				•
	Sample preparation		•			•
	Sample randomization		•		•	•
	Microarray experiment		•		•	•
III	Scanning		•		•	•
	Visual inspection of arrays		•		•	•
	Feature extraction		•		•	•
	Basic QC testing parameters		•		•	•
	Data storage (in DB)		•			•
IV	Data extraction (from DB)			•		
	Microarray experiment			•		
	Data transformation & normalization			•	•	
	Data validation				•	
	Data analysis	•		•	•	

tation study (section 4.7). Through concepts evaluation we can receive feedback on how different users envision and interpret their work in this new environment (see Part III: chapter 5, chapter 6, and chapter 7).

4.3 User Requirements and Design Implications for Multidisplay Environments

As the user requirements study and task analysis confirm, molecular biology in general is a highly visual discipline [Campbell and Laurie, 2006]. Visualisations play a large role in the analysis and interpretation of omics experiments [van der Vet et al., 2007], Figure 4.6. Next, we discuss how visualisations on large displays can support group discussions in co-located multidisplay environments. We also present our own ideas and concepts on situation awareness support of scientific teamwork in a life science context 4.3.1. We argue that situational awareness can be supported in such environments by bringing relations between various visualisations to the focus of attention.

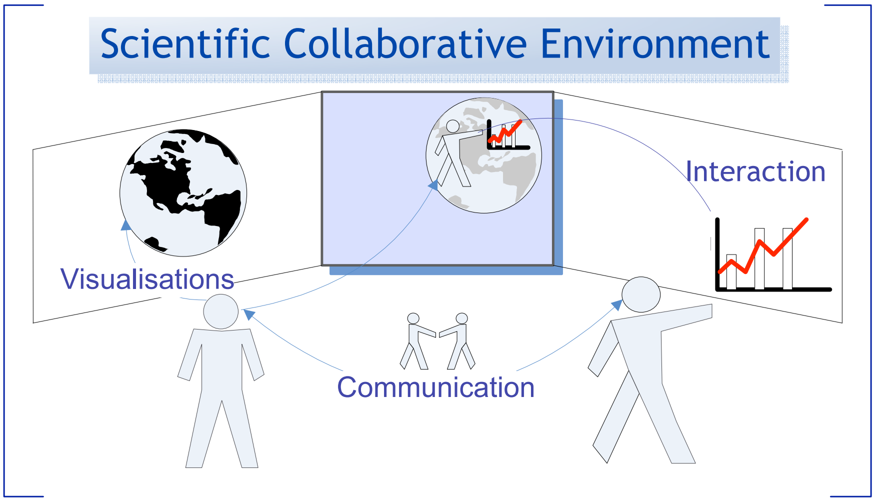


Figure 4.7: Concept: multidisplay environment for scientific collaboration

4.3.1 Situational Awareness Support for Multidisplay Environments (MDEs)

In a multidisplay collaborative environment, scientists with different scientific backgrounds use large shared displays to show their preferred types of visualisations in order to discuss progress and results of experiments (see Figure 4.8). The *e*-BioLab is a multidisplay environment intended to facilitate multidisciplinary teams during project meetings that require multidisciplinary collaboration for their design and interpretation, such as a microarray experiment [Rauwerda et al., 2006].

In interpreting a microarray experiment in the *e*-BioLab (Figure 4.8, right), both the results of the experiment itself and those of statistical data analysis can be displayed in the form of visualisations on the large display, as in the example in Figure 4.8. In this way, team members can assess an entire microarray experiment. Moreover, in a multidisciplinary setup a large high-resolution display connected to online genomics resources can be used to construct models of biological mechanisms, thus enhancing omics experimentation and collaborative interpretation of the results. The largest tiled display is split into a number of displays (Figure 4.9). Visualisation of various statistical representations of the data on the tiled display enables scientists to assess the quality of the entire experiment at once. Even though various parts of the display are obviously related in the sense that the visualisations presented on each part refer to the same experiment, it is not always evident what the precise relation is. Therefore a Highlighting-on-Demand concept has been developed (section 4.3.2) which allows scientists to bring certain visualisations into the focus of attention, thus making the relationship between them explicit. Chapter 5 elaborates further on the design and evaluation of the Highlighting-on-Demand interface in the real multidisplay environment, the *e*-BioLab.

In addition, in situ observations and video analysis [Jordan, 1996; Jordan and

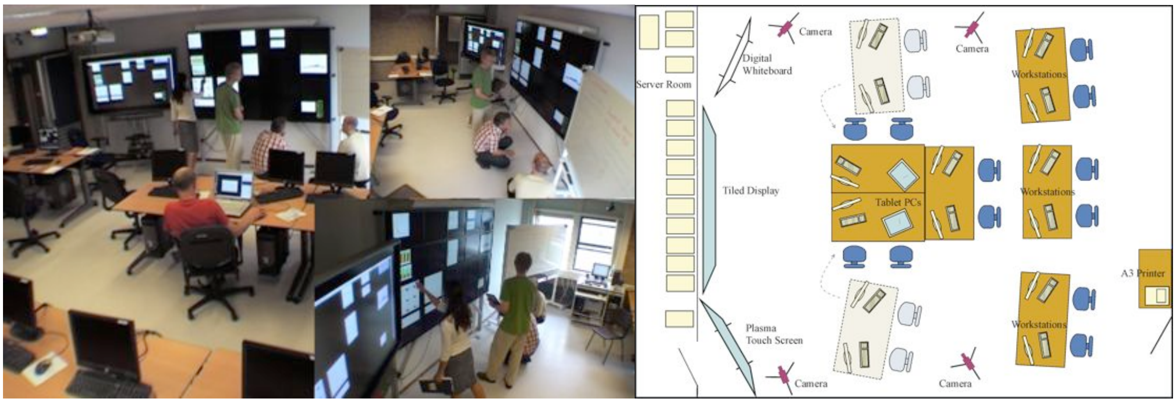


Figure 4.8: Three camera views of group discussion session in the *e*-BioLab (*left*); layout of the multidisplay *e*-BioLab, MAD-IBU, University of Amsterdam (UvA) (*right*) [Rauwerda et al., 2006].

Henderson, 1994] was performed on the series of multidisciplinary group discussions on microarray results in a real multidisplay environment, the e-BioLab [Rauwerda et al., 2006], using the interaction analysis approach of Jordan and Henderson [1994]. We were not only interested in the group discussion, even though it is an important focus of our research, but also on the interactions of the users with various displays and devices and the use of the displays to share visualisations between different experts. We imagine that, as prices of large, high-resolution displays drop, these shared displays and the associated interactions will become more common not only in the collaborative environments, but also in scientists' daily working spaces [Rauwerda et al., 2006].

The results of the observations and video analysis of scientific team discussions in the multidisplay e-BioLab environment showed that life scientists tend to walk to the shared tiled display to inspect a specific detail of a visualisation. This indicates that, unlike a static projection in the meeting room, a large shared display plays an important role in engaging the group members in the discussion. This points to the dynamic nature of interactions as reported in other studies [Tan et al., 2006].

Next, we present three situational awareness support concepts for large displays based on the SA requirements summarized below. The purpose of these concepts is to explore various alternative solutions for SA support in multidisplay environments to enhance group decision making and to facilitate co-located group discussions.

4.3.2 SA Requirements for Large Displays

Below, we present a short summary of the main SA requirements for large displays based on the generalized findings of the exploratory user study and task analysis reported earlier in this chapter (section 4.1, 4.2):

- Enable information sharing
- Provide alternatives
- Visualise changes

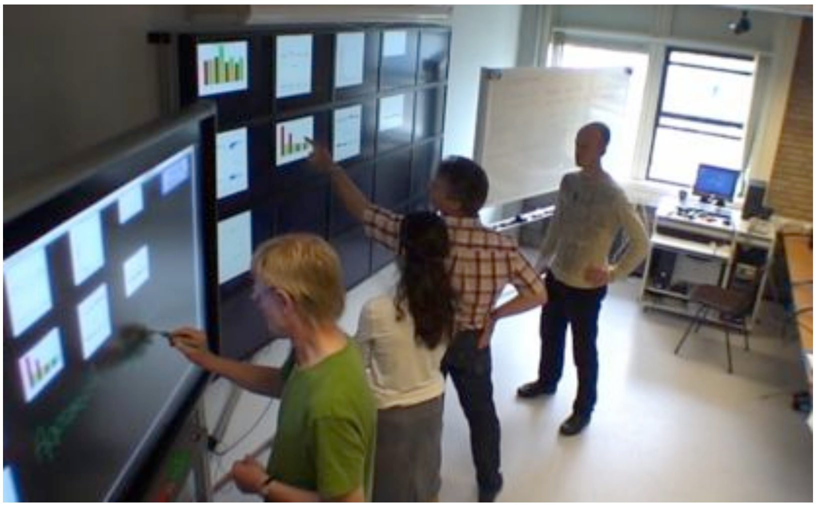


Figure 4.9: Snapshot from a real group discussion on microarray results in *e*-BioLab, group member annotating visualisations on a plasma touch screen.

- Visualise a history of changes
- Provide feedback about the current selection
- Provide feedback on who is making changes
- Make relations between visualisations explicit
- Support annotation
- Support for drawing attention of various experts
- Provide the status summary
- Allow switching between different views

Concept I: *Highlighting-on-Demand Interface*

The Highlighting-on-Demand interface enables the team member who is currently controlling the tiled display to draw the attention of the team by highlighting a certain visualisation using a slider on a personal interaction device (for instance, via a TabletPC) or a shared interaction device (for instance, via a shared touch screen).

Based on the theory of situational awareness (chapter 2) and on the results of the user study and task analysis presented above, displaying all alternatives on a shared large display should foster information sharing and the Highlighting interface should enable group members to draw the attention of the group to a certain visualisation, while still keeping the other alternatives in view. The highlighting-on-Demand concept supports level 1 of situational awareness, perception (see chapter 2). The detailed description of the Highlighting-on-Demand interface, as well as results of the user evaluation are presented later on in chapter 5.

Concept II: *Chain-of-Thoughts Interface*

The Chain-of-Thoughts interface enables group members to store and visualise the history of changes and annotations of the shared display content, allowing users to go back in time and retrieve annotations, for example, made on a previous slide or visualisation. This Chain-of-Thoughts serves as a peripheral awareness display that affords memorability and supports levels 2 and 3 of situational awareness, comprehension and projection (see chapter 2). The detailed description of the Chain-of-Thoughts prototype and the empirical results of the user study are discussed in chapter 6.

Concept III: *Control Interface*

The Control Interface provides support on the status information about who is in control of a shared display or another shared artefact. This makes every member of a team aware of who is making the changes and what changes are being made. The control Interface enforces information sharing and thus supports coordination mechanisms and group awareness of who is currently manipulating and annotating the visualisations (Figure 4.9).

We also predict that the Control Interface will help to prevent the potential control negotiation conflicts about the annotation of visualisations and about manipulation of the shared display. Thus, this concept supports level 3 of situational awareness, projection (see chapter 2). The Control Interface concept was integrated with the Highlighting-on-Demand interface, presented in chapter 5.

4.3.3 Discussion

Although the number of participants limits the generalisability of our findings, the combination of regular observations with other user analysis techniques in real-life settings makes the contribution of this user study novel. The related study by Bartlett and Topms [2005] presents the results of the task analysis based on the interviews with bioinformatics experts, but does report on any in situ observations or further design implications. Another study by Javahery et al. [2004] on the use of the bioinformatics tools discusses the results of the interviews carried out with 19 scientists: biologists, medical practitioners, and computer scientists. The authors conclude with the user profile description of novice and expert users with no further design implications.

Saraiya et al. [2004] report on a controlled user evaluation of five existing microarray visualisation tools with 30 participants (21 microarray experts and lab technicians, plus 9 computer scientists) using an artificial task. The authors try to identify a vaguely defined notion of ‘insight’ in the use of the visualisations [Saraiya et al., 2004]. To conclude, none of the related studies used a combination of user analysis methods, such as interviews and task analysis, with in situ observations in real work settings. Our user analysis approach can be used to study multidisciplinary teams in other domains. Further, user requirements above have to be validated through design concepts based on real-life tasks performed by a multidisciplinary team of experts assembled in a co-located multidisplay environment.

4.4 Summary

This chapter presented the generalized results of the user requirements study and design guidelines. We came up with the general situational awareness support concepts: Highlighting-on-Demand, Chain-of-Thoughts and Control Interface. Further, we aim at evaluating the usefulness of these three concepts in real multidisplay environments in three different domains, introduced earlier in chapter 3. In two of the domains (agile software engineering and enhanced brainstorming), we performed additional in situ observations and interviews, before introducing a SA support, to find out *what* type of SA support is mostly suited, *when* it should be introduced and *how*.

The next part of the thesis presents the evaluation results of three SA concepts (chapter 7, chapter 5, and chapter 6). Empirical user studies were performed in real multidisplay environments in three different domains presented earlier (chapter 3).

Part III

Empirical Results

Chapter 5

Highlighting-on-Demand Support for Group Decision Making

"Everything should be made as simple as possible, but not simpler."
–Albert Einstein

5.1 Introduction

This chapter[1] presents the results of the empirical user study on the effect of the Highlighting-on-Demand concept on situational awareness and satisfaction with the group decision-making process in a real multidisplay environment.

The complexity of communication processes in a co-located decision-making environment requires the combination of several approaches to support situational awareness. This, in turn, requires a practical method to capture and analyse the dynamics of technology-mediated interactions in context. The nature of the interfaces as well as the physical characteristics and affordances of the environment influence the way in which interactions occur [Fruchter and Cavallin, 2006]. Therefore our approach for data analysis includes a combination of behaviour, interaction and environment analysis.

We will assess shared situational awareness of team members when we provide supportive visualisations on a shared large display. We aim at reducing disturbing factors that are considered a distraction from the primary group decision-making task. We intend to establish an indication of the relations between situational awareness, team satisfaction, group processes like decision making and the perceived task performance. Video recordings from several viewpoints will enable us to analyse several simultaneously ongoing interactions. In addition to observations, post-interviews and

[1]accepted for publication in: Kulyk, O., de Kler, T., Leeuw, W., Veer, G. C., Dijk, E.M.A.G. *Staying Focused*: Highlighting-on-Demand as Situational Awareness Support for Groups in Multidisplay Environments. In: *Human Aspects of Visualization*, A. Ebert, A. Dix, N. Gershon and M. Pohl., editors, Lecture Notes in Computer Science, volume 5727. Springer Berlin, 2010.

questionnaires are carried out to obtain subjective judgments of the team members, for example, on group satisfaction, awareness and distraction from primary tasks [Cadiz et al., 2002; Kulyk et al., 2007a; Olaniran, 1996]. Group satisfaction will be assessed by a combined validated post-task questionnaire featuring the group process and decision making [Olaniran, 1996]. We apply these questions to assess the perceived usefulness and impact of the Highlighting-on-Demand interface on the shared situational awareness of team members, on distraction from the primary task, and on team satisfaction with the group process and decision-making process.

5.2 Theory Grounding: Social Psychology of Groups and Technology

Research in social psychology has demonstrated that our ability to make group decisions is frequently flawed because we overly rely on social cues during a group discussion [McGrath, 1984; McGrath and Hollingshead, 1993]. Conversations held by groups for the purpose of making decisions are fraught with complications. Social psychologists have demonstrated that individuals allow the presence of the other people in the group to influence their behavior to such a degree that through the process of exchanging opinions, the group is led to a lower quality decision, as compared to aggregating individual decisions [Bray et al., 1982; Hackman, 1992; Janis, 1982; Myers and Bishop, 1971; Whyte, 1991].

While groups have flawed decision processes, Raven [1998] describes a well-known experiment that aptly illustrates the difficulty in universally stating that groups hinder decision-making. The results of his experiment show that the groups that reached a unanimous decision felt more satisfied with their decision than those that did not, even if they were shown to be incorrect in their judgment. This experiment illustrates that individuals rely on the opinion of others as an indicator of the accuracy of their judgments, but this reliance can occasionally lead to an error in judgment. Yet, as a corollary to this, if a criterion of decision success is satisfaction with the outcome, then individuals' use of this decision-making strategy may be beneficial even in cases where their judgment is wrong.

With this understanding of the complexity of our limitations, what can we do to limit the harm and harness the benefits of groups? By altering its decision-making process, a group can avoid the above communication flaws and over-reliance on others. According to DiMicco et al. [2004] and based on the related studies on the psychology of groups, there are three possible areas that should be examined to enhance decision-making processes with technology. First, determine ways to encourage vigilance in considering choice alternatives in the discussion [Janis, 1982]. Second, limit the effects of group polarisation (a group's tendency to shift towards risk or caution) [Brown, 1986]. And third, increase the sharing of information between individuals [Stasser and Titus, 1987].

For example, vigilance can be fostered by a system that keeps all the alternative ideas in front of the group, and makes the infrequently mentioned alternatives reappear within the discussion. Group polarization can be limited with a reframing of decisions in terms of gains, not losses, and an interface or tool that enables a group to reframe questions from different points of view. Information sharing can be encouraged within a group by allowing the documentation and presentation of individual decisions that will later be shared with the group.

Technology is already a part of daily decision-making environments (e.g., smart meeting rooms and multidisplay environments), both as communication tools and information devices. As these devices (e.g., large displays) and tools become more accessible, there is an increasing opportunity to develop applications that enhance group communication abilities, rather than restrict them. If tools can be designed such that the satisfaction with the group decision-making process increases, then the potential for achieving more gains of group interaction increases.

5.3 Objectives and Hypotheses

Based on the results of the exploratory user study and task analysis results (chapter 4.3), we have come up with a number of situational awareness (SA) concepts to explore various alternative solutions [Kulyk et al., 2008a] in order to support group decision making in co-located collaborative environments, presented earlier in chapter 4.3. One example is a Highlighting-on-Demand interface, which enables a team member who is currently controlling the shared display to draw the attention of the other team members by highlighting a certain visualisation, for example, using a slider on a shared display or a personal interaction device.

The goal of this experiment is to perform a controlled comparative case study in order to measure the effect of the Highlighting-on-Demand concept on: a) satisfaction with the final group decision and b) satisfaction with the group decision-making process in a multidisplay environment. We will assess satisfaction with the decision-making process of team members, providing supportive visualisations on a shared large display. We aim at reducing the distraction from the primary decision-making task, and increasing the group member's satisfaction, with the decision-making process and group communication, as well as satisfaction with the perceived task performance (individual decision versus group decision).

Based on theories on the formation of shared situational awareness (Chapter 2) and social psychology of groups [Janis, 1982; Brown, 1986; Stasser and Titus, 1987], displaying all alternatives on a shared large display should foster information sharing and the highlighting interface should allow group members to draw attention of the group by highlighting a certain alternative, while keeping the other alternatives still in view. Therefore, by presenting all alternatives on a shared large display and enabling highlighting on a shared touch screen, it is hypothesized that satisfaction with the group decision-making process will increase. These predictions are summarized as two hypotheses:

H1 — In the condition with the Highlighting-on-Demand interface, participants' satisfaction about group process and decision-making process will be higher.

H2 — Participants' satisfaction about the final group decision, in relation to their individual decision, will be higher in the condition with the Highlighting-on-Demand interface.

Next section presents the experiment design and procedure.

5.4 Setting and Procedure

Within-group design is applied in this experiment, which means that each group of participants performs a group decision-making task in both conditions: one Without (N) and one With (Y) the Highlighting interface. The conditions are balanced (See Table 5.1 below).

Table 5.1: Experiment design

Group Session	**Condition (N/Y)**	**Image Set (A/B)**	**Questionnaire** (*see Section 5.4.5 below)*
1	N	A	Part I
	Y	B	Part I & II
2	Y	B	Part I & II
	N	A	Part I
3	N	B	Part I
	Y	A	Part I & II
4	Y	A	Part I & II
	N	B	Part I

Legend, Table 5.1:
Conditions:
N (=NO): Without Highlighting
Y (=YES): With Highlighting

Image Sets:
Set A = 7 various large paintings (landscape, portrait, abstract, fantasy etc.) – Figure 5.1.
Set B = a set of 7 other various large paintings – Figure 5.2.

5.4.1 Target Group

The chosen target group for this experiment is ad-hoc small groups of four to five members. Group members are scientists who might be colleagues working together at the same faculty at the university, or in the same research group (e.g. human-computer interaction or visalisation research group), with multidisciplinary backgrounds. We mixed-up group members to create balanced small groups. As a result, some of the participants knew each other well beforehand, and others have never worked in one team together.

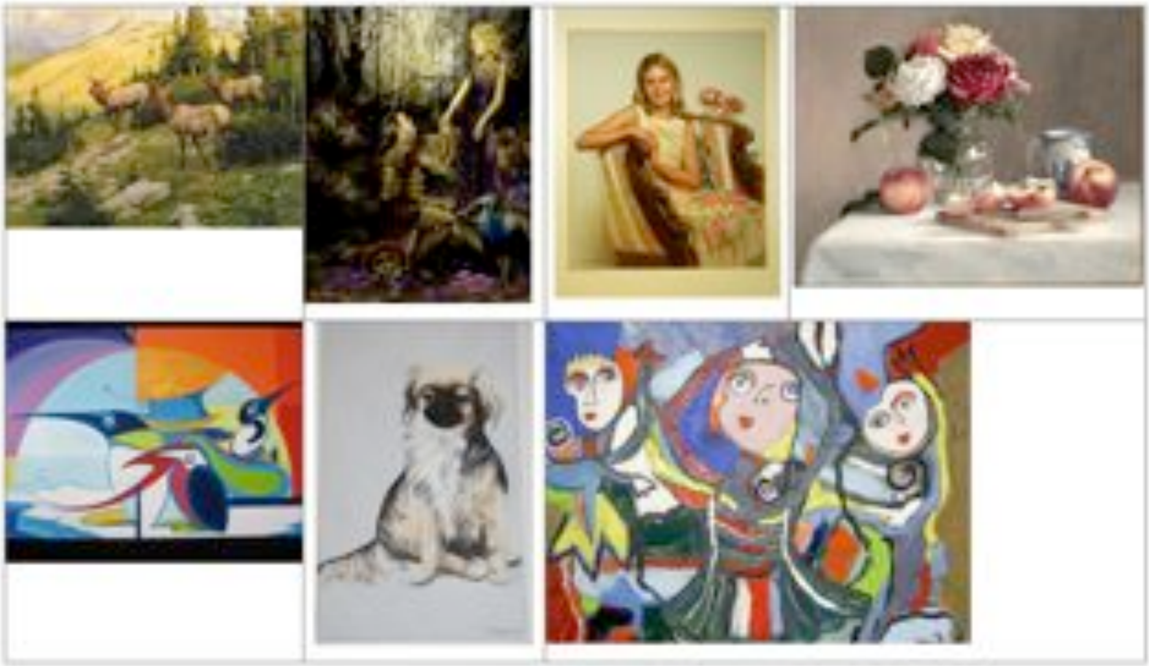


Figure 5.1: Paintings: set A

5.4.2 Group Task Scenario

In this study we address the domain of the group decision making which involves group discussion and review of the arguments prior to making a final decision. The goal of the group task in this study was to initiate a group discussion on a topic of joint interest and motivate the team members to develop an individual and a group decision-making strategy. Since it was not feasible to find several life science teams to participate in the study, we decided to choose a general task for group decision making, not related to omics experimentation or life sciences. Taking into account that ad-hoc groups consist of group members from different disciplines, we picked a general task, which would be of interest to each participant and to the whole group at the same time.

A group decision-making scenario was presented as a group task, where a group had to discuss seven paintings and then pick three of them to put it in the shared coffee room. After discussing each painting with the whole team, and the pros and cons of putting it in the shared coffee room, each group member had to pick a maximum of three favourite paintings individually. After that, participants were asked to play a ranking game, where everybody had to share their individual choice with the rest of the group by dividing 3 points between three, two or one painting. Finally, a group

Figure 5.2: Paintings: set B

Figure 5.3: Paintings: test set 0

had to reach a decision by picking three paintings only, either by summing up the individual scores or by agreeing on the mutual group decision.

Each group had a limited time of ten minutes to reach a group decision. The main goal for the group was to reach a group decision that each group member would agree with. Each participant received a €8 gratuity coupon for their participation.

Table 5.2: Session planning - group session 1 (see Table 5.1)

Time duration (Total: 60 min.)	**Activity**
7 min.	Intro & Example (interaction via plasma touch screen) – Image **Test Set 0** (Figure 5.3)
10 min.	**Task** (N = No Highlighting, only moving) – Image **Set A** (Figure 5.1)
5 min.	**Pre-Q**uestionnaire (**Part I**)
3 min.	Intro & Example (Highlighting & resizing) – Image **Test Set 0** (Figure 5.3)
10 min.	Task (Y = With Highlighting & resizing) – Image **Set B** (Figure 5.2)
10 min.	**Post-Q**uestionnaire (**Part I & II**)
5 min.	Illustrate extra function: Highlight one image, fade out the rest automatically
10 min.	**Debriefing**: post group interview

Legend, Table 5.2:
Set 0 = a set of 7 different large paintings (Figure 5.3) used only for the introduction.

Instructions to the group

Your faculty at UvA has received 7 paintings as a present from students of Utrecht Art Academy. Only 3 paintings can be put in the coffee room of your research group. Your goal is to discuss these 7 paintings (presented on a large tiled display in front of you) as a group and choose 3 paintings for the coffee room of your research group. After discussing each painting (pros/cons, why you like it, why does it suit in the coffee room etc.) in a group, you will have to score them to make a group decision. Each of you will have 3 points that you can choose to either divide between 2 (e.g.: Painting 3 = 2 points, Painting 5 = 1 point) or 3 paintings, or you can give all 3 points to just one painting of your personal choice. You have to announce your group choice of favorite 3 paintings after 10 minutes. Please use a blank A4 page or a whiteboard (on your right) to put your personal and group scores.

5.4.3 Pilot Test

Before the actual experiment, a pilot session was conducted in order to test the procedure, the experiment design, the prototype, the position of the paintings on the

Figure 5.4: Group session, Highlighting-On-Demand Experiment: group member interacting with the Highlighting interface on a plasma touch screen (*left*); group members discussing paintings displayed on the shared tiled display (*right*).

shared tiled display and the displays setting. Several technical problems were found and solved during the pilot test. We only name a relevant one here:

Namely, the ‘Highlight one image - fade the rest’ checkbox (Figure 5.5, right bottom) was removed due to the distraction caused by the flashing effect on the Plasma Touch Screen. Since the Highlighting prototype was running on a Windows platform via SAGE interface, it was not possible to solve the flashing and therefore it was decided to ask the participants about the usefulness of this feature during a post group discussion and in the post-task questionnaire instead. The sliding bar (Figure 5.5, bottom) was left visible on the Highlighting interface. A user could highlight or fade a selected painting (or any projected window on the Tiled Display) by moving the slider left or right via direct touch or using a mimio pen on a Plasma Touch Screen (Figure 5.4, left). The effect was immediately visible on the Tiled Display (Figure 5.4, right).

Figure 5.5: Highlighting-On-Demand pilot

5.4.4 Multidisplay Environment Setting

The experiment took place in the E-BioLab multidisplay meeting environment (see Figure 5.7). In all conditions, images were displayed on the central Tiled Display (5x4 lcd-monitors, resolution 1600x1200, 38 Megapixels) in the middle of the lab (Figure 5.7)).

In condition N (No Highlighting interface), only a moving feature (via direct touch or using a mimio pen on a 63-inch Plasma Touch Screen with a resolution of 1360x768, Figure 5.4, left) of the interface was shown to the participants. That means that group members were only able to move and rearrange images on the Tiled Display (Figure 5.4, right), using the Highlighting-on-Demand interface version without a sliding bar below (Figure 5.6).

In condition Y (Highlighting interface), in addition to a moving feature as in N condition, participants were able to highlight or fade paintings (via direct touch or using a mimio pen on a Plasma Touch Screen, Figure 5.4, left). Interaction with the Highlighting interface was logged in a text file with time stamps. All sessions were captured with four video cameras from four different angles (see Figure 5.7).

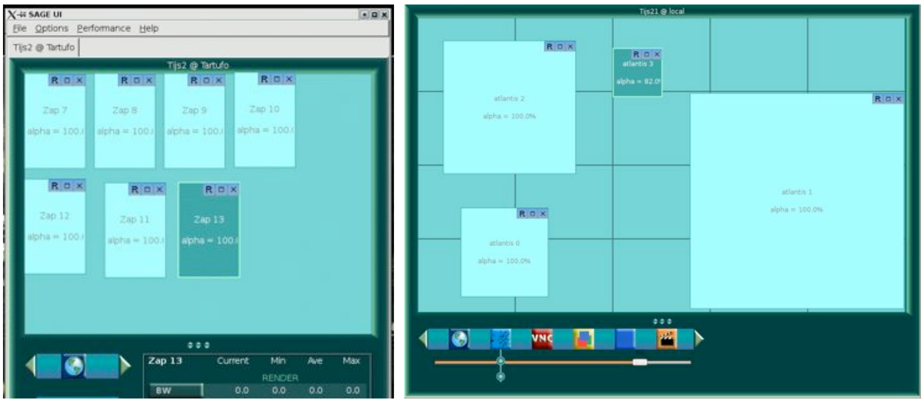


Figure 5.6: Highlighting-On-Demand prototype: desktop version (*left*), image courtesy of Tijs de Kler, SARA; a touch screen version (*right*).

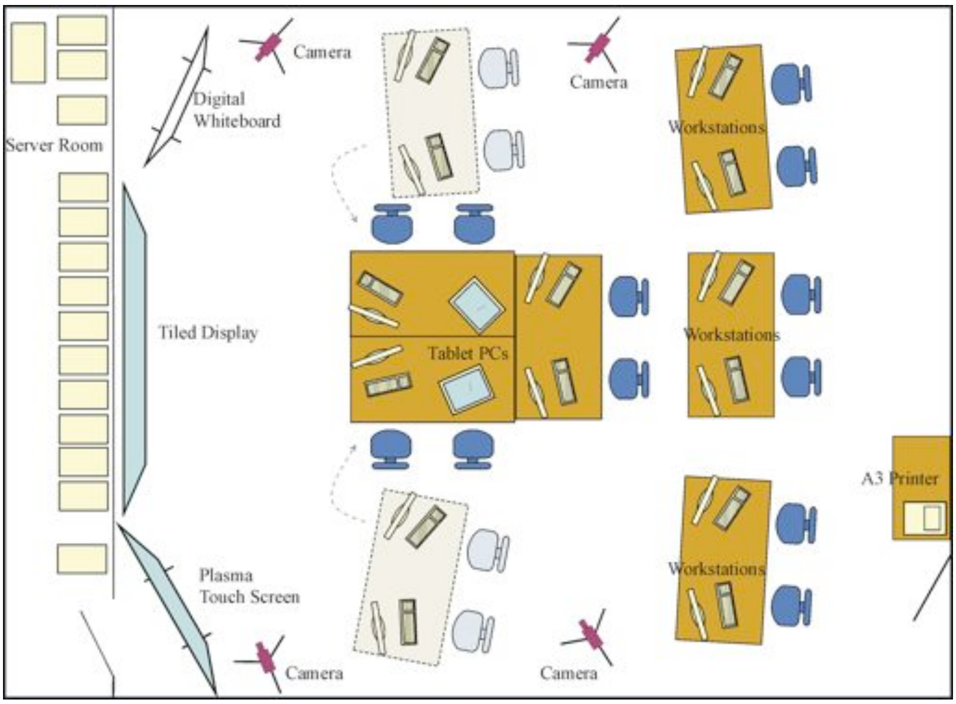


Figure 5.7: Layout of the multidisplay *e*-BioLab, MAD-IBU Department, University of Amsterdam (UvA) [Rauwerda et al., 2006]

5.4.5 Measures

Two dependent variables were measured: group process and decision making, and satisfaction. By keeping the team composition balanced and the task case constant in all groups, the effect of this variable was diminished. Likert scale questionnaires were applied to access the perceived group process quality [Olaniran, 1996], satisfaction with the decision-making process [Kulyk et al., 2006; Paul et al., 2004], and the perceived agreement with the final group decision (Appendix I, A & B). All questionnaires used 5-point Likert-scale, where '1' meant 'Strongly agree' and '5' – 'Strongly disagree'. Group process and decision making questionnaire was administered to team members in both N and Y condition.

As previously discussed in chapter 2.4, direct self-rating techniques, such as SART [Taylor, 1989], have a potential limitation that participants may experience difficulties rating low periods of SA [Salmon et al., 2006]. In view of the rather short duration of the study, we predict that SART measure might not be sensitive enough for our case. Instead, we use perceived agreement with the final group decision as an indirect measure of shared situational awareness [Bolstad and Endsley, 2000; Wickens, 1992].

An additional set of questions (Appendix I, C) addresses participants' subjective judgments about satisfaction with and usefulness of the Highlighting-on-Demand interface (including distraction and awareness) [Cadiz et al., 2002; Kulyk et al., 2006; Paul et al., 2004]. Post-task usefulness questionnaire was administered to team members only in Y condition. The overview of all measurements and techniques is given below.

- Questionnaires:
  1. Satisfaction with group process and decision making (Part I, see Appendix I)
  2. Perceived agreement (Part I: question B-8, Appendix I)
  3. Usefulness and satisfaction with the Highlighting-on-Demand interface; awareness and distraction (Part II, see Appendix I)
- Observations (observation protocol, Appendix H)
- Post-session group interviews
- Video capturing (4 cameras)

5.5 Data Analysis and Results

The experiment results indicate that the use of the Highlighting interface on the shared display positively influenced team members' satisfaction with the final group decision. The main findings from the data analysis are discussed below.

5.5.1 Participants

In total 18 participants (15 male and 3 female, age range 25-31 years) were recruited from the university community and assigned in 4 groups (2 groups of 5 members each, and 2 groups of 4 members each). Gender was split so that 3 groups out of 4 had members of both genders. Participants were mostly students, scientific programmers and postdoc researchers from three different research groups at the same university (University of Amsterdam, UvA) and had various scientific backgrounds (e.g., computer science, physics, computational biology, mathematics, engineering). None of the participants had experience with group discussion in the multidisplay environment before.

5.5.2 Questionnaires

Group process, Decision Making and Situational Awareness

Wilcoxon Signed Ranks test was conducted to compare group members' satisfaction with the decision-making process in Y (Highlighting - condition 2) and N (No Highlighting - condition 1) conditions. There was a significant difference in the scores on the satisfaction with the final group decision, in relation to the personal preference, for the Y-Highlighting (M=4.67, SD=0.48) and N-No Highlighting (M=4.11, SD=0.83) conditions; p=0.02 (z=-2.33). Table 5.3 shows the results of a Wilcoxon Signed Ranks test only for the significant result – satisfaction with the final group decision. There was no significant difference found in the scores on the satisfaction with the group process and the decision-making process (Wilcoxon Signed Ranks test).

Table 5.3: Wilcoxon signed ranks test for the differences between N (*No Highlighting*) and Y (*Highlighting*) condition

Questions: Decision Making Process	N: Mean (SD)	Y: Mean (SD)	Sig.
Overall, I am satisfied with the final decision of the group, in relation to my personal preference.	4.11 (0.83)	4.67 (0.48)	0.02

These results suggest that the Highlighting-on-Demand interface really does have an effect on the satisfaction with the final group decision. Specifically, our results suggest that when group members use the highlighting interface during the discussion, the satisfaction with the final group decision increases. In this manner, H2, stating that participants' satisfaction about the final group decision, in relation to their individual decision, will be higher in the condition with the Highlighting interface, is confirmed. On the other hand, H1, stating that in the condition with the Highlighting-on-Demand interface participants satisfaction about the group process, and the decision-making process will be higher, is not confirmed.

Perceived agreement with the final group decision is an implicit measure of shared situational awareness [Bolstad and Endsley, 2000; Fjermestad, 2004; Wickens, 1992]. This suggests that in the condition with the Highlighting-on-Demand support, the situational awareness was higher in terms of the perceived quality of group decisions and level of consensus. As the study of Wickens [1992] also indicates the ability of group members to accurately perform probabilistic diagnosis (situational awareness) coupled with the assigned values of different alternatives (ranking game), results in more satisfactory group decisions.

Usefulness, Awareness and Distraction

We balanced the valence of our satisfaction questions. For negatively phrased questions (marked with an asterisk in Table 5.4 and Table 5.5), we reversed the rating so that higher was always positive. The rating for the ability to focus the attention of others on certain information on the large display was above the average but not high enough. One of the reasons could be the difficulty to self-report the allocation of attention of oneself and others. More objective measures like eye gaze might be more efficient in this case, though there is still no eye-gaze tracking system applicable for dynamic group settings. Counting the number of times a participant attends to a certain display or a part of the display is another option, though it is burdensome and requires at least one observer per participant.

Ratings on awareness and distraction were also mostly neutral to positive (see Table 5.5). Awareness and distraction ratings indicate that the Highlighting interface did not distract participants from group discussion, but did not make then more aware of the information on the large display.

Ratings on usefulness and satisfaction with the Highlighting interface were mostly neutral to positive (see Table 5.4). From the ratings, it is clear that participants had no difficulty understanding the Highlighting interface and did not need more training to understand the interface. Group members also stated that they had confidence in the information provided by the Highlighting interface.

Table 5.4: Questionnaire results: usefulness and satisfaction

	Question	**Average Rating (SD)**
1.	I have difficulty understanding the highlighting interface.*	4.7 (0.5)
2.	Highlighting interface is easy to use.	3.3 (1.4)
3.	Highlighting interface is reliable.	3.0 (1.4)
4.	I have confidence in the information provided by the highlighting interface.	4.0 (0.9)
5.	I need more training to understand the highlighting interface.*	4.8 (0.4)
6.	I find the information provided by the highlighting interface informative.	3.3 (0.8)
7.	The information provided by the highlighting interface is comprehensible.	3.6 (0.8)
8.	Overall, I am satisfied with the highlighting interface.	3.1 (1.1)
9.	I would be happy to use the highlighting interface in the future.	3.3 (1.3)

User Preferences on the Highlighting Interface Features

Three additional questions in the post-task questionnaire addressed the user preferences of the various features of the Highlighting interface, as well as the interaction

Table 5.5: Questionnaire results: awareness and distraction

	Question	Average Rating (SD)
1.	I found the highlighting interface distracting.*	3.6 (1.1)
2.	Highlighting interface helped to grab my attention at the right time.	3.0 (1.2)
3.	Highlighting interface interrupted me during the group discussion.*	4.1 (0.9)
4.	Highlighting interface helped me to be aware of information on the large display.	3.0 (1.3)
5.	Highlighting interface helped me to focus the attention of others on certain information on the large display.	3.3 (1.2)
6.	I would rather have the highlighting interface displayed only privately.*	2.1 (1.0)

preferences. The results indicate that 12 out of 18 participants found highlighting an image the most useful feature. Participants mentioned that the highlighting was helpful when eliminating choices: *"...so that we could quickly/efficiently move on to a decision. Visually removing eliminated options aided my group focus on the remaining choices"*. It was also used to emphasize, select an image, and to fade away the painting that didn't pass the vote. Among other mentioned useful features were: fading an image (7 of 18) and moving an image (4 out of 18).

Concerning the interaction preferences, 11 out of 18 participants preferred to interact with the highlighting interface via the touch screen. Tablet PC or a private PC screen was preferred by 6 out of 18 group members. Among other mentioned preferred means of interactions were, the direct manipulation on a tiled display (2 out of 18), interaction via speech (2 out of 18) and multitouch (2 out of 18).

User Comments

Most participants had very positive responses about the highlighting interface:

- *"I liked the intuitive interaction, you can directly manipulate things and everyone can see the changes right away";*
- *"Intuitive and fast. Would use it for spatial positioning";*
- *"I would like to use this for visualising data and manipulating how the data is visualised and discuss the data with others".*

This first comment points to the ongoing awareness of changes in the environment, which relates to the second level of situational awareness (chapter 2).

Several group members also mentioned that a feature to highlight one image and fade the rest would be useful. The wish-list features for the future highlighting interface is the multi-user and multitouch gesture interaction on the large display. Some participants complained about the black lines on the tiled display (2 out of 18), and about the reaction time of the touch display when resizing an image (1 out of 18).

Next, we discuss the qualitative results of the observations and the post-session discussions with the teams.

5.5.3 The Use of Large Shared Display

At the beginning of the discussion, group members would discuss each painting, why it would or would not be good to put it in the shared coffee room.

N condition: No Highlighting interface

In N condition, participants used the Plasma Touch screen less intensively. If the whole group would eliminate a certain painting, a group would ask one member interacting with the plasma screen, to move that painting below or to the side of the Tiled display. In this way, participants were free to rearrange the screen as they wished, putting the most preferred paintings, or 'to be discussed' paintings in the middle or at the top of the tiled display.

Y condition: Highlighting interface

While going through each painting, in Y condition one of the participants would highlight or enlarge[2] the discussed painting. Spontaneous interactions also occurred frequently, when one group member would approach the plasma touch screen and would start interacting with the highlighting interface during the discussion, intuitively following the requests of the other team members as to which painting to highlight or to fade.

N & Y conditions

The results of our previous observations (chapter 4) and video analysis of scientific team discussions in the multidisplay e-BioLab environment showed that life scientists tend to walk to the shared tiled display to inspect a specific detail of a visualisation. This indicates that, unlike a static projection in the meeting room, a large shared display plays an important role in engaging the group members in the discussion. This points to the dynamic nature of interactions as reported in other studies [Tan et al., 2006]. Even though in this experiment only paintings were displayed and there was no need to inspect specific details of each painting during the group task, in both conditions participants still tended to gather around the display while discussing the alternatives and making the group decision. Participants tended to point at the shared large display when referring to one painting, also referring to it by a given name, such as a 'boy', or 'flowers' (Figure 5.2, paintings set B).

5.5.4 Interaction with the Highlighting-on-Demand interface

The majority of participants liked interacting with the Highlighting interface via the shared Plasma Touch Screen as it helped the other group members to follow what was being changed on the shared large screen during the discussion. Some participants

[2] Despite that only the Highlighting feature was encouraged to use in the Y condition, and moving in N condition, users also discovered the resizing feature during the test session as it was fairly intuitive. Even though resizing was not very easy, it was still used by some participants.

also mentioned that they would also like to interact with the Highlighting interface on a private Tablet PC.

Next to using the Highlighting-on-Demand in Y condition, and moving feature in N condition, users also discovered the resizing feature during the test session as it was fairly intuitive. One of the shortcomings of the particular touch screen used in this study was the response delay when resizing an image, also caused by the fact that the SAGE user interface was originally designed for the Tablet PC. Precision was hard to achieve when resizing an image by hand on a Plasma Touch Screen. Even though resizing was not very easy, it was still used by some participants. Therefore resizing might have effected the results. Since a resizing feature was a standard SAGE interface option, and in this experiment we focus only on the Highlighting interface, we did not focus on the redesign of the SAGE interface.

Several participants who were previously very familiar with touch screens, missed the multitouch feature on the Plasma Touch Screen. On the other hand, though the Plasma Touch Screen allowed only one person to interact at a time, it helped other group members to constantly stay aware of who was in control of the shared large display during the discussion. We did not observe any conflicts between group members concerning the interaction with the Plasma Touch Screen.

5.5.5 Individual and Group Decision Making Strategies

Most groups used the individual ranking approach to come up with the group decision, by summing up the individual ranks after they had made their personal choice. One of the group members would usually use a whiteboard to write down the ranks, or alternatively one by one each group member would write his/her personal rank on the whiteboard.

Some of the groups tended to discuss the strategy of the individual ranking for longer than 10 minutes. For instance, one very active participant in the fourth group changed the personal ranking of paintings in order to influence the final group decision in his favour.

5.6 Reflections and Future Work

The results of the observations and post-session group discussions indicate a high involvement of group members in the discussion while interacting with the highlighting interface on the shared display. This effect could be partially caused by the novelty of touch displays.

One of the shortcomings of the study is that it was hard for the participants to make a clear distinction between the Highlighting interface and the rest of the touch screen's features such as moving and resizing. Some of the participants even mentioned that, if they had not been being told clearly, they would refer to all interfaces and displays in the environment while filling in the usefulness questionnaire on the usefulness of the Highlighting interface.

Previous studies by van Nimwegen et al. [2006] and O'Hara and Payne [1999] discuss a counterproductive effect of the interfaces that present information externally on the display and fade out irrelevant information. On one hand, when information is externalized on the display (for example, by graying out momentarily unavailable buttons), users might quickly perform a problem solving task in a short run. On the other hand, the strong reliance on a visual display may have negative consequences for knowledge acquisition and task performance in the long run. We believe that giving users control over what parts of the information should or should not be externalized might be an alternative solution to the automatic information externalization. Although we did not study the long-term learning effects on the perceived performance (satisfaction with the final group decision), the results of our study suggest that providing the Highlighting-on-Demand support might help to prevent the counterproductive effects named above on the group performance in problem solving tasks.

One of the other points on our research agenda is to study the long-term effects of shared large displays on situational awareness and decision-making strategies between co-located and distributed groups.

5.7 Summary

This chapter presented the results of the first empirical user study on the effect of the Highlighting-on-Demand concept on satisfaction with the group decision-making outcome in a real multidisplay environment. The Highlighting-on-Demand interface enables a team member who is currently controlling the shared display to draw the attention of the other team members by highlighting a certain visualisation by using a slider on a touch display. The results suggest that when group members use the Highlighting-on-Demand interface during the discussion, the satisfaction with the final group decision increases. Participants expressed willingness to use the Highlighting awareness support for visualising data and manipulating how the data is visualised to discuss the data with other team members in real project discussions.

In the next chapter we discuss the results of an empirical user study on assessing the affect of the Chain-of-Thoughts SA support concept on group process, decision-making process and outcome in another domain and in another multidisplay environment. Based on the results of this study, we will apply the adjusted and additional measurements (e.g., workload assessment).

Chapter 6

Chain-of-Thoughts Visualisation as SA Support for Brainstorming

"We all have times when we think more effectively, and times when we should not be thinking at all."
–Daniel Cohen

6.1 Introduction

The existing meeting support technology, such as brainstorming and voting support tools, and electronic minutes mainly focus on the content of meetings. Project success often depends upon small group decision making, which is in turn influenced by the communication and interpersonal skills of group members. Group success depends upon its members' ability to interact with each other. The goal of this experiment was to evaluate the Chain-of-Thoughts visualisation concept that enables group members to capture, summarise and visualise the history of ideas on a shared display providing an awareness of the group decision making progress and status.

We support shared situational awareness of team members by providing a supportive visualisation on a shared large display, without distracting the group from the primary decision making task. The objective of this evaluation is to find out how the Chain-of-Thoughts interface affects group collaboration during co-located meeting discussions, the effect on the satisfaction of group members with the group process and decision making process, and the perceived workload.

6.2 Small Group Discussions

6.2.1 Small Groups

Most researchers define a small group as having at least three and no more than twelve or fifteen members. A group needs to have at least three members, otherwise it would simply be a dyad. With three members, coalitions can be formed and some kind of organization is present. Overly large groups (more than 12 or 15 members) prevent the group members' ability to communicate with everyone else in the group. It is important for the group's members to be able to communicate freely and openly with all of the other members.

Groups develop norms about discussion and group members develop roles which will affect the group's interaction. Group members must have a common purpose or goal and they must work together to achieve that goal. The goal brings the group together and holds it together through conflicts and tensions [Shaw, 1981]. Groups are often capable of producing higher quality work and better decisions than individuals. In addition to its increased ability to perform work, the group can provide encouragement and support to its members while working on a big project [Shaw, 1981].

Researchers have studied small groups to understand how they develop. Several different models have been suggested, but they all tend to follow a similar advancement. We will shortly present the Tuckman's small group development theory [Tuckman, 1965]. In the forming stage, group members learn about each other and the task at hand. The storming phase appears as group members become more comfortable with each other, and they then engage each other in arguments and want to have a status in the group. During the norming stage, group members establish implicit or explicit rules about how they will achieve their goal. They address the types of communication that will or will not help with the task. In the performing stage, groups reach a conclusion and implement the conclusion. As the group project ends, the group disbands in the adjournment phase.

Conflict can be good for a group if it is managed appropriately. By airing differences, group members can produce quality decisions and satisfy interpersonal relationships. The climate in which conflict is managed is important. Groups should avoid a *defensive climate*, which is characterized by these qualities [Shaw, 1981]:

- *Evaluation*: judging and criticizing other group members.
- *Control*: imposing the will of one group member on the others.
- *Strategy*: using hidden agendas.
- *Neutrality*: demonstrating indifference and lack of commitment.
- *Superiority*: expressing dominance.
- *Certainty*: being rigid in one's willingness to listen to others.

Instead, groups should foster a *supportive climate*, marked by these characteristics [Shaw, 1981]:

- *Description*: presenting ideas or opinions.
- *Problem orientation*: focusing attention on the task.

- *Spontaneity*: communicating openly and honestly.
- *Empathy*: understanding another person's thoughts.
- *Equality*: asking for opinions of other group members.
- *Provisionalism*: expressing a willingness to listen to the ideas of others.

Description, *empathy*, and *equality* are the three meeting parameters in our scope. During the meeting, the Chain-of-Thoughts interface should support equality, empathy, description and avoid superiority and control.

6.2.2 Meeting Types and Communication Problems

Meetings are investigated and constrained differently for different research purposes. The three types of meetings in terms of experiment control are defined below.

Scripted meetings are held according to a pre-specified sequence of actions, where these may be actual words, or lower granularity actions such as presentations, decisions, usage of a white-board, and so on. This is the most artificial and constrained type of meeting.

Scenario-based meetings are motivated by a scenario or situation, which is given to participants before the meeting to guide their behaviour. The scenario may describe aspects relating to the meeting as a whole, such as the purpose, topic, contextual information, expected duration, and so on. Other than these general guidelines, the participants behave naturally. These meetings allow aspects of the meeting content to be influenced without imposing the strong constraint of a script. In general, participants in these meetings will act as themselves, but will perhaps assume an artificial role (e.g., project manager). In social psychology, this methodology for studying groups is called laboratory experimental study [Weingart, 1997]. The aim is to set up groups that behave as much like real groups of the type being studied as possible whilst still being able to control the conditions under which data is collected.

Real free-form meetings concern real projects or issues, and have people behaving naturally, only constrained by data collection requirements (wearing of microphones, seating locations, available artifacts, etc). Unlike the other two meeting types, these are generally meetings that would have taken place independently of the data collection. In social psychology, this methodology for studying groups is one kind of field observation [Weingart, 1997], although often field observation involves ethnography rather than working from recordings.

In this study, the focus is on real meetings in the requirements elicitation, though scenario-based meetings were used for the experiment (see section 6.5.1). The underlying assumption is that the process itself is an important determinant of the way the meeting evolves, and that providing Chain-of-Thoughts support will affect the decision making process and may make it possible to spot and avoid well-known problems in meetings.

During the co-located meetings, group members might encounter several communication problems, for example, when somebody speaks for a long time, and some of the participants do not get a chance to speak or communicate. Well-known pitfalls in meetings are, for instance, lack of clear goals, lack of understanding how the current discussion relates to goals, lack of willingness to participate, and lack of opportunity to participate [Nijholt et al., 2006; Kulyk et al., 2006]. Lack of clear goals is addressed by this study. Failure to see how the current discussion relates to goals is a multi-faceted problem. One possible cause is that the current goal was not clearly defined. Another possible reason is the lack of expertise of some of the participants. A third potential cause is lack of structure in the discussion. This cause is directly related to the objectives of this study as well. Lack of willingness to participate and lack of opportunity to participate is out of the scope of our project.

6.2.3 Chain-of-Thoughts Support for Small Group Discussions

Based on the requirements elicitation results (chapter 4.3), we have come up with a number of situational awareness (SA) concepts to explore various alternative solutions in order to support group decision making in co-located multidisplay environments (section 4.3) [Kulyk et al., 2009]. One example is a *Chain-of-Thoughts* interface, which enables group members to capture, summarise and visualise the history of ideas on a shared display throughout the brainstorm session, allowing team members to go back in time and retrieve ideas generated at the beginning or in previous brainstorm sessions. By displaying the Chain-of-Thoughts on a large shared display throughout the whole discussion, we expect every group member to become aware of what is being and of what has been discussed, what the mid-decisions are and what the final group decision is.

The Chain-of-Thoughts interface serves as a peripheral display that affords memorability and supports level 2 of situational awareness, comprehension (see chapter 2) in a multimodal way, combining visual and textual representations.

The goal of this experiment is to perform a controlled comparative case study in order to measure the effect of the Chain-of-Thoughts concept on: a) satisfaction with the final group decision and b) satisfaction with the group decision-making process in a multidisplay environment. We will assess satisfaction with the decision-making process of team members, providing supportive visualisations on a shared large display. We aim at reducing the distraction from the primary decision making task, and increasing the group member's satisfaction, with the decision-making process and group communication, as well as perceived agreement with the final group decision (see section 6.5.6).

6.3 Requirements Elicitation

In order to find out how the Chain-of-Thoughts concept would fit into a meeting discussion and to get insights into the current practices of facilitated small group meetings, user requirements had to be elicited first. We have chosen to focus on project team meetings involving 4 to 6 members. Team meetings are clearly very informal, equal hierarchy meetings of similar people.

6.3.1 Interviews and In-situ Observations

Semi-structured interviews were conducted with five experts in meeting facilitation (1 female and 4 male, average age 34 years) in order to gather requirements and to get early feedback on the Chain-of-Thoughts concept and ideas. In addition, *in-situ* observations of two real group brainstorm sessions were carried out in order to get insight into the common practices of facilitated meeting sessions. The chosen venue for the observations and for the final experiment was the multidisplay TX(T-Xchange[1])-Lab located at the University of Twente, Enschede, the Netherlands (Figure 6.1, Figure 6.7). We also aimed to define what roles different experts play in meetings, and what types of meetings take place in the multidisplay TX Lab.

Figure 6.1: T-Xchange lab, Enschede, The Netherlands).

Role of Facilitator and Capturer

The results of interviews and observations demonstrate that there are two types of experts that support meeting sessions in the multidisplay TX-Lab (Figure 6.1, Figure 6.7): the facilitator and the capturer. The *facilitator* guides the group through the discussion and explains various tools that can be used: the Carousel / Card game (see the explanation below), how to use a Tablet PC, whiteboard, etcetera. The *capturer*'s role is to write down words and ideas group members say out loud during the discussion and input them into a MindMap (Figure 6.10). The capturer also controls the three large projection displays (Figure 6.1). Some capturers also design the custom-made visual tools, such as the Carousel game, and scenario-based games supporting group discussions in a particular domain.

Meeting types and brainstorming tools

Several main types of meetings take place in the TX-Lab: brainstorm sessions, statement sessions, simulation game sessions. The Carousel game and the Card game are the tools commonly used by facilitators during the brainstorm sessions. These games are used during the group discussions to stimulate the idea generation and to 'break

[1]T-Xchange, part of Thales Nederland: www.t-xchange.nl/, last retrieved: Dec 5, 2009.

the ice' at the beginning, to get the discussion 'going' so to speak. The Card game randomly displays an image in the shape of a playing card on a large display in front of the group. Then the facilitator asks the group members to name words they associate with this particular card in relation to the topic of a meeting discussion. Similarly, the Carousel game randomly displays a famous character on a large display in front of the group (Figure 6.2). Next, the facilitator asks the group members to imagine what this famous person or character would do in which situation, and how would he/she solve which problem. Both games stimulate associative memory and engage the group members in the discussion.

In addition, sketching is possible using a digital Mimio pen on any of the large vertical displays, which can be turned into a digital whiteboard by a capturer (Figure 6.1). However, some preparation is needed beforehand to enable sketching on a large display and therefore it is rarely used. Personal Tablet PC's are used for browsing the background information on the discussion topic, browsing the web, searching for the images to illustrate individual ideas. Once an image is found, a participant can save it using shortcut keys into the invisible shared directory. Then a capturer, who controls the large vertical displays and has access to this directory, brings the generated images up on the large shared screen in front of the whole group. Currently there is no visual feedback confirming that an image has been saved on a personal Tablet PC, and therefore there is a lack of a direct way to share the information with the group. As we observed in the real brainstorm sessions, group members tend to verbally request feedback from the capturer asking if their image has indeed been saved in the shared directory. To save time, sometimes group members would split the tasks and one person would look for an image.

Figure 6.2: The Carousel game: Spider-Man character (characters rotate clockwise and one of the characters is then randomly displayed in the middle of the screen)

As expert facilitators reported in the interviews, image search and any other activity on a Tablet PC distracts group members from the discussion. Therefore a facilitator might only rely on verbal ideas captured by the capturer into a MindMap (Figure 6.10). MindMaps can get too large as the typical brainstom session can last from three hours up to the whole day. Often a MindMap does not fit onto the large vertical display and it gets hard for the group members to keep an overview of the discussion sessions. The capturer's job also gets hard when group members shout out many ideas simultaneously. Group members make verbal requests to the capturer about the rephrasing or arranging the ideas. Another problem is that the MindMap is basically the capturer's reflection of what is being discussed and what ideas are generated. It is useful during the discussion, but it is difficult to interpret and to make sense of afterwards. As a result, group members do not have visual support during the follow-up sessions to refresh their memory on what has been discussed and decided upon. Experts reported that there is a lack of multimedia support in the MindMap, namely both text and images together.

Based on the observation and interview results, we decided to focus on the brainstorm type of group discussion sessions, involving decision making, that commonly take place at the multidisplay TX-Lab environment.

6.3.2 Conceptual Design Brainstorm

After gathering the first results from the semi-structured interviews and in-situ observations, a brainstorm session was carried out with one experienced facilitator and two capturers (also designers). The conceptual design brainstorm session aimed at exchanging ideas and getting feedback on metaphors and first ideas for the Chain-of-Thoughts prototype. The session took place in the multidisplay TX-Lab environment (Figure 6.1).

Figure 6.3: Conceptual design brainstorm: examples of the inspiration images for the Card game, representing alternative metaphors for the Train-of-Thoughts interface.

The brainstorm session was split into two main phases: (1) discussing ideas and design alternatives, followed by a break and continued with (2) discussing metaphors, sketching and final concept. The Card game was used during the first phase in order to engage the participants in the discussion. Cards, namely various illustrative images, served as an inspiration to discuss and generate various ideas and stimulate associative memory.

Several questions were addressed during the conceptual design brainstorm:

What to Display?

- Status / middle results
- Image / text / summary
- Image and text source (e.g., name of a participant): *'Whose idea is that?'*

When to Display?

- During the summary / middle results discussion
- During the whole discussion

Where to Display?

- Shared large display (left / central / right) (horizontally / vertically) / private display (e.g., tablet PC).

How to Display?

- Full size version on a large shared display
- Collapsed status line on a private display

Which metaphor is most suited (Figure 6.3)?

- Status line
- Horizontal / vertical tree metaphor
- Graph

After the conceptual design brainstorm, it was decided not to display the participants name next to the generated ideas, either represented by an image or by text, for the following reason. Namely, as was mentioned by the expert facilitator, it is important that brainstorm enables equal idea generation and sharing with the whole group. If the name tag were always visible on the shared display, some participants in unbalanced groups might not feel like sharing some ideas, for example in the presence of a senior colleague. Therefore we agreed that, as the current practice shows, it is better to let the facilitator ask the group who has generated which idea if needed.

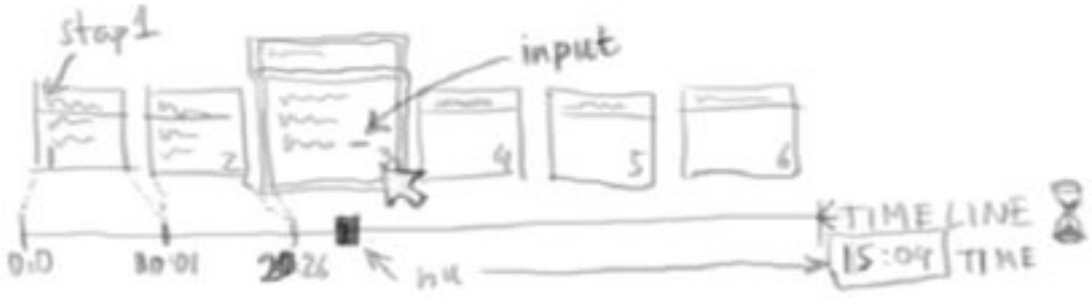


Figure 6.4: Conceptual design: early idea, *image courtesy of Rafal Hrynkiewicz, T-Xchange.*

6.3.3 User Requirements and Design Concept

The following user requirements are formulated based on: the literature summarized above; the results from the observations and interviews; and the results of the conceptual design brainstorm. Finally, it was decided that the Chain-of-Thoughts visualisation should: incorporate the dynamics of individual and group aspects of the decision making process; include an iterative time aspect, combined with text and image input. The detailed requirements and main design decisions are listed below:

What to Display?

- Integrated view: images and text
- Status:
  - Where are we?
  - What have we achieved / discussed so far?
  - What has to be done?
- Middle results
- Photos / images
- Summary of an idea (made by all group members)
- Group decisions

When to Display?

- During the whole discussion

Where to Display?

- Vertical shared display (Figure 6.7, right)

How to Display?

- Two modes: large display mode and a small display (Tablet PC) input mode

Which metaphor is most suited?

- Train (Figure 6.5)

Final Concept: Train-of-Thoughts Prototype

The Train-of-Thoughts metaphor was chosen for the final concept, where names of wagons represent the ideas or 'thoughts' (see Figure 6.9). Wagons 'carry' the short summary and the descriptions of ideas, represented as square cards above each wagon. Train-of-Thought has two modes: (1) full size version in a large shared display and (2) small display interactive version with a simple Flash-based input interface for the input of ideas and middle results into the Train-of-Thoughts (Tablet PC). The 'Focus' highlighting feature enables highlighting of a certain part of the train, for example, Idea 1 (Figure 6.5, bottom). The 'Play' button in the bottom right corner shows an animation of the moving train, displaying the history of the idea generating process, allowing the group members to go back in time and retrace their memory on what was decided in the earlier stages of the discussion.

Figure 6.5: Train-of-Thoughts prototype: large display version (*top*) and focus highlighting (*bottom*), images courtesy of Tije Oortwijn, T-Xchange ©2009.

6.4 User Evaluation: Objectives and Hypotheses

The goal of this user evaluation is to perform a controlled comparative user study in order to measure the effect of the Train-of-Thoughts visualisation on: a) satisfaction with the final group decision and b) satisfaction with the group decision-making process and outcome in a multidisplay environment. The Train-of-Thoughts prototype will be visualised on a shared large display. We aim at reducing the distraction from the primary decision-making task, and increasing the group members' satisfaction, with the decision-making process and the group process, as well as satisfaction with the perceived task performance (individual decision versus group decision).

Based on findings from the literature and related studies on small groups (see section 6.2), meeting support (section 6.2.2) and the formation of shared situational awareness (Chapter 2), we conclude that incorporating the dynamics of individual and group aspects of the decision making process and an iterative time aspect should allow group members to enhance the awareness of the group members of what has been discussed and what is being discussed and what are the middle and final group decisions. Therefore, by presenting all alternatives on a shared large display and enabling Train-of-Thoughts on a shared large screen, it is hypothesized that satisfaction with the group decision-making process and outcome will increase. These predictions are summarized as two hypotheses:

H1 — In the condition with the Train-of-Thoughts interface, participants' satisfaction about the group process and the decision-making process will be higher.

H2 — Participants' satisfaction about the final group decision, in relation to their individual decision, will be higher in the condition with the Train-of-Thoughts interface.

The next section presents the experiment design and procedure.

6.5 Experiment Design

A within-group design is applied in this experiment. Namely, each group of participants performs a group decision making task in both conditions: with and without the Train-of-Thoughts interface.

Table 6.1: Conditions

Group	**Condition (N/Y)**	**Facilitator (F) & Capturer (C)**	**Plastic Soup Part (A/B)**	**Questionnaire** *(see Section 6.5.6 below)*
1	N	F1, C1	A	Part I
	Y		B	Part I & II
2	Y	F2, C2	B	Part I & II
	N		A	Part I
3	Y	F1, C1	A	Part I & II
	N		B	Part I
4	N	F2, C3	B	Part I
	Y		A	Part I & II

Legend, Table 6.1:
F: Facilitator

C: Capturer

Conditions:
N (=NO): Without Train-of-Thoughts interface (T-O-T)
Y (=YES): With Train-of-Thoughts interface

Plastic Soup Part **A**: Plastic as Material (see subsection Plastic Soup below).
Plastic Soup Part **B**: Garbage (see subsection Plastic Soup below and Appendix K).

We should note that the the facilitators and capturers pares were not intentionally assigned in this order. We did not intend to introduce another variable in this way. We tried to ensure that facilitator-capturer pairs stay constant. One capturer, however, could not assist in one of the experiment sessions. Therefore another experienced capturer replaced this role. All capturers are used to work with different facilitators in their daily practice.

6.5.1 Task

The aim of this study was to investigate whether Train-of-Thoughts (T-O-T) supports group decision making in a scenario-based meeting. The goal of the group task was to initiate a group discussion on a topic of joint interest and motivate the team members to develop an individual and a group decision making strategy. A real brainstorming task was chosen based on the real previously observed brainstorm sessions. Namely, an existing Plastic Soup case was chosen as a main task (see subsection Plastic Soup below). Throughout the group discussion session, two experimenters provided support: a facilitator (see subsection 6.5.4) and a capturer (see section 6.5.4). The facilitator provided guidance to the group to ensure the correct focus. Recording of what was said during the group discussion into a MindMap (see Figure 6.10) was done by a capturer.

First, a facilitator asked the group members to do a quick getting-to-know group members round. Each participant was asked to write their name on the tag so that the other group members could refer to each other more easily.

Warming-up: EU elections

Before the actual brainstorm session on the Plastic Soup problem, a warming-up session took place aiming at letting the participants get to know each other, the multidisplay environment, and the assisting tools: image search and saving on a Tablet PC, the Carousel game, the ranking game (whiteboard, Mimio pen) and the Train-of-Thoughts interface. Below, we present a description of the warming-up task:

"What would you do to make as many people participate in the EU elections?" (Carousel game & Train-of-Thoughts interface).
"EU committee has given budget for the further R&D development of only 3 ideas. Please choose 3 ideas you as a group agree on as the most worthy ideas for the further development. To help you to come to the group decision, you can play a ranking game.

Each of you has 3 points you can freely give to either 1, 2 or 3 ideas of your personal choice. At the end you as a group have to agree on the 3 top ideas.”

Plastic Soup Problem

A Plastic Soup / Pacific Garbage Patch Problem was picked for the brainstorm discussion (Appendix K), where the group was given a task to generate as many ideas on the possible solution of part of the plastic soup problem. All participants received background material and the topic of the brainstorm discussion prior to the brainstorm (Appendix K).

Two parts of the Plastic Soup Problem Space (Appendix K) were used as tasks for the main brainstorm session (Table 6.2): Plastic as Material & Garbage. The Problem Space was revealed by the facilitator at the beginning of the brainstorm and each participant could also look it up on their Tablet PC at the table (Figure 6.6). At the end of the brainstorm each group had to choose the best 3 ideas. Group members could use the ranking game on a digital whiteboard, sharing their individual choice with the rest of the group by dividing 3 points between three, two or one idea.

At the very beginning of the brainstorm participants were asked to pick their favourite colour for the ranking game, from a pack of M&M’S. Using a Mimio pen, each participant selected his/her personal colour and marked the favourite ideas on the left large display (an electronic whiteboard, see the ranking results on Figure 6.8). Finally, a group had to reach a decision by picking the three ideas they find most worthy, either by summing up the individual scores or by discussing what would be the mutual decision. In the Y condition, the group had to fill the best ideas in the Train-of-Thoughts. Each group had a limited time of ten minutes to reach a group decision. The main goal for the group was to reach a decision each group member agreed with.

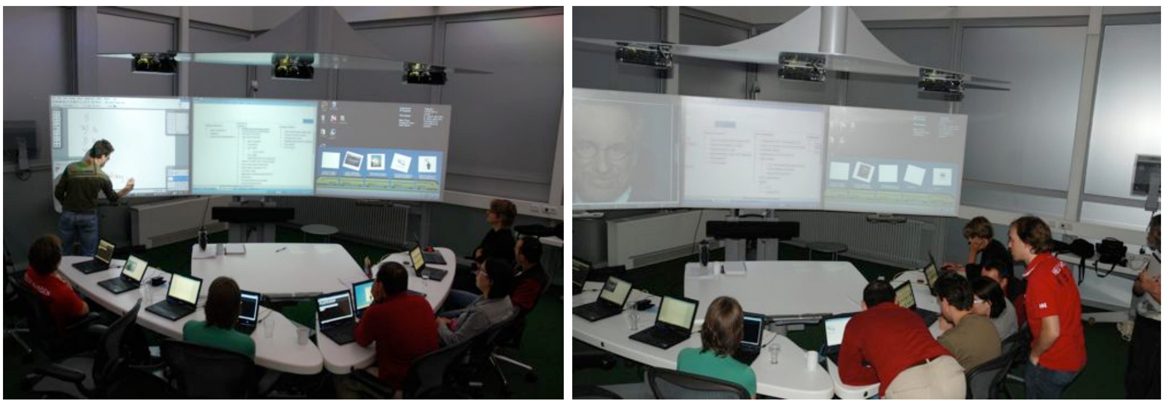


Figure 6.6: Chain-of-Thoughts experiment: Plastic Soup brainstorm sessions (T-Xchange lab, Enschede, NL).

Table 6.2: Brainstorm session setup - group 2 (see Table 6.1)

Time	Group Activity	Condition (Y/N)	Display arrangement
15 min.	Intro & Warming-up Brainstorm (EU elections)	Y	Carousel on the left display, MindMap in the middle, T-O-T right
5-10 min.	Filling mid-results in T-O-T	Y	Carousel on the left display, MindMap in the middle, T-O-T right
15 min.	Brainstorm A (Plastic as Material)	Y	Carousel on the left display, MindMap in the middle, T-O-T right
10 min.	Choosing 3 best ideas: ranking game	Y	Brainstorm ideas on the left large display, MindMap in the middle, T-O-T right
5-10 min.	Filling end-results in T-O-T	Y	Brainstorm ideas on the left large display, MindMap in the middle, T-O-T right
5-10 min.	Questionnaire, Part I & II	Y	Brainstorm ideas on the left large display, MindMap in the middle, T-O-T right
15 min.	Brainstorm B (Garbage)	N	Carousel on the left display, MindMap in the middle, No T-O-T
10 min.	Choosing 3 best ideas: ranking game	N	Brainstorm ideas on the left large display, MindMap in the middle, No T-O-T
5-10 min.	Questionnaire, Part I	N	Brainstorm ideas on the left large display, MindMap in the middle, No T-O-T

6.5.2 Pilot Test

Before the actual experiment, a pilot session was conducted in order to test the procedure, the experiment design, the prototype, the setting of displays and the position of the Train-of-Thoughts prototype on the shared large display. Several adjustments were made after the pilot test. It was decided to display the Train-of-Thoughts on the righthand side of the large shared display. In addition, facilitators would only instruct the group during the generation of the ideas phase of the brainstorm (the Carousel game), and not during ranking or during the input of the in-between summary and top 3 ideas into the Train-of-Thoughts. The Carousel game and the ranking game procedures were adjusted as well. The mix of famous celebrities (male and female) and extreme personalities were added into the Carousel: Margaret Thatcher, Steven Spielberg, Madonna, Spider-Man, Michael Jackson, Bill Gates, Barbie, Ghandi, Stalin.

6.5.3 Participants

The chosen target group for this experiment is ad-hoc small groups of four to six members. Group members were researchers and students with multidisciplinary backgrounds working or studying at the university. We mixed-up team members so that some of the participants knew each other well before, and others had never worked in one team before.

Participants who took part in this study were Master's students, PhD students, scientific programmers and postdoc researchers from three different research groups at the same university (University of Twente, Enschede, the Netherlands). In total, 21 participants (17 male and 4 female, age range 23-32 years) were recruited from the university community and assigned into 4 groups. Originally all 4 groups had 6 members, not all participants showed up. Genders were split so that each group had both genders. Participants had various scientific backgrounds (e.g. cognitive psychology, artificial intelligence, arts and neuroscience). All participants were discussing in the multidisplay TX-Lab environment for the first time.

6.5.4 Experimenters

Facilitator:

One experimenter facilitated the brainstorm session, guiding the group through the discussion and explaining the task, the Carousel game, the use of a Tablet PC for the background info and image search, and the ranking game. In total, two facilitators took part in the experiment (see Table 6.1). Facilitators followed the same procedure:

- During the warming-up (EU elections), a facilitator will encourage a group to put the ideas a group finds most worthy in the Train-of-Thoughts (T-O-T) at the end of a short brainstorm (after 25 min.)

- In Y condition with the T-O-T interface, the facilitator will give a group a signal (see Table 6.2), inviting them to fill in T-O-T by saying:
  "What do you (as a group) find important to keep at this moment?"

- At the end (10 min.), a group can apply their own strategy with respect to ranking and choosing the best three ideas they find most worthy and to fill them in the Train-of-Thoughts.

Capturer:

The capturer was sitting at the right side of the V-shaped table (not to be a part of the group discussion, Figure 6.7). The capturer's task was to take notes of the generated ideas and put them into the MindMap. In addition, the capturer controlled the three large vertical displays to put various case material (presentation, the Carousel game, etc.) on the right part of the display, see Figure 6.7. Ten minutes before the end of each brainstorm part, the facilitator gave a sign to the capturer to put the generated brainstorm ideas on the lefthand vertical display for the ranking game with a Mimio pen (Figure 6.6, left).

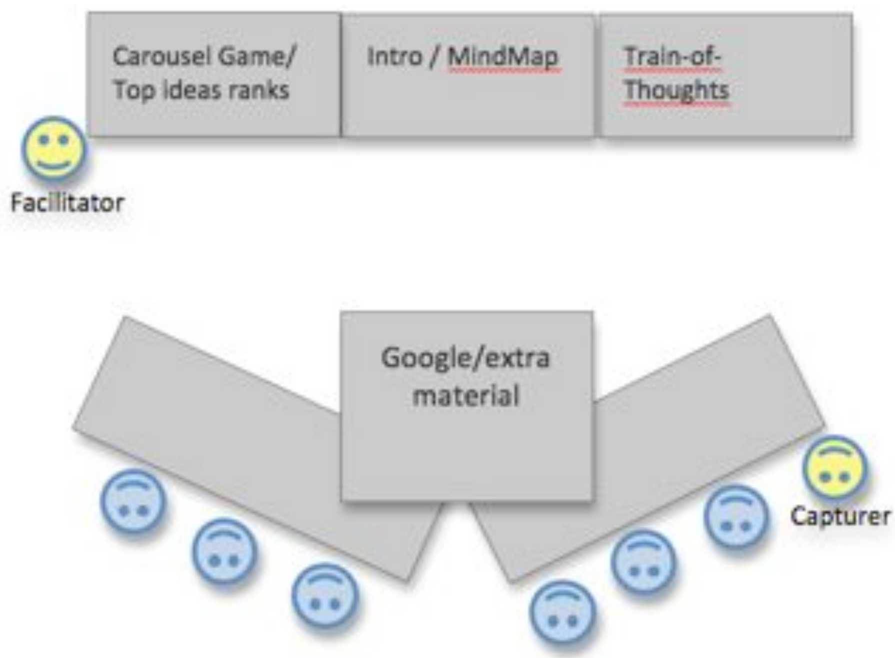


Figure 6.7: Screen space and sitting arrangement, T-Xchange lab (Enschede, the Netherlands)

Observer:

The observer's task was to take notes on the group behavior (dynamics, turn-taking, attention to the displays) and the use of the large displays and the Train-of-Thoughts interface during the brainstorm session.

All experimenters participated in the 10 minutes debriefing session before the experiment.

6.5.5 Lab and Display Setting

The experiment took place in multidisplay TX-Lab (T-Xchange Cell, Figure 6.6).

In condition **N** (Without Train-of-Thoughts), only MindMap, Carousel game and Sketching (ranking game) were used.

In condition **Y** (With Train-of-Thoughts), the Train-of-Thoughts interface was displayed on the righthand vertical large display (Figure 6.7). Participants were given a sign (reminder from the facilitator) to fill in the mid-results (2 times) and the end -results (1 time – 3 best ideas), of the brainstorm that the whole group found most worthy in the Train-of-Thoughts (T-O-T) interface. MindMap, Carousel game and Sketching (ranking) were used the same as in the N condition. All sessions were captured with two video cameras per group table from two different angles.

6.5.6 Measures

Three dependent variables were measured: group process and decision making, satisfaction, and perceived workload. Team composition was balanced and task case was constant in all groups. Likert scale questionnaires were applied to access the perceived group process quality [Olaniran, 1996], satisfaction with the decision-making process [Kulyk et al., 2006; Paul et al., 2004], and the perceived agreement with the final group decision in relation to the individual decision (Appendix I, A & B).

Satisfaction with and usefulness of the Train-of-Thoughts interface was assessed using a post-task questionnaire administered to team members after the group discussion only (Appendix I, C). The usefulness questionnaire contained nine questions from [Paul et al., 2004] and six questions to address distraction and awareness [Cadiz et al., 2002; Kulyk et al., 2006], All questionnaires used 5-point Likert-scale, where '1' meant 'Strongly agree' and '5' 'Strongly disagree'.

In addition, perceived workload was measured using a scale of 1 to 150 [Christ et al., 1993], which is often used as an implicit and indirect measure related to situational awareness and decision making [Bolstad and Endsley, 2000; Wickens, 1992]. As we previously discussed in chapter 2.4, self-rating techniques, such as SART [Taylor, 1989] have a potential limitation that participants may experience difficulties rating low periods of SA [Salmon et al., 2006]. In view of the rather short duration of the study, we predict that SART measure might not be sensitive enough for our case.

Two observers observed instances of 30 minutes per each group in Y and N condition (Note: two group sessions were carried out in parallel, as TX-lab has two equal tables on the opposite sides of the lab). In total two observers took part in the experiment using a standard observation protocol (Appendix H). The overview of all measurements and techniques is given below:

- Questionnaires:
  1. Satisfaction with group process and decision making (Part I, Appendix I)
  2. Perceived agreement (Part I: question B-8, Appendix I)
  3. Usefulness and satisfaction with the Train-of-Thoughts interface; awareness and distraction (Part II, Appendix I)
  4. Perceived workload (Scale 1-150) [Christ et al., 1993]
- Observations (see section 6.5.4 and Appendix H)
- Video capturing (2 cameras per group)
- Post group interview (also captured on video).

6.6 Data Analysis and Results

The experiment results indicate that the use of the Train-of-Thoughts interface positively influenced some aspects of the group process and decision-making process. The main findings from the data analysis are discussed below.

6.6.1 The Use of the Train-of-Thoughts on Large and Small Display

In both N and Y conditions, at the beginning of the brainstorm group members shared their ideas with the group saying them out loud while playing the Carousel game. Some participants searched for the images first, associated with the solution a famous character from the Carousel game would come up with to solve the Plastic Soup problem.

In the Y condition, after generating the ideas, group members stood around the Tablet PC discussing what they found important to put into the Train-of-Thoughts (Figure 6.6, right). Spontaneous interactions also occurred frequently, when one group member would approach the Tablet PC and would start interacting with the Train-of-Thoughts interface during the discussion, following the requests of the other group members which idea, summary and/or image to add.

One of the shortcomings of the Flash-based input interface on the Tablet PC is that the amount of text that can be put as a summary of an Idea in the Train-of-Thoughts is limited. Even though it was possible to enlarge the summary to the full size, some participants preferred to have not only keywords, but the whole summary texts visible in the T-O-T all the time. Other group members, however, mentioned in the questionnaire that the keywords are more helpful for keeping an overview than having all text visible as currently visualised in the MindMap (Figure 6.10).

6.6.2 Questionnaires

Satisfaction with Group Process and Decision Making

We balanced the valence of our satisfaction questions for convenience. For negatively phrased questions (marked with an asterisk in Table 6.3), we reversed the rating so that higher was always positive.

Wilcoxon Signed Ranks test was conducted to compare group members' satisfaction with the group process and decision making process in Y (Train-of-Thoughts - condition 2) and N (No Train-of-Thoughts - condition 1) conditions. The results showed a significant difference between answers for Y and N conditions in favour of Y in 4 out of 23 questions. Table 6.3 shows the results of a Wilcoxon Signed Ranks test for the statements where the significant difference between N and Y condition was found ($p<0.05$).

There was a significant difference in the scores on the satisfaction with contribution to the final group decision, for the Y (M=3.86, SD=0.48) and N (M=3.57, SD=0.59) conditions, p=0.01 (z=2.45) (Table 6.3, question 4). There was also a significant difference in the scores on the satisfaction with the fact that: (**1**) there are no disruptive conflicts, for the Y (M=4.62, SD=0.49) and N (M=4.05, SD=0.86) conditions, p=0.02 (z=2.23); (**2**) the team discussion was organized, for the Y (M=3.76, SD=0.83) and N (M=3.29, SD=1.00) conditions, p=0.01 (z=2.67); (**3**) important criticism is not ignored, for the Y (M=4.19, SD=0.81) and N (M=3.71, SD=1.05) conditions, p=0.01 (z=2.49) (Table 6.3).

Figure 6.8: Brainstorm session output: ideas ranking

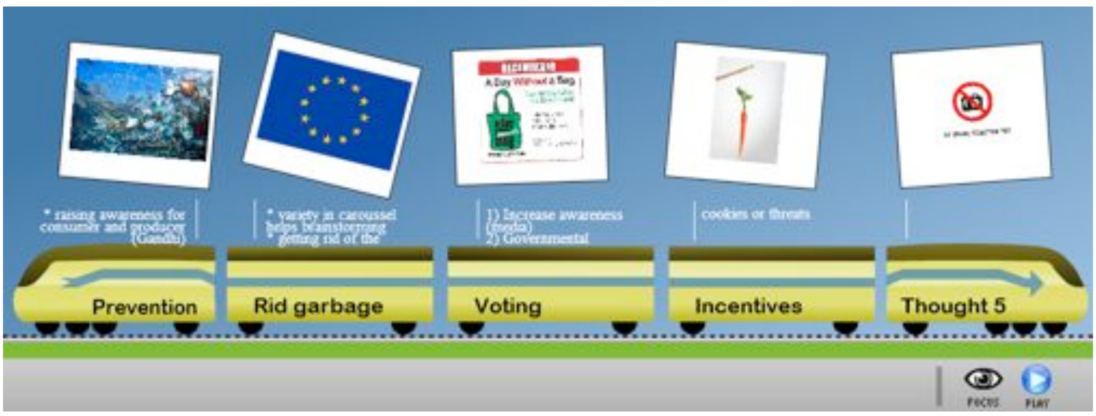


Figure 6.9: Brainstorm session output: top ranked ideas represented by the Train-of-Thoughts

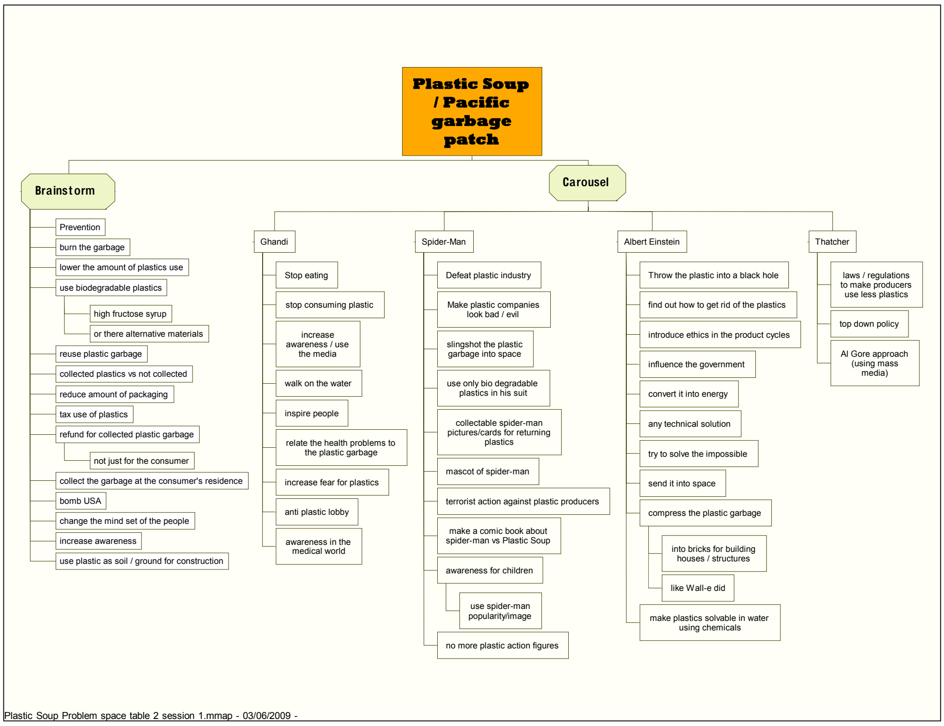


Figure 6.10: Plastic Soup brainstorm session: MindMap output

These results suggest that the Train-of-Thoughts interface has an effect on the satisfaction with the group process and decision making process. Specifically, our results suggest that when group members use the Train-of-Thoughts interface during the discussion, the satisfaction with some aspects of the group process, decision-making process and with the contribution to the final group decision increases (see Table 6.3). In this manner, the Hypothesis 1 (H1), stating that in the condition with the Train-of-Thoughts interface, participants' satisfaction about group process and decision-making process will be higher, is confirmed. On the other hand, H2, stating that participants' satisfaction about the final group decision, in relation to their individual decision, will be higher in the condition with the Train-of-Thoughts interface, is not confirmed.

Table 6.3: Significant Wilcoxon signed ranks test results for the differences between Y (*Train-of-Thoughts*) and N (*No Train-of-Thoughts*) condition

	Questions: Group Process and Decision Making	**N: Mean (SD)**	**Y: Mean (SD)**	**Sig.**
1.	There were disruptive conflicts.*	4.05 (0.86)	4.62 (0.49)	0.02
2.	The team discussions are unorganized.*	3.29 (1.00)	3.76 (0.83)	0.01
3.	Important criticism is often ignored.*	3.71 (1.05)	4.19 (0.81)	0.01
4.	I believe my contribution to be significant in helping our team to arrive at final decisions.	3.57 (0.59)	3.86 (0.48)	0.01

6.6.3 Questionnaires

Usefulness, Awareness and Distraction

Ratings on usefulness and satisfaction, and on awareness and distraction with the Train-of-Thoughts interface were mostly neutral to positive (see Table 6.4 and Table 6.5). We balanced the valence of our satisfaction questions. For negatively phrased questions (marked with an asterisk in Table 6.4), we reversed the rating so that higher was always positive.

Participants reported that they found the Train-of-Thoughts interface comprehensible and they did not need more training to understand the Train-of-Thoughts interface (question 5 & 7, Table 6.4).

From the ratings on awareness and distraction (see Table 6.5), it was clear that the Train-of-Thoughts interface did not distract and did not interrupt the group members during the discussion (question 1 & 3, Table 6.5).

Table 6.4: Questionnaire results: usefulness and satisfaction

	Question	**Average Rating (SD)**
1.	I have difficulty understanding the Train-of-Thoughts interface.*	3.1 (1.2)
2.	Train-of-Thoughts interface is easy to use.	3.2 (1.0)
3.	Train-of-Thoughts interface is reliable.	3.0 (0.8)
4.	I have confidence in the information provided by the Train-of-Thoughts interface.	3.0 (1.0)
5.	I need more training to understand the Train-of-Thoughts interface.*	4.0 (1.0)
6.	I find the information provided by the Train-of-Thoughts interface informative.	3.2 (1.0)
7.	The information provided by the Train-of-Thoughts interface is comprehensible.	3.6 (0.7)
8.	Overall, I am satisfied with the Train-of-Thoughts interface.	3.2 (0.9)
9.	I would be happy to use the Train-of-Thoughts interface in the future.	3.0 (1.2)

Table 6.5: Questionnaire results: awareness and distraction

	Question	**Average Rating (SD)**
1.	I found the Train-of-Thoughts interface distracting.*	3.9 (1.2)
2.	Train-of-Thoughts interface helped to grab my attention at the right time.	3.0 (1.0)
3.	Train-of-Thoughts interface interrupted me during the group discussion.*	3.8 (1.3)
4.	Train-of-Thoughts interface helped me to stay aware of information that is critical during the discussion.	3.0 (1.1)
5.	Train-of-Thoughts interface helped me to stay aware of the discussion process.	3.1 (0.9)
6.	would rather have the Train-of-Thoughts interface displayed only privately.*	2.0 (1.0)

User Preferences on the Chain-of-Thoughts Interface Features

Three additional questions in the post-task questionnaire addressed the user preferences of the various features of the Train-of-Thoughts interface, as well as the interaction preferences. The results indicate that 11 out of 21 participants found adding an *image* a useful feature for a quick overview and as a salient reminder. Images were also found appealing and useful for focusing attention: *"...when proposing an idea it gives quick information"*. Adding text summary and keywords is the first preferred feature (14 out of 21). Participants found the *text* useful for summarising thoughts and experiences, and for getting a good communal definition about ideas: *"Keywords are useful for the decision process"*. Other mentioned useful features are: *highlighting* an idea in the Train-of-Thoughts (2 out of 21).

Concerning the interaction preferences, 13 out of 21 participants preferred to have the Train-of-Thoughts interface displayed on a shared vertical display. Individual Tablet PC was preferred by 3 out of 21 users. Gestures were mentioned as alternative preferred means of interaction (1 out of 21).

Perceived Workload

The results of the perceived workload indicate that the average workload was 45 in the N condition and 56 in the Y condition, on a scale 1 to 150 [Christ et al., 1993]. There was no significant difference found between Y (Train-of-Thoughts) and N (No Train-of-Thoughts) conditions in the scores on the perceived workload (paired T-test).

Participants Comments

Most participants had very positive responses about the Train-of-Thoughts interface. Some of the quotes from the usefulness questionnaire are listed below:

- *"It provides a chronologic overview the MindMap doesn't. Less information – easier to digest"*;
- *"It is a support of memory/process"*;
- *"The ability to combine text with pictures – it allows you to provide better and more information to others"*;
- *"I liked that it forces the group to summarize the enormous set of brainstorming ideas to general important solutions"*;
- *"It's happy and a bit childish, makes you feel that it gives information easily"*.

Several group members also mentioned that it was nice that everyone could write ideas in the Train-of-Thoughts together. An expressed desired feature for the next version of the Train-of-Thoughts interface is the ability to use gesture interaction on the large display.

6.6.4 Individual and Group Decision Making Strategies

In both conditions, groups used the individual ranking approach to come up with the group decision, by summing up the individual ranks after they have made their personal choice. First, each group member would walk to a left large display (an electronic whiteboard), select a favourite colour he/she picked at the beginning of the discussion, and mark the favourite ideas with a Mimio pen (Figure 6.8). Participants reported that they liked using different colours with different group members during the ranking game, as it helped their creativity.

6.7 Conclusions and Design Implications

The analysis of the observations and post-group discussion indicate a high involvement of group members in the discussion while interacting with the Train-of-Thoughts interface on the shared Tablet PC. Group members tended to stand around the Tablet PC while one of the members would input the group decisions on the summary and the top 3 ideas (Figure 6.6, right). Some participants said they might prefer to have the Train-of-Thoughts input interface on their own personal display. However, as participants' comments and post-group discussion results indicate, interacting via a shared display was beneficial for the awareness of the group about what is actually being put into the train.

One of the shortcomings of the study is that it was hard for the participants to make a clear distinction between the Train-of-Thoughts interface and the rest of the large displays' content (e.g., Carousel, MindMap, ranking), despite the fact that it was always displayed on the right part of the large display in the Y condition. We observed the same effect in the previous Highlighting-on-Demand experiment (chapter 5). As we assume based on participants' feedback during the post group discussion, one of the reasons might be that the users perceive the visual content of the multiple large displays as one integrated system of supportive tools. The upside is that this might be an indication that participants perceive the Train-of-Thoughts as a well-integrated part of the whole system of supportive tools in the multidisplay environment rather than an appraisal of our visual design. What we measured, appropriately represented the perception of participants about the quality of the group discussion. More in-depth studies are required to investigate whether such effect really exists.

As post-group discussions indicate, it might be useful to integrate the Train-of-Thoughts interface with the MindMap. Parts of the MindMap, related to a certain idea, could be linked to the idea summary. Once an idea summary is displayed in full size, part of the MindMap would become visible. We plan to investigate this in future studies. Another useful feature could be the explicit visual indication which card/character (from the Card and the Carousel game) leads to which ideas during the brainstorm. In addition, we plan to investigate the use of a personal display versus shared display version of the Train-of-Thoughts input mode.

6.8 Summary

In this chapter we discussed the findings of an empirical user study on assessing the effect of the Chain-of-Thoughts SA support concept (chapter 4.3.1) on the group and decision-making process during the brainstorm sessions in a multidisplay TX-Lab environment. The Chain-of-Thoughts concept enables group members to capture, summarise and visualise the history of ideas on a shared display providing the awareness of the group decision-making progress and status. The results indicate that the Train-of-Thoughts visualisation presented on a shared large display had a positive influence on the participants' satisfaction with their contribution to the final group decision, and with some of the aspects of the group process and decision making. Team members reported that interacting via a shared display was beneficial for the awareness of the group about what is actually being put into the shared Train-of-Thoughts visualisation. Participants liked the fact that the awareness visualisation enables the group to summarize the enormous set of brainstorming ideas to general important solutions.

Next, we present the results of the design and evaluation of a shared awareness display to support situational awareness of software teams' activities and project health. The main findings of the next chapter include **(1)** detailed insights into how software developers maintain awareness of ongoing team activities using existing techniques and tools, **(2)** a novel awareness visualisation based on developers' needs, and **(3)** new insights into the use of a shared display to support team awareness of work item data in software repositories. We also discuss a conceptual overview of new design ideas based on the results of the field user study.

Chapter 7

Assessing the Impact of Shared Awareness Display on Collaboration of Software Teams

> *"Vision is not enough; it must be combined with venture. It is not enough to stare up the steps; we must step up the stairs."*
> *–Vaclav Havel*

Team collaboration and coordination in software development is complex [Sarma et al., 2008]. First, it may require frequent coordination to plan and review the progress of a team. Second, completing a task often involves team collaboration because knowledge is divided between team members who have different roles or own different parts of the system. Team members may work on multiple task items at a time, or belong to more than one team, adding to the challenge of coordination. Thus, team members need to be aware of what others on the team are doing [Ko et al., 2007; Sarma et al., 2008].

This chapter[1] presents the results of the design and evaluation of large display visualisation to support situational awareness of development teams' activities and project health in co-located team workspaces. We discuss the results of design and evaluation of WIPDash (Work Item and People Dashboard), a shared awareness visualisation of work items in a team's software repository. Our goal is to help software teams be aware of the overall status of a project, and understand ongoing activities related to the team. Initially, we conducted interviews and field observations within a software development organization in order to understand the needs of co-located software teams. We then discussed these results in a series of focus groups to iteratively design WIPDash. Finally, we deployed WIPDash with two software teams in an attempt to observe which features and functions the team actually used, and how

[1]Adapted from: Jakobsen, M. R., Fernandez, R., Czerwinski, M., Inkpen, K., Kulyk, O., and Robertson, G. WIPDash: Work Item and People Dashboard for Software Development Teams. In: *Proceedings of the 12th IFIP Conference in Human-Computer Interaction (Interact'09)*, pages 791-804. Springer, 2009; the internship work reported in this paper has mainly being done by M. R. Jakobsen and O. Kulyk.

they used those features. Our findings led us to a number of design lessons, and yet another design iteration, which we introduce at the end of the chapter.

The main contributions of this work include **(1)** detailed findings about how developers maintain team awareness using existing techniques and tools, **(2)** a novel awareness visualisation based on developers' needs, and **(3)** lessons learned from a deployment with two teams along with a conceptual overview of new design ideas based on that deployment.

7.1 Supporting Software Team Awareness

One way to improve team awareness is to show data from a team's repository on a large display in a shared workspace (e.g. [Biehl et al., 2007; Gutwin et al., 2004b]). FASTDash [Biehl et al., 2007] showed developers' current activities in a code base. A field study showed that FASTDash increased communication within the team by 200%, though the authors did not have an explanation for this, and left more in depth exploration of the concepts and their effects on team behavior for future work. The results report that FASTDash helped team members know who had which files checked out, who was blocked and needed assistance, and helped resolve conflicts with checked out code. The authors also learned that basing screen real estate on file size was a poor use of the space in a treemap. Improvements were suggested based on the study, such as using metrics other than file size to allocate screen space, and to add support for people to track work items that are assigned to them. Still, it was not clear which types of information were most useful or how visualisations could be best designed to get awareness information at a glance. The study of de Souza et al. [2005] have also shown that the software source code can actually be mined to visualize both social and technical relationships of projects.

In other research, O'Reilly et al. [2005] visualized checked-in code changes on a multi-monitor display. The authors reported a field study in which a software team was instructed to use the display console for morning stand-up meetings. From observations and comments, the study concluded that the visualisation helped to inform developers about progress and overall effort of the team. However, it is not clear how participants used the display, and in particular, whether they only used it during their stand-up meetings. The authors of another study [de Souza et al., 2005] have shown that source code could be mined to visualize both social and technical relationships of projects. We were inspired by these findings and focused our visualisation on support for work item awareness.

A study of Fitzpatrick et al. [2006] presented a ticker tape tool for software teams that displayed messages from a revision control system, CVS. The authors found from a long-term study that the ticker tape tool stimulated more focused discussion about source code changes, reduced the number of empty check-in messages, and helped coordinate and negotiate work within the team. While the ticker tape messages were mainly found to support synchronous communication between developers, they were also found to catch up on what others on the team had been doing by browsing the log of ticker tape messages that they had missed. The authors mentioned the modest screen real estate requirements of the ticker tape tool as an important benefit.

Hill et al. [1992] describe the concept of showing the history of a user's interactions with files as part of the representation of the files. Recent research has empirically studied use of interaction history to help software development teams [DeLine et al., 2005; Froehlich and Dourish, 2004]. TeamTracks [DeLine et al., 2005] directs the attention of a programmer to important parts of the source code based on the history of programmers' interactions with the code. Augur [Froehlich and Dourish, 2004] combines information about code activity with a line-oriented source code visualisation similar to Seesoft [Eick et al., 1992]. Froehlich and Dourish [2004] present case studies of four developers who used Augur to gain insight into their code and their development activities. Their findings support the idea of combining information about activity and code in one view that is based on spatial organization of the code. However, Augur's potential usefulness as an awareness tool for a co-located team remains unknown.

The research efforts mentioned so far involved representations of source code, check-ins, and the use of code files. In contrast, Ellis et al. [2007] aimed at helping large distributed software teams to coordinate their work on change requests by visualizing bugs. They presented SHO, a visualisation with bugs shown as circles ordered, colored, and sized by different importance metrics. Participants in an experiment were more successful at completing tasks using SHO than using Bugzilla. Advantages of SHO included being able to see all bugs in one view and being able to identify bugs with certain patterns, such as frequent reassignments. D'Ambros et al. [2007] visualized the frequency of bugs in components of a project in a timeline view and also visualized state changes of individual bugs over time in a 'bug watch view'. Another recent study by Sarma et al. [2008] presented a desktop awareness system based on code activity and check-ins. Their Palantír tool addressed mainly artifact changes in order to prevent potential conflicts. The visualisations were useful for exploring databases of bugs to identify areas of concern. However, it is not clear how useful these types of visualisations are for maintaining awareness of work items activity and project progress in co-located software teams, which is the focus of this chapter.

7.2 Design for Software Teams

This chapter presents research by design following a user-centered design approach [Mayhew, 1999; Wassink et al., 2008]. We began by gathering observations and conducting semi-structured interviews with software developers to gain insight into their work practices and needs in co-located team workspaces. Our goal was to understand how co-located teams coordinate their work and to get input on what visualisation features and views would be most useful for them. As a result of those interviews and observations, we produced an initial design of a shared awareness visualisation to support situational awareness of software teams, which we presented to a focus group for feedback. Based on that feedback, we designed and built a prototype called WIPDash (Work Item and People Dashboard), and then ran a field study on its use.

7.2.1 Interviews and In Situ Observations

In situ observations were performed with two agile teams (see Figure 7.1). The teams were observed for five hours during one week. Observations were carried out at different times of the day and included morning stand-up meetings and iteration planning meetings. One team typically had five to ten members present, while the other team typically had eight to fifteen members present. We also carried out semi-structured interviews with ten individuals from these teams (eight males). Each interview lasted 35-40 minutes and was audio recorded with the participants' permission. Interviewees received a free lunch coupon as gratuity for their participation. Participants of the interviews had two to fifteen years of experience in software development and ranged in age from 20 to 46. Based on questions from related studies [Ko et al., 2007; de Souza and Redmiles, 2008] and questions motivated by our in situ observations, the interviews focused on the following aspects (see Appendix C):

- experiences working in a co-located team workspace;
- what tools and alerts are currently used to keep track of what other team members are working on and what is missing in existing tools;
- how work items and tasks are currently managed;
- types of meetings and the use of a projector in the team room;
- how progress and project health in general is monitored;
- wishes on what to display on the large shared screen and how to support work flow.

Figure 7.1: Shared workspaces of two observed software teams

7.2.2 Interview and Observation Results

The interviews and observations showed that the teams work in iterations, which are blocks of time typically one to two weeks long. Daily stand-up meetings in the morning help the team to keep track of who is working on what, and they are considered an important time for team bonding. The teams varied in work style, size, and physical workspace arrangement. Both teams adopted a seating arrangement that corresponded to individual roles on the team: developers, testers, writers, and support (including program managers).

The teams used many software tools to coordinate their activities, including Team Foundation Server (TFS), email, instant messaging, Live Meeting, and SharePoint. Work items were created in a TFS repository. However, developers found it burdensome to continuously update work items in the repository and felt that they did not get a proper return on the time they invested in doing so. While information shared on whiteboards and sticky notes on the walls of the team room was often visible to team members, it is not easy for them to see changes to work items in a software repository. The TFS repository they use today provides only textual list views for work items. Team members sometimes find it difficult to visually scan for changes or work items that they care about. Also, the status of the work item is often not up to date, as team members sometimes forget to change it.

In addition to regular stand-up meetings, iteration planning, and bug triages (where resolved bugs are discussed and new bugs are assigned to team members), ad-hoc conversations frequently occurred in the team rooms. Some team members used chat or email, but often team members just shouted out a question or rolled their chairs over to talk to each other. Moreover, other people came in and out of the team spaces.

Although shared team rooms can be noisy and distracting, and offer less privacy than private offices, most team members felt that the team room was more effective for team work. An exception to this is documentation writers (two out of ten interviewees) who said that they preferred to work in a private office or from home; they needed to concentrate and only came to the team room for meetings or when they needed to speak to another team member. Since they were frequently absent from the team room they tended to be less aware of activities that were going on within the team.

Both teams used shared whiteboards and sticky notes on the walls. Team members defined, categorized, and prioritized work items during iteration planning meetings and used sticky notes to represent tasks or work items. The teams also used a projector on the wall to display information for various tasks such as work items during iteration planning, when assigning new tasks, or for code reviews.

The dynamic nature of stand-up meetings required a quick, glanceable overview of recent activity. Teams did not have a suitable tool for displaying important information. TFS gave no overview of unassigned tasks, and did not allow more than one person to be assigned to a task. Also, team members had to make a burn down chart or a task list for each meeting, which was time consuming. It was possible to export charts and work items from TFS, but this often resulted in a long Excel table with no way of synchronizing changes back with work items in TFS.

7.2.3 Focus Group Results

Based on what we learned from the interviews and observations, we sketched an initial design for a team awareness visualisation. This initial design sketch, based on the current iteration of one of the team's work items repository, was presented to a focus group on a large projection screen in a meeting room to help participants imagine how the visualisation would look when deployed in their own team room. Eight participants from two agile development teams took part, including an architect, program managers, developers, lead developers and testers. The participants ranged in age from 30-48. The focus group session was video recorded with the teams' permissions.

Participants found that the awareness display presented information in a new perspective that they had not seen before and they liked being able to see an overview of the whole project in one view. Team members expressed the need for different filters and view modes, since some work items could be irrelevant for their role.

We derived three key requirements for our design based on this feedback. The awareness visualisation should **(1)** give an overview of *iteration progress*, with the ability to summarize over the last day, week, month, or version, **(2)** give details on *individual work items* and the people these are *assigned to*, and **(3)** list current and recent *activities*, either of people or on work items.

7.3 Work Item and People visualisation Design

Based on all of these results, we developed WIPDash, a visualisation suitable for a large shared display in a co-located software team space. The visualisation was implemented as a Windows application that reads data about work items from TFS. Our intention was that team members could glance at the shared display to see the overall status of the project and the recent changes made (especially from the past 24 hours). We also wanted team members to be able to use WIPDash on their individual machines, where they could switch between different views and filters, and get details on demand.

The WIPDash window consists of two parts (see Figure 7.2). The bigger left part of the window contains a spatial representation of areas of the project and the work items in those areas. For instance, the area labeled 'Docs' contains items related to project documentation. The right part of the window consists of a list of view modes, a team panel, and drop-down lists of iterations, work item states and types. These lists can be used to filter and highlight work items in the left view.

7.3.1 Work Item Treemap

WIPDash uses a squarified treemap for laying out project areas as rectangles [Bruls et al., 2000]. The treemap is a scalable approach to spatially organizing hierarchically structured data such as a hierarchy of project areas. Each rectangle is sized proportionally to the number of open work items in the area. A minimum threshold is used to ensure that areas that do not contain any open items are shown in the map. Rectangles are labeled with the name of the project area.

We wanted to preserve the spatial layout of project areas and work items to make it easier for users to remember where areas are located in the visualisation. However, treemap algorithms can cause the spatial layout to change considerably when the data change. Since WIPDash would be shown on both a large display and on individual team members' displays (which may have different screen dimensions), the layout had to vary across instances of WIPDash. In order to keep the layout consistent for the purpose of the field study, the treemap was fixed and then shared by all instances of WIPDash. This layout could be explicitly updated and the treemap would render again. Since the relative size of an area does not change dynamically to reflect the number of open work items, we color a rectangle darker as more open work items are associated with the area.

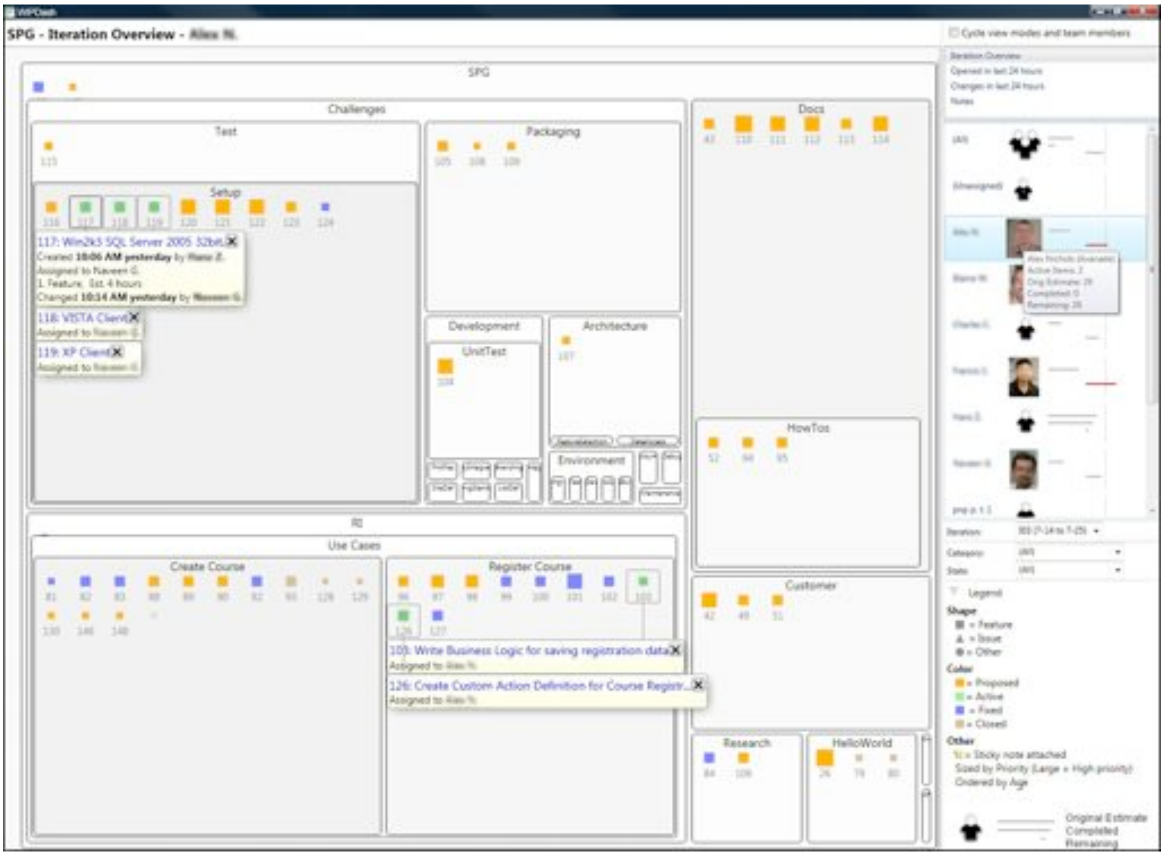


Figure 7.2: WIPDash showing the iteration overview for the current iteration of a project.

Each rectangle in the treemap contains icons that represent the work items associated with that area. The icons in a rectangle are evenly spaced in a grid, placed in the order they were created starting from the top-left corner. Space between icons is reduced to fit all icons within the rectangle, and if there is enough space between icons, the ID number of the item is shown below the icon. The color of an icon indicates the state of the work item (e.g., proposed, active, resolved, or closed) and the shape of an icon indicates the type of the work item (e.g., feature, bug, or task). Icon size represents either priority level or estimated hours of the work item, with larger sized icons representing items of higher priority or higher estimate of work hours, as designated by the user or team.

Moving the mouse cursor over a work item icon shows a tooltip with details about the item. Clicking on an icon shows a popup window with details about the work item. An 'Add note' section in the detailed window can be expand to add a sticky note to the work item. A small yellow sticky note symbol is displayed on the work item to indicate that it has a note attached.

7.3.2 Iteration Filtering and Highlighting

Selecting an iteration in the *"iteration list"* (Figure 7.2, right) shows all work items that are assigned to that iteration and highlights them on the treemap. Since teams are usually only interested in closed items for the current iteration, we removed closed items that were not assigned to the selected iteration in order to avoid clutter.

7.3.3 Team Panel

The team panel (see Figure 7.3.A) contains the names and pictures of the team members. Clicking on a team member shows the icons for all work items assigned to or closed by the selected team member. The team panel contains two options in addition to the team members: **(1)** *"all"* which is used to select all items regardless of whom they are assigned to, and **(2)** *"unassigned"*, which is used to select all unassigned work items.

For each person, WIPDash shows horizontal lines that represent the total amount of work, the amount of completed work, and the work remaining in the iteration that is assigned to that person (Figure 7.3.B). The x-axis measures work hours and a dotted vertical line represents the end of the iteration, corresponding to the total number of work hours in the iteration. The remaining work line is colored red if the estimated hours of remaining work exceeds the time left in the iteration.

7.3.4 View Modes

One goal of our design was to make the information on the display glanceable. Thus, to avoid cluttering the display by showing too much information in one view, users can choose between four different view modes.

The *Iteration overview* mode highlights all work items in the current iteration. This view aims to provide an overview of the iteration status. Team members can see how much work has been done and how many work items remain in the iteration. Details are automatically displayed for work items that are currently being worked on, including who is working on the item. More details about an item can be shown by clicking on *"More"* (see Figure 7.2).

The *Opened in last 24 hours* view is designed to keep the team aware of incoming tasks and issues. Work items opened within the last 24 hours are highlighted with a yellow border and background. The opacity of the border and background varies to distinguish recently opened items from items that were opened less recently. Also,

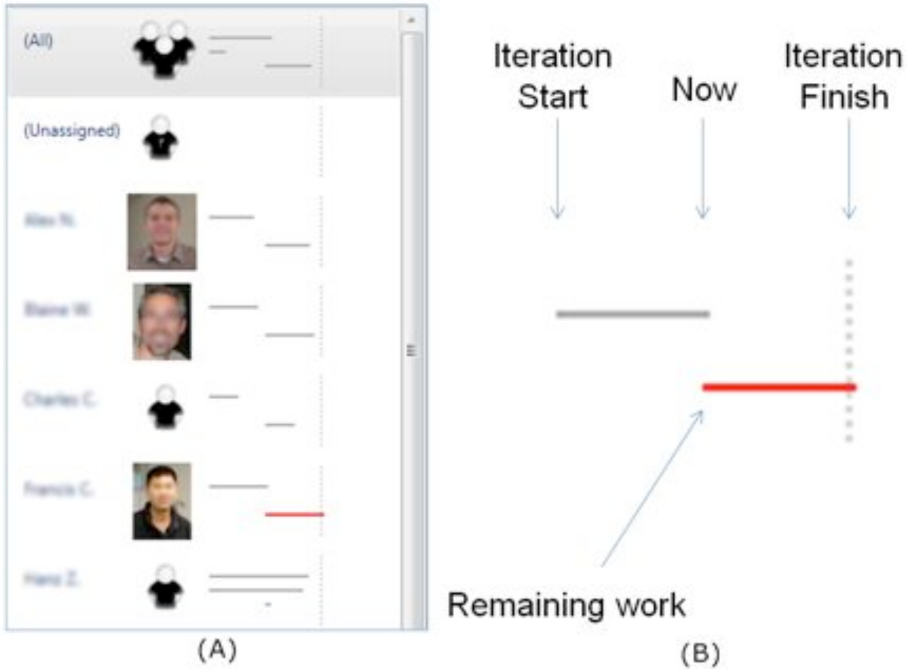


Figure 7.3: (A) Team panel showing names and pictures of team members, and (B) a graphical representation of the amount of work each member has assigned, completed and remaining.

similar to the iteration overview, details are shown for recently opened items, including when an item was opened and by whom.

The *Changed in last 24 hours* view aims to keep the team aware of recent changes to work items. Similar to the Opened view mode, a yellow border and background is shown around icons of work items that changed within the last 24 hours. Again, details are automatically displayed for recently changed work items, including the change made and who made the change. For simplicity, the same color coding is used for both *Opened* and *Changed* view modes in order to draw users' attention to work items with any recent activity.

The *Notes* view calls up the sticky notes for all work items with a note attached. The Notes view allows users to spot work items that need attention, for example if a team member makes a request to pair up on a specific task.

In order to provide continuous awareness and to allow passive use, WIPDash allows cycling through view modes and through team members within each view mode. A person remains selected for ten seconds before the next person on the team panel is selected. The next view mode is selected after cycling through all team panel selections. We were interested to see if this cycling behavior was useful or distracting to the teams we studied. The visualisation updates with new or changed work items by querying Team Foundation Server (TFS) once per minute. All of the information used in our visualisation came from the teams' data entries in TFS.

7.4 Field Study

We conducted a field study with co-located software teams and observed the use of WIPDash for one week. Our aim was to understand the usefulness of WIPDash and the effect it had on team members' situational awareness and on group processes.

7.4.1 Participants

Two co-located software agile teams participated in the field study, with a total of 24 participants. Team A had eight members (seven male), with an age range of 22-46. Team B had 16 members (14 male), with an age range of 27-48. Individual roles on both teams included lead developer, developer, tester, test lead, program manager, writer and group manager.

7.4.2 Measures

Three dependent variables were measured: situational awareness, group process and decision making, and satisfaction with the interface. Situational awareness was measured using SART (Situation Awareness Rating Technique) questionnaire, a widely used self-rating technique that involves an individual subjective assessment of system designs in terms of demands placed on attentional resources and understanding of system states [Taylor, 1989]. Perceived quality of the group process [Olaniran, 1996] and decision making [Kulyk et al., 2006; Paul et al., 2004] was assessed by a combined questionnaire (see Appendix D, Part I).

Questionnaires on situational awareness (SART, [Taylor, 1989]), group process [Olaniran, 1996] and decision making [Kulyk et al., 2006; Paul et al., 2004] were administered to team members *before and after* the field study. Usefulness and satisfaction with WIPDash interface was assessed using a questionnaire administered to team members only *after* the field study. The questionnaire contained nine questions from [Paul et al., 2004] and eight questions to address distraction and awareness [Cadiz et al., 2002; Kulyk et al., 2006]. All questionnaires used a five-point Likert-scale with lower scores reflecting negative responses.

In addition, observations, interaction logging, and video capturing (including the post-usage discussion with teams after the field study) were used to collect data during the field study. Two observers performed in situ observations using a validated coding scheme [Biehl et al., 2007], which included four main categories: (1) communication, (2) shared display use, (3) collaboration type, and (4) collaboration configuration (adapted from [Biehl et al., 2007], see Appendix G for a complete list of the categories and subcategories).

It total, observations were collected for 190 minutes per group throughout one iteration, which equals the length of the field study. Observations were carried out at different times of the day and included morning stand-up meetings and iteration planning meetings. Observation logs automatically adds time stamps when an observer registers an event or an instance of the communication behaviour, which makes it easier to trace the events back to the video data if needed.

7.4.3 Setting and Procedure

WIPDash was installed on a large display in the team rooms and on team members' individual workstations. Data were automatically collected in WIPDash in order to describe how participants interacted with the visualisation throughout the study. WIPDash was installed on a Thursday and an orientation session was given the following day. Each team received an overview of WIPDash features and was encouraged to ask questions and share any requests for assistance at any time. We observed the teams the following week (Monday through Friday). Afterwards, we met with each team for post-usage discussions. Each participant received a $50 gratuity coupon for their participation. In the Team A room, the awareness visualisation ran on a projected wall display on the most accessible wall to the whole team. In the Team B room, the awareness display was installed on a 52-inch plasma touch screen toward the front and right side of the team room. Some members of Team B had their desks facing away from the display. Both teams also had WIPDash running on their private displays, some on desktop computers and some on laptops.

7.5 Field Study Results

The observations and post-group discussions were translated into the use of the shared awareness display for daily stand-up meetings and the different use of shared and individual displays.

7.5.1 Supporting Daily Stand-Up Meetings

Team A used WIPDash daily on their large display during stand-up meetings to coordinate these meetings. Specifically, they found the *Iteration overview* useful, both in terms of status and also to jog their memories about work items from the previous day. During stand-up meetings, one of the team members selected each person from the team panel to display his information, and that person then talked about his work. The team considered details about the active items assigned to a person to be especially useful. Team members said they would have found it beneficial to have team members displayed in a random order during stand-up meetings – just to make it more fun. They also referred to the display to view the status of a remote team member when she called in for the standup meeting. This suggests that WIPDash could be useful for supporting collaboration with distant team members. Some team members commented that they liked to look at the awareness display first thing in the morning to see what team members in Argentina had been doing for the last ten hours. Some team members who were on vacation for most of the time during our study also said that they used the awareness visualisation when they got back to get a sense of what the team had been doing for the past week and *"Where are we now?"* in the iteration.

We observed that the available information in WIPDash was not completely sufficient for reviewing what had been worked on during the previous day. Specifically, if a developer had completed his work on a work item and then reassigned the item to somebody else for testing, that item no longer showed in the *Changed* view for that developer. This was discussed during a stand-up meeting, and the team suggested a view where all work items that a person had worked on would be highlighted, even if they had been reassigned. The team further elaborated on an idea of one, concise overview containing all the information they would need for their standup meetings, including recently resolved items that were reassigned to other members and items that members had worked on yesterday. Finally, the team expressed a wish for extending the shared wall display with an additional projector to show project information such as spreadsheets or code next to WIPDash.

7.5.2 Automatic Cycling

The automatic cycling between views was found to be problematic. WIPDash cycled between all members in the team panel, including people with no items assigned or without any recent activity. Thus, nothing of interest is shown in parts of the cycle. Members of Team A suggested that cycling would make sense if done only between views that contain recent changes. Team B had only one work item assigned per person at a time and therefore cycling through each view for each team member was not useful.

Team members commented that notifications needed to be more assertive when a change or an update happened, such as an audio herald combined with a fisheye notification message about the change on the awareness display. Also, team members wanted to configure which views were displayed on their personal displays and when notifications should appear. An RSS-style feed would probably be a useful option for the personal workstations. We are pursuing that idea in the next iteration.

7.5.3 Use on Large Display and Individual Displays

We analyzed data logged by WIPDash to see how the two teams used WIPDash on the large display and on their individual machines. In all, we collected log data from ten personal machines, five members on Team B and five members on Team A, in addition to the two machines running the large shared displays. When a user started interacting with WIPDash, the default cycling between views was suspended. The log data showed that Team A used the large display (showing the iteration overview) during their stand-up meeting every morning around 9:30 am. Apart from the stand-up meetings, Team A physically interacted with the large display only twice during the study. In contrast, Team B interacted with the large display on average five times per day. In Team B some of the participants did not have WIPDash installed on their own machines. For this team WIPDash was running on a new touch screen display, which had a lot of appeal. One possible reason why Team A did not interact much with the large display was that it was projected high up on one of the walls, making personal display interaction more reasonable than going to the laptop in the corner of the room that controlled the view in order to interact with the group view.

7.5.4 Types of Interaction

In all, 596 selections were made in the right panel of WIPDash. Selections were primarily made in the team panel (66%). The view mode panel (17%), and iteration panel (15%) were also used to change the view. Iteration overview was the most frequently selected view mode, selected more than 50% of the time. The Changes view and the Opened view were each selected between three and eight times, whereas the Notes view was only selected once. Participants from Team A clicked on items to call up details 21 times while participants from Team B brought up additional details 22 times. Only two sticky notes were created in WIPDash, both by a lead developer on Team A. Follow-up discussions related to sticky notes revealed that users would rather use the existing 'comments' data structure in TFS to view and add notes to work items in WIPDash.

7.5.5 Questionnaires

Situational Awareness and Group Process

Results of the situation awareness rating test (SART, [Taylor, 1989]) were mostly neutral to positive overall as all ratings were above average and are summarized in Table 7.1. Wilcoxon Signed Ranks test showed no significant differences in Before and After measurements.

Table 7.1: SART results: Before and After measurements

	Question	**Before: Average Rating (SD)**	**After: Average Rating (SD)**
1.	The situation is highly unstable.	2.9 (1.1)	3.1 (1.0)
2.	The situation is complex with many components.	2.9 (1.0)	3.1 (1.0)
3.	There are a large number of factors varying in the situation.	2.8 (1.0)	2.9 (1.1)
4.	You are alert and ready for activity.	3.9 (0.8)	3.6 (1.0)
5.	All your attention is concentrated on the situation.	4.0 (0.7)	3.6 (1.1)
6.	You are concentrating on many aspects of the situation.	3.2 (0.8)	3.3 (0.8)
7.	You have sufficient mental capacity to attend to the situation.	3.6 (0.7)	3.3 (1.3)
8.	You have gained and understood a great deal of knowledge about the situation.	3.8 (0.7)	3.5 (1.0)
9.	The knowledge communicated about the situation is very useful.	3.8 (0.7)	3.6 (1.0)
10.	You are familiar with the situation and you have a great deal of relevant experience.	3.8 (0.8)	3.7 (1.1)
11.	Please rate your workload.	3.4 (0.5)	3.7 (0.8)

Wilcoxon Signed Ranks test showed no significant differences for either situational awareness, or for the group process and decision making between the Before and After measurements. The results for situational awareness could be affected by a particular iteration stage or the day of the week the questionnaire was completed. As we previously discussed in chapter 2.4, self-rating techniques have a potential limitation that participants may experience difficulties rating low periods of SA [Salmon et al., 2006].

In view of rather generic statements in the SART questionnaire, this measure might not be sensitive enough for our case.

Usefulness, Awareness and Distraction

We balanced the valence of our satisfaction questions. For negatively phrased questions (marked with an asterisk in Table 7.2), we reversed the rating so that higher was always positive.

Ratings on usefulness and satisfaction with the system were mostly neutral to positive (see Table 7.2). Team members said that they had confidence that the information was displayed correctly and on time. From the ratings it was clear that participants had confidence in the information provided by WIPDash, but it was seen as less reliable than we would have liked.

From the awareness and distraction ratings (see Table 7.3), it was clear that the notifications of changes were not grabbing attention well enough. However, the teams did not find WIPDash distracting and were not embarrassed to show their personal work item information.

User Comments

Most participants had very positive responses about the awareness display interface:

- *"I liked to see what each person was working on";*
- *"...Good for standing meetings... What did I do? What am I blocked on?";*
- *"I liked that it gave the team an idea of what is happening during an iteration".*
- *"It's good to know the status of my working items".*

Participants mostly liked Iteration overview (14 out of 24) for stand-up meetings, for the overall progress of the iteration and for the overall status of the projects. The second favourite view from the questionnaire comment is the Changed in last 24 hours view, that team members found useful for *"seeing reassignments"* of the work items and for activity reports (7 out of 24).

7.6 Reflections and Design Implications

Several factors may have affected the use and adoption of WIPDash. First, size and location of the shared display affected how team members made use of the display by glancing at it or physically interacting with it. During observations of Team A, we saw that team members often looked at the display when entering or leaving the room. This was not the case in the Team B room. One reason may be that the Team A room had a large display, projected high up on a wall, that was visible to everyone in the room. In contrast, Team B's shared display was smaller, located in a corner of the room, and was not directly visible to all team members.

Table 7.2: Usefulness and satisfaction

	Question	**Average Rating (SD)**
1.	I have difficulty understanding WIPDash.*	4.1 (0.7)
2.	WIPDash is easy to use.	3.6 (0.8)
3.	WIPDash is reliable.	2.6 (1.1)
4.	I have confidence in the information provided by WIPDash.	3.9 (0.7)
5.	I need more training to understand WIPDash.*	4.1 (0.9)
6.	WIPDash is informative.	3.3 (0.9)
7.	WIPDash is comprehensible.	3.4 (0.8)
8.	Overall, I am satisfied with WIPDash.	3.0 (1.1)
9.	I would be happy to use WIPDash in the future.	3.1 (1.1)

Table 7.3: Awareness and distraction

	Question	**Average Rating (SD)**
1.	I find WIPDash distracting.*	4.0 (0.9)
2.	WIPDash grabs my attention at the right time.	2.8 (0.9)
3.	It's worth giving up the screen space to run WIPDash on my PC.	2.7 (0.9)
4.	WIPDash helps me stay aware of information that's critical.	2.7 (1.0)
5.	I like being notified when a work item gets reassigned.	3.2 (1.2)
6.	WIPDash's notifications often distract me.*	3.8 (0.8)
7.	Having WIPDash displayed in front of the team is embarrassing.*	4.2 (1.0)
8.	I would rather have WIPDash displayed only privately.*	4.2 (1.1)

Second, the two teams in our study organized their work differently. Team A assigned work items to team members during an iteration planning meeting, and had daily stand-up meetings to follow up on the progress of the team. Using the shared display during stand-up meetings may have influenced Team A's familiarity with the display, and consequently increased their use of the display. In contrast, Team B did not have daily stand-up meetings; instead, they talked with each other about progress and status throughout the day. Also, Team B assigned only one work item to each person and viewed work in terms of releases that spanned several iterations, not single iterations. This suggests that Team B could make even better use of an overview of activities, but using different time spans.

Third, Team B had many proposed items in their repository, but most items were not scheduled to be worked on. Also, many of the project areas, which were shown in WIPDash because they contained proposed work items, were simply not considered relevant by the team at the time of our observations. Thus, as Team B had many more items to track than did Team A, and since WIPDash showed all work items in 'proposed' state, the display for Team B was more cluttered.

Our study has limitations that should be considered when interpreting the results. Although very different in work styles, two teams from the same organization participated in the study. Therefore, our results may not be generalizable to software teams everywhere. In addition, we only observed the teams for one week. While we learned much from the initial feedback, it would be interesting to see the long term effects of WIPDash on the coordination within the teams. As we learned from the post-group discussions, team members on both teams were willing to keep using the awareness visualisation.

Another concern is that we do not know how the co-located agile teams that we have focused on compare with larger, distributed teams. It could be that a focus on co-located software teams may reveal some issues in team coordination that also apply to distributed software teams. For example, Gutwin et al. [2004b] suggest a need for awareness of areas of expertise within a distributed open source project team because developers work on all parts of the code. This might relate to the information needs we seek to provide with our visualisation (e.g., what people are working on and have been working on). For example, a glance at WIPDash first thing in the morning to see what team members in Argentina have been doing for the last ten hours could be very useful in terms of setting daily priorities or offering more timely assistance.

Team member's feedback suggested that an awareness display could be a useful overview of the project progress for project members from outside the core development team, for example, for the upper management during code reviews. Moreover, product managers who manage several projects at the same time expressed interest in the display visualisation, as they imagined it would be a nice high level awareness tool for the overall progress across different projects.

Informed by the insights we have gained from our study of WIPDash, including the findings from the field observations and post-study interviews, the following improvements of the current awareness display have been proposed:

- a more glanceable display, where users can comprehend the latest changes within 1-2 seconds;
- sound alerts when information changes, so users can know when to look at the dashboard;
- when running on a user's personal display, it will run in a "hidden" mode that will only show alerts as information changes;
- more flexible schema mapping, so it is easier to accommodate a wide diversity of project data field definitions and usages;
- support for add-on visualisations developed by a dashboard community;
- data caching to reduce the load on the repositories from dashboard clients.

7.7 Conclusion and Future Work

This study on WIPDash suggests benefits from providing awareness of work item status. Earlier work on FASTDash [Biehl et al., 2007] showed benefits from providing a team situation awareness display based on code activity. An interesting perspective for future work is to combine information about work items with information about code activity in one visualisation [Sarma et al., 2008]. A potential disadvantage of such an approach is that the display may get busy. However, linking code activity and the state of work items could give the team a solid shared context if it focused simply on what is or has just recently changed. A simple list of recently changed work items should be created, showing the people who are actively related to them. In addition, the shared awareness display should have integrated chat and RSS feeds for notifications to the personal display. The ethnographic study of de Souza and Redmiles [2008] confirms our observations: (a) a need for awareness of who made the changes; (b) a need to integrate peripheral awareness notifications into an existing work items repository, and to link them to code changes in order to keep work items' status better up to date and thus coordinate work more proactively.

In this chapter, we have reported on a human-centered design of a shared display application to develop a situational awareness dashboard visualisation to help software development teams track people and work items. From observations and interviews of development teams we learned about their current work practices and what might be provided to improve situation awareness. We then developed a dashboard for supporting awareness in teams, called WIPDash (Work Item and People Dashboard). We gathered feedback on an initial design from a focus group, which drove the detailed design and the implementation of WIPDash. Finally, we have studied the use of WIPDash in situ with two development teams, and reflected on the observations and data we gathered. While questions remain to be answered, the results from our study provide initial insights into the use of a shared display to support team awareness of work item data in software repositories.

7.8 Summary

In this chapter, we presented the results of the design and evaluation of a shared awareness display to support situational awareness of software teams' activities and project health. The main contributions of this study include **(1)** detailed findings into how software developers maintain awareness on ongoing team activities using existing techniques and tools, **(2)** a novel awareness visualisation based on developers' needs, and **(3)** new insights about use of a shared display to support team awareness of work item data in software repositories. We also presented a conceptual overview of new design ideas based on the results of the field user study.

Next, conclusions, lessons learned, generic implications and the applicability of this research in different domains are discussed. After presenting the general conclusions and future work directions, we discuss challenges in evaluation of merging collaborative workspaces.

Chapter 8

Conclusions

> *"The knowledge that we consider knowledge proves itself in action. What we now mean by knowledge is information in action, information focused on results."*
> *–Peter F. Drucker*

A new wave of advanced collaboration environments, such as collaborative interactive environments [Borchers, 2006], multiple display environments [Huang, 2006; Rogers and Lindley, 2004] and smart environments [van der Vet et al., 2007] requires new methods for design and evaluation in order to adequately address different aspects of collaborative work. The goal of the research presented in this thesis is to analyze how to design and evaluate situational awareness (SA) support interfaces for large displays in order to enhance decision making of co-located groups in multidisplay environments.

8.1 Contributions

This thesis contributes with the design of several alternative visualisations for group decision-making and awareness support, namely (**1**) *Highlighting-on-Demand* (chapter 5), (**2**) *Chain-of-Thoughts* (chapter 6), and (**3**) *Awareness Display* (chapter 7).

Three user experiments were carried out, each investigating the effect of a specific situational awareness concept on team collaboration, the decision-making process and the outcome in three domains: scientific experimentation, enhanced brainstorming and software engineering. We study situational awareness in relation to the group decision-making, which is an alternative approach in relation to the traditional situational awareness studies in military and command control domains.

These experiments, described in chapters 5 through 7, concerned the effects of SA support on satisfaction with the group process, the decision-making process and the perceived task performance. Several conclusions can be drawn from these three user studies. These are presented here together with their implications for the design of future situational awareness support visualisations and awareness displays.

8.2 Overall Conclusions from Experiments

At the conclusion of the evaluation of supportive situational awareness visualisations on large shared displays, there are several findings across the three experiments that suggest some further points to consider.

8.2.1 Effect on Decision Making

The main conclusion across the three experiments is that designing for SA in teams can positively impact collaboration. We showed that situational awareness support may positively affect the group decision-making process and satisfaction with the final group decision. Providing a Highlighting-on-Demand interface visualisation on a large shared display during the group discussion appeared to have a significant positive effect on the satisfaction with the final group decision. The Chain-of-Thoughts interface positively influenced the satisfaction with the contribution to the final group decision, and satisfaction with some aspects of the group and decision-making process (such as, well organized discussions and no disruptive conflicts). This suggests that using a shared situational awareness visualisation leads to decision making with a greater satisfaction when groups share information on a large display.

8.2.2 Supporting Situational Awareness

The results of the two (chapter 5 and chapter 7) out of three experiments indicate that interacting with the SA interface via a shared display helped the group members to stay aware of what is being changed in the SA interface on the shared large display during the discussion. This fosters awareness of changes in the environment, knowing what team members do and have done regarding current events in the environment. Thus, the evaluated SA concepts support the third level of SA awareness (our own definition, chapter 2.1), *interpretation* and reconfiguration of understanding and knowledge in a continuous process during the group collaboration effort.

The last aspect of the third *interpretation* level of SA (our own definition, chapter 2.1), namely 'keeping track of the discussion and work progress' is supported by the Chain-of-Thoughts visualisation evaluated in the second case study (chapter 6) and with the Awareness Display - WIPDash (chapter 7) in the third case study. The observation and post-group interviews' results of these two studies suggest that the Chain-of-Thoughts interface and Awareness Display support awareness of the group decision-making progress, state of work, and overall project progress.

Based on the results of all three experiments, we conclude that providing supportive visualisations on large shared displays aids group members in the discussion (e.g., during real stand-up meetings in agile teams or during brainstorm discussions). Supportive SA visualisations were additionally used as external representations and are often referred to during the group discussions.

8.2.3 Design Implications

Several main implications for the design of supportive SA visualisations are listed below, based on generalized user preferences across three experiments:

Integrate images and text. Though images are mostly preferred, and text is in the second place, the results indicate the clear advantage for the users when both visual and textual modalities are enabled (chapter 6).

Use Highlighting and Fading. Highlighting and fading are highly preferred features. Highlighting is found useful for focusing the attention of group members on specific parts of the supportive SA visualisation, while fading helps to keep an overview of all alternatives (e.g. decisions, ideas, chapter 5).

Enable direct manipulation on a shared display. A shared display is clearly preferred for interaction with the shared SA visualisations: for example, *"You can directly manipulate things and everyone can see the changes right away"* (chapter 5).

Provide integrated view. Results clearly indicate the stronger preference for one integrated view showing the most important concise information (e.g., full idea summary) to get a quick overview of work progress and current status. Additional views showing specific details turned out to be less useful(chapter 7).

8.3 Reflections and Limitations

Reporting findings and differences in awareness needs per domain and per multidisplay environment has learned us practical and useful lessons. Similar evaluation measures were applied in all three experiments. Performing empirical case studies in three different domains increases the possibility of the general applicability of the results.

Different methods were used in this research: controlled experiments, field studies, contextual interviews, task analyses and surveys. Applying the combination of different methods allowed us to investigate the collaboration and awareness needs of teams in various domains. In case of the field study, it has provided a very practical real world situation where we could observe the actual use of the situational awareness display in the course of team members daily activities. The limitation of the field study was the lack of significant results. The results that did not show significant in the field study may have been confounded by factors that a controlled experiment would have avoided.

The relation between situational awareness and decision making we presented for evaluating the supportive situational awareness visualisations needs further validation with larger samples of users. In addition, more standards and objective measures are needed for evaluation of team situational awareness support specifically for large displays in order to guarantee the reliability and validity of the obtained results.

The results of the two studies (chapter 5 and chapter 6) suggest that the users perceive the visual content of the multiple large displays as one integrated system of supportive tools. When providing these supportive SA visualisation tools, in two out of three experiments participants had difficulty in making a clear distinction between the supportive tool and the rest of the large displays' content. The upside is that this might be an indication that participants perceive the supportive SA interface as a well-integrated part of the whole system of supportive tools in the multidisplay environment rather than an appraisal of our visual design. What we measured, appropriately represented the perception of participants about the quality of the group discussion. More in-depth studies are required to investigate whether such effect really exists.

Next, we discuss future work directions and challenges in evaluation of merging collaborative workspaces.

8.4 Research Agenda

8.4.1 Awareness Displays and Notification Services

As de Souza et al. [2005] and Filho et al. [2003] had found earlier, event notification servers can facilitate distributed software development. Given that the future design of the awareness displays could be used with co-located and non-co-located teams, it will be interesting to compare and contrast the notification features across the two different kinds of multidisciplinary teams.

In the longitudinal field studies real meetings are of course the optimal floor to investigate the real usage effects of the SA support.

8.4.2 Challenges in Evaluation of Collaborative Workspaces

Although our primary focus is on co-located collaboration in which situational awareness plays a crucial role, we also consider remote collaboration scenarios for future case studies in which, apart from the situational awareness concept [van der Veer et al., 2009], *social awareness* [Röcker and Magerkurth, 2007] and *presence* [Bystrom et al., 1999] concepts are of a great importance. The study of Röcker and Magerkurth [2007] on the Hello.Wall display shows that people are apparently not always willing to display their presence in the collaborative environment publicly and prefer to set their own activity status. In our vision, this can be easily resolved by the abstract representation of the general current level of activity in the collaborative environment based on the level of activities of present members. Such an activity representation can provide awareness for the remote project members, and may raise curiosity and encourage them to join the team discussion remotely or even to walk to the building and take a look at what is going on in the lab.

One of the future extensions on the *e*-BioLab environment is real-time teleconferencing in order to collaborate with other e-BioScience labs across the Netherlands. New challenges arise when we attempt to merge physical and virtual workspaces in collaborative environments. Figure 8.1 (right) shows how a 3D teleconferencing and

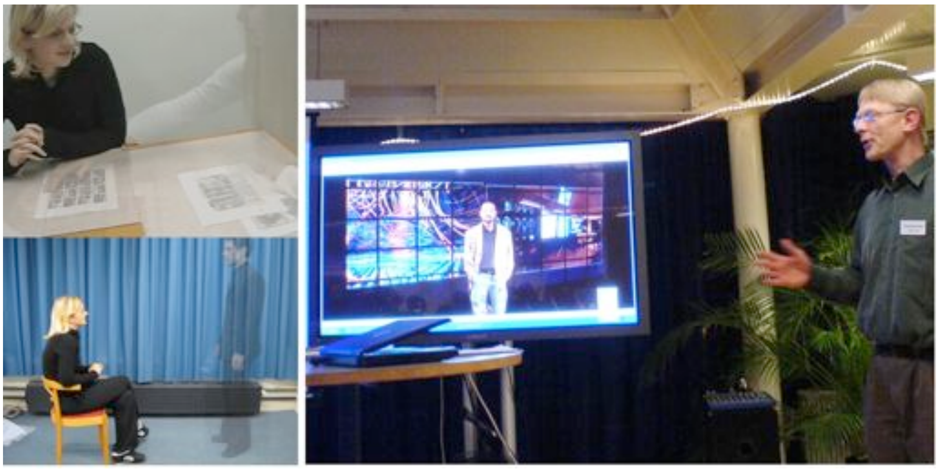


Figure 8.1: 3D teleconferencing and natural document sharing concepts affording presence (*left*); official opening of the *e*-BioLab at the University of Amsterdam by Han Rauwerda and by Jason Leigh from the University of Chicago (*right*).

natural documents sharing concept[1] (Figure 8.1, left) that was once presented for the future office vision, was partially realised during the official opening of the *e*-BioLab.

We have to explore the transfer of information between different types of displays, between the virtual workspace and the real one. Control of the shared display remains a potential problem to tackle. Our expectation is that, just as in the physical environment, team members will develop their own coordination mechanisms, negotiating about the control over the central large shared display. The shared visualisation of the control interface on a plasma touch display currently remains the optimal solution. Sharing enforcement is shown to positively impact coordination strategies, and therefore should work better for the team than several personal controllers. Furthermore, refined evaluation techniques and measures are needed in order to address these aspects of collaborative work in such hybrid workspaces adequately.

[1]Amin, A., Kulyk, O., Metin, B., Schneider, J. Pervasive Office. Videoprototype presented at the *European Symposium on Ambient Intelligence (EUSAI '04)*, Eindhoven, the Netherlands, 2004.

Chapter 9

Appendices

A: Requirements Elicitation Questionnaire

Below follows an exact copy of the questionnaire as it was distributed among the bioinformatics students.

Please fill in the first 4 questions and then read the next block. It is **important that you answer all of them**. Thank you.

You may answer the questions in Dutch

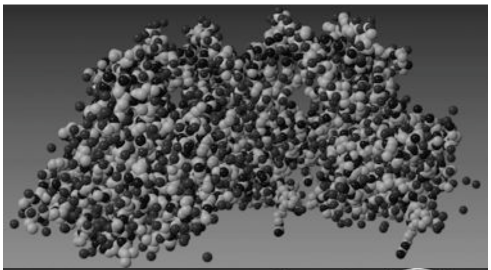
1. Age:……
2. Gender:
   O Female
   O Male
3. Study background:…………………………………………………………
4. Which software tools do you use?
   Please underline which software you use or specify which other program you use:
   a. Operating System: Windows / Linux / Unix / Apple
   b. Text editor: Word / OpenOffice / LaTeX / Other ....
   …………………………………………………………………………
   c. Spreadsheet: Excel / OpenOffice / Lotus Notes / Other ………………
   …………………………………………………………………………
   d. Browser: Internet Explorer / Firefox / Netscape / Opera / Other………
   …………………………………………………………………………
   e. Mail program: Outlook Express / Outlook / Bat / Eudora / Thunderbird / Hotmail /GMail / Other …………………………………………………
   …………………………………………………………………………..
   f. Search Engine: Google / Altavista / Yahoo / Other ……………………
   …………………………………………………………………………
   g. Other frequently used software: ....
   ....
   ....

On the following pages you will be asked questions about your experiences regarding use of bioinformatics applications during the course. There are no right or wrong answers; we are interested in your personal opinions and experiences. Do not think about questions for a long time, but try to rely on your first reaction. It is no problem if you are not sure about this. Just try to give the answer that *you* think is most suitable. This questionnaire is completely anonymous and the results will not be associated with your name.

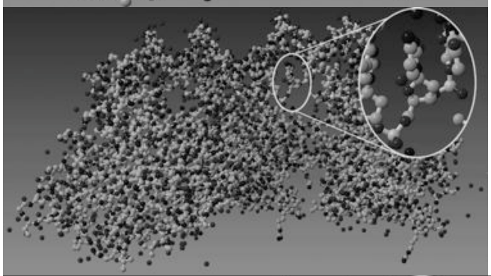
Part I: 3D Visualization tools: Yasara, JMol, Chime

1 I prefer the following 3D view of **a complete protein** structure:

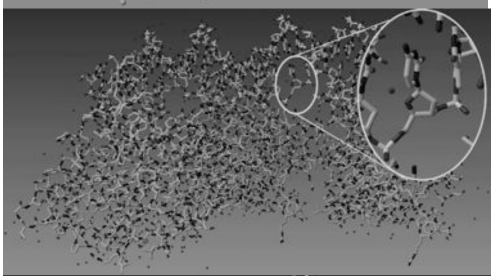
O Balls



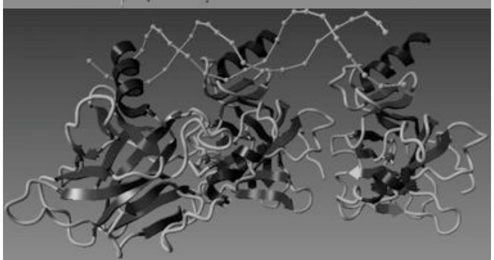
O Balls and sticks (See the enlarged part -->)



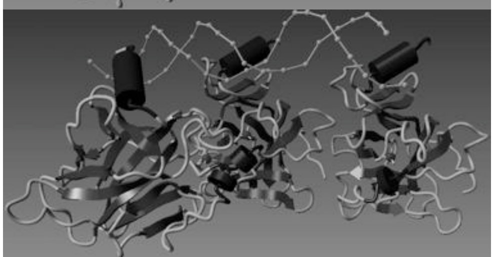
O Sticks (See the enlarged part -->)



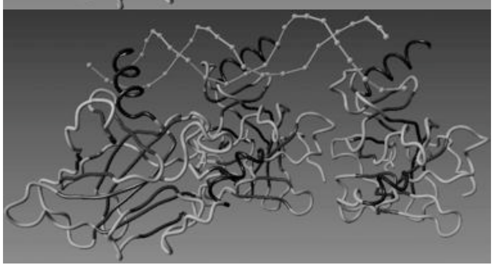
O Ribbon



O Cartoon



O Tube



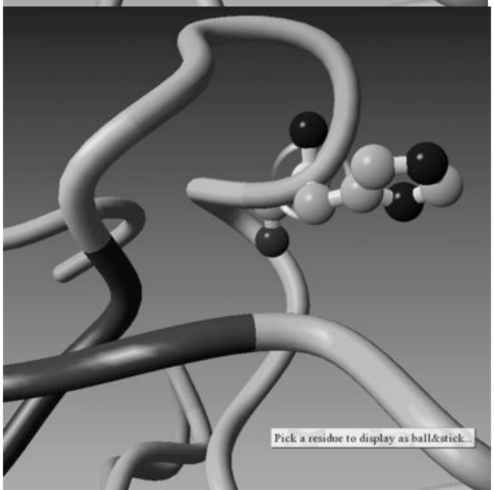
O I have no preference

O It depends on (please specify) ……………………………………………
……………………………………………

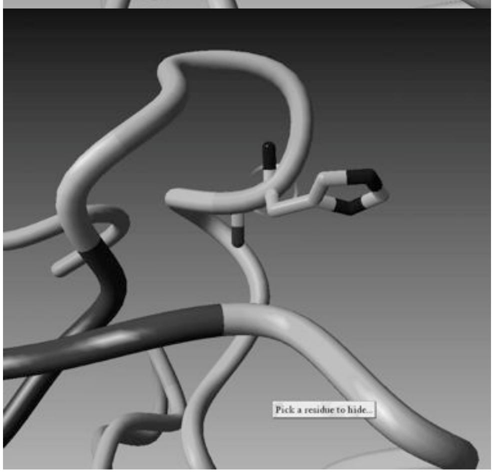
2 I prefer the following 3D view for **a part of a protein** structure:

O Balls

O Balls and sticks



O Sticks



O I have no preference

O It depends on (please specify) ………………………………………….
………………………………………….

3 I often use an option to make only a selection of the protein structure visible.

O disagree strongly O disagree O neutral O agree O agree strongly

4 It is easy to recognize residue's structure in a protein.

O disagree strongly O disagree O neutral O agree O agree strongly

5 I often use several 3D visualization tools (Yasara, Chime, JMol) to get more insight into a molecule.

O disagree strongly O disagree O neutral O agree O agree strongly

6 I often make only the required information of an interesting residue visible (for example, only side chain of the interesting residue).

O disagree strongly O disagree O neutral O agree O agree strongly

7 The 3D structure of a protein gives me information about what the function of a residue is.

O disagree strongly O disagree O neutral O agree O agree strongly

8 The 3D position of a residue in a protein in combination with my background knowledge about the residue always gives me enough information to determine a possible function of a residue.

O disagree strongly O disagree O neutral O agree O agree strongly

9 When I know the position of a residue, I often use additional resources (like access to other databases, Google, etc.) to gain more information about the protein.

O disagree strongly O disagree O neutral O agree O agree strongly

10 When I know the function of an entire protein, I often use additional resources (like access to other databases, Google, etc), to verify my conclusions.

O disagree strongly O disagree O neutral O agree O agree strongly

11 When I know the function of a part of the protein, I often use additional resources (like access to other databases, Google, etc), to verify my conclusions.

O disagree strongly O disagree O neutral O agree O agree strongly

12 I search first for existing information about the protein in sources on the internet before trying to discover more about the protein myself.

O disagree strongly O disagree O neutral O agree O agree strongly

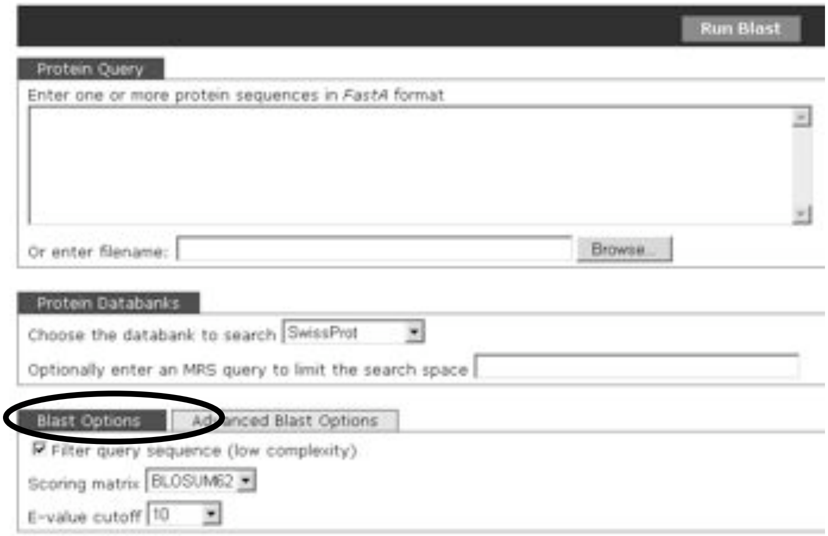
13 I often use an option to hide some irrelevant part of the protein.

O disagree strongly O disagree O neutral O agree O agree strongly

Please write here your extra comments about the about the 3D Visualization tools:

Part II: SRS & MRS

1 I often change search options (e.g. "**Blast options**" for BLAST search, as on the figure below) to optimize my search.



O disagree strongly O disagree O neutral O agree O agree strongly

2 I use the extended query form (for example in SRS to find previous annotations of a protein in order to see the history of this protein annotation, as on the figure below).

O Often
O Sometimes
O Never

3 When I receive results from a tool (e.g. for sequence alignment), I try to change parameters to see how it will influence the results.

O disagree strongly O disagree O neutral O agree O agree strongly

4 The tools often give cross references to other databases with additional information. I often use these cross references to get more information.

O disagree strongly O disagree O neutral O agree O agree strongly

5 When I am not satisfied with the information that I find in the SwissProt database, I use the following additional sources (**more than one option** can be chosen):

O Search engines

O Cross references

O Search manually in other databases

O Knowledge from other students

O Other ……………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

O None

6 When I search for information about a disease related to a protein, I use the following additional sources to get more information (**more than one option** can be chosen).

O Search engines

O Omim cross references

O Other cross references

O Other ……………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

O None

7 When I look for information, the most important to me is:

Rank the options by importance to you (1..3)

( ) O Detailed answers

( ) O Reliable answers

( ) O Non-redundant answers

( ) O Easy-to-use answers (standard format, like Fasta used in ClustalW)

( ) O Well-documented answers (with respect to the traceability of their origin)

8 When I use cross-references, I use the cross reference according to:

Rank the options by importance to you (1..3)

( ) O The kind of information I want to get

( ) O The reliability of the source which is going to provide the data

( ) O The fact that I know whether the cross-reference has been added manually

( ) O The fact that I know whether the cross-reference has been added automatically (e.g. by computer systems)

( ) O Other…………………………………………………………………………..

Comments:

Please write here your extra comments about **MRS&SRS or any other comments**:

You have finished the questionnaire. Thank you very much!

B: Questionnaire Results (Chapter 4)

Question	**Scale**	**Mean / %**	**SD**
Part I. 3D Visualization Tools: Yasara, JMol, Chime			
1. 3D view preference of a complete protein	Mult. choice		
1a. Balls		0%	
1b. Balls and sticks		11%	
1c. Sticks		26%	
1d. Ribbon		**49%**	
1e. Cartoon		4%	
1f. Tube		2%	
1g. No preference		0%	
1h.It depends		8%	
2. 3D view preference of a part of a protein	Mult. choice		
2a. Balls		0%	
2b. Balls and sticks		38%	
2c. Sticks		**62%**	
2d. No preference		0%	
2e. It depends		0%	
3. I often use an option to make a selection of a protein visible	Likert 1-5	3,7	1,0
4. It is easy to recognize residue's structure in a protein	Likert 1-5	2,9	0,9
5. I often use several 3D visualization tools to get more insight into a molecule	Likert 1-5	3,3	1,1
6. I often make only the required information of an interesting residue visible	Likert 1-5	3,8	0,8
7. 3D structure of a protein gives me information about what the function of a residue is	Likert 1-5	3,7	1
8. 3D pos. of a residue in a protein in comb. with my backgr. knowledge about the residue always gives me enough info to determine a possible function of a residue	Likert 1-5	3,0	0,9
9. When I know the pos. of a residue, I often use additional resources to gain more information about the protein	Likert 1-5	3,3	1
10. When I know the function of an **entire protein**, I often use additional resources to verify my conclusions	Likert 1-5	3,3	1,0
11. When I know the function of a **part of the protein**, I often use additional resources to verify my conclusions	Likert 1-5	3,2	1,0
12. I search first for existing info about the protein in sources on the internet before trying to discover more about the protein myself	Likert 1-5	3,3	1,1
13. I often use an option to hide some irrelevant part of the protein	Likert 1-5	3,5	1,0
Part II. SRS & MRS			
1. I often change search options to optimize my search	Likert 1-5	2,7	0,9
2. When I receive results from a tool (e.g. for sequence alignment), I try to change parameters to see how it will	Likert 1-5	2,7	0,8

influence the results			
3. I often use these cross references to get more information	Likert 1-5	3,7	0,8
4. I use the extended query form	Single choice		
4a. Often		23%	
4b. Sometimes		**64%**	
4c. Never		13%	
5. When I am not satisfied with the information that I find in the SwissProt database, I use the following additional sources	Mult. choice		
5a. Search engines		18%	
5b. Cross references		**28%**	
5c. Search manually		15%	
5d. Knowledge from others		19%	
5e. Other		19%	
5f. None		1%	
6. When I search for information about a disease related to a protein, I use the following additional sources to get more information	Mult. choice		
6a. Search engines		30%	
6b. Omim cross references		**40%**	
6c. Other cross references		23%	
6d. Other		5%	
6e. None		2%	
7. When I look for information, the most important to me is	Ranking 1-3		
7a. Detailed answers		19%	
7b. Reliable answers		**40%**	
7c. Non-redundant answers		4%	
7d. Easy-to-use answers		22%	
7e. Well-documented answers		15%	
8. When I use cross-references, I use the cross reference according to	Ranking 1-3		
8a. Kind of information		**48%**	
8b. Reliability of the source		31%	
8c. Cross references added manually		13%	
8d. Cross references added automatically		7%	
8e. Other		1%	

C: Interview Questions (Chapter 7)

Introduction:

When working on a project in a software development team it is difficult to stay aware of each other's activities at all times. The aim of this project is to build and evaluate a visualization tool that can support shared awareness of group development activities. The visualization tool gives an overview of the entire project on a large shared display. It provides awareness of the fellow developers' activities, potential conflict situations, e.g. source files checked out, bugs, code activity etc.

The purpose of this interview is to learn about working practices. The session will take about 35 minutes. Please feel free not to give an answer to a question. We'd like to audio record the interview to assist notes and for research purpose only, if you don't mind. You can stop this interview any time. We promise to protect your privacy at all times. We will also ask you to fill a short survey based on the interview later.

Questions:

Background Information:

Name:________________________

Age:______

Gender: M/F

What is the current project/s you're working on?

Role within this team: DEV/PM/Tester/Doc/Other (Architect/Technical Lead/…)

How long are you working in this team?

Experience (in years): How long are you working in software development teams?

Experience (in years): How long are you working in software development teams?

I. Experience working in co-located team workspace

1. What is your personal experience working in co-located team workspace?
    a. How long have you been working in similar co-located team workspace?
        i. Pros: What do you like about it?
        ii. Cons: What do you miss?
    b. Please describe the other workspace type you are used to work in (if any)?

i. Pros: What do you like about it?

ii. Cons: What do you miss?

II. Working practices

2. What communication modalities do you use to contact your team members?
    a. Ad hoc chats/Email/IM/Phone/LiveMeeting/other
    b. TFS/SharePioint/ /Groove/other
    c. Why do you choose to use one of these tools?
    d. For what purpose? In which case?
    e. What do you miss about them?
3. How do you keep track of what each of what your team members are working on?
    a. What tools / alerts do you use for that?
    b. What do you miss?
4. How often do you meet?
    a. What types of meetings do you have with your team?
        i. Stand-ups
        ii. Iteration planning
        iii. Triage meetings
        iv. Ad hoc meetings
        v. Scrums
        vi. Shipping / war room meetings
    b. How frequently do these meetings occur / at what stage of the project?
    c. How long are they usually taking?
5. Do you use a large display / projector within the team space?
    a. If yes: how? What is usually displayed (what type of meeting)?
    b. If not: why?

6. Do you use a large display/projector only during meetings or in the other setting too?
    a. If yes: how? What is usually displayed?
    b. If not: why?
7. What tools do you use for managing work items/tasks?
    a. TFS/SharePioint/Excel Sheets/Charts/Slides/Groove/other
    b. How do you create/prioritize (time estimate)/assign/reassign work items/tasks?
        i. What types of work items do you work with in your team?

           (bugs/dev tasks/documentation/defect work items/ other)
        ii. How does the type/state of a work item change in this process?

           (open/assigned/fixed/postponed/closed/' burned out'/ other)
8. How do you detect and monitor project's ' health'/ problems ?
    a. State changes (iteration progress) / outstanding bugs?
    b. What is important for your role/ what do you worry about?
9. *How do you handle bugs on daily bases**
10. Is there anything you'd like to add?
    a. A 'wish list': what would you like displayed on the large shared screen that'd help your work?

D: Questionnaire (Chapter 7)

Please do not forget to fill this part in: Thank You!

Age:

Gender: M / F

Role on the team:

On the following pages you will be asked questions about you experiences. There are no right or wrong answers. We are interested in your personal opinions and experiences. Do not think about questions for a long time, but try to rely on your first reaction.
We are interested in your view on their feelings and experiences, so it is no problem if you are not sure about this. Just try to give the answer that *you* think is most suitable.

1 = I strongly disagree
2 = I disagree
3 = I agree nor disagree
4 = I agree
5 = I strongly agree

Part I.

1. Team members work together very well.

Strongly disagree	1	2	3	4	5	Strongly agree

2. There are disruptive conflicts.

Strongly disagree	1	2	3	4	5	Strongly agree

3. Comments reflect respect for one another.

Strongly disagree	1	2	3	4	5	Strongly agree

4. Team members get bogged down in petty arguments.

Strongly disagree	1	2	3	4	5	Strongly agree

5. The teamwork process is not satisfying.

Strongly disagree	1	2	3	4	5	Strongly agree

6. Team members reach agreement.

Strongly disagree	1	2	3	4	5	Strongly agree

7. I dislike the discussion or interaction processes used by my team.

Strongly disagree	1	2	3	4	5	Strongly agree

8. People are friendly on my team.

Strongly disagree	1	2	3	4	5	Strongly agree

9. The quality of my own contributions to group discussions is very good.

Strongly disagree	1	2	3	4	5	Strongly agree

10. The general quality of the team members' contributions to group discussions is very good.

Strongly disagree	1	2	3	4	5	Strongly agree

11. The evaluation of arguments is very thorough.

Strongly disagree	1	2	3	4	5	Strongly agree

12. Team members bring a variety of perspectives to bear on the tasks.

Strongly disagree	1	2	3	4	5	Strongly agree

13. The team discussions are unorganized.

Strongly disagree	1	2	3	4	5	Strongly agree

14. Important criticism is often ignored.

Strongly disagree	1	2	3	4	5	Strongly agree

15. Team discussion procedures are clear.

Strongly disagree	1	2	3	4	5	Strongly agree

16. I participate extensively in the decision making processes of my group.

Strongly disagree	1	2	3	4	5	Strongly agree

17. I am able to evaluate a number of alternatives during the decision making sessions.

Strongly disagree	1	2	3	4	5	Strongly agree

18. I believe my contribution to be significant in helping our team to arrive at final decisions.

Strongly disagree	1	2	3	4	5	Strongly agree

19. I do not rush to provide my solutions to the team.

Strongly disagree	1	2	3	4	5	Strongly agree

20. I am not rushed by others in team discussion sessions.

Strongly disagree	1	2	3	4	5	Strongly agree

21. Overall, as a member of our team, I am satisfied with the process I employed in arriving at the final decision.

Strongly disagree	1	2	3	4	5	Strongly agree

22. Overall, I am satisfied with the solution process our team employs to arrive at final decisions.

Strongly disagree	1	2	3	4	5	Strongly agree

Part II.

1. I had difficulty understanding WIPDash.

Strongly disagree	1	2	3	4	5	Strongly agree

2. WIPDash is easy to use.

Strongly disagree	1	2	3	4	5	Strongly agree

3. WIPDash is reliable.

Strongly disagree	1	2	3	4	5	Strongly agree

4. I have confidence in the the information provided by WIPDash.

Strongly disagree	1	2	3	4	5	Strongly agree

5. I I need more training to understand WIPDash.

Strongly disagree	1	2	3	4	5	Strongly agree

6. I find the information provided by WIPDash isformative.

Strongly disagree	1	2	3	4	5	Strongly agree

7. The information provided by WIPDash is comprehensible.

Strongly disagree	1	2	3	4	5	Strongly agree

8. Overall, I am satisfied with WIPDash.

Strongly disagree	1	2	3	4	5	Strongly agree

9. I would be happy to use WIPDash in the future.

Strongly disagree	1	2	3	4	5	Strongly agree

10. I found WIPDash distracting.

Strongly disagree	1	2	3	4	5	Strongly agree

11. WIPDash grabs my attention at the right times.

Strongly disagree	1	2	3	4	5	Strongly agree

12. It's worth giving up the screen space to run WIPDash.

Strongly disagree	1	2	3	4	5	Strongly agree

13. WIPDash interrupts me when I'm trying to do other work.

Strongly disagree	1	2	3	4	5	Strongly agree

14. WIPDash helps me stay aware of information that's critical for me to keep track of.

Strongly disagree	1	2	3	4	5	Strongly agree

15. I like being notified by WIPDash, e.g., when a work items has been reassigned.

Strongly disagree	1	2	3	4	5	Strongly agree

16. WIPDash's notifications often distract me from doing important work.

Strongly disagree	1	2	3	4	5	Strongly agree

17. Having WIPDash displayed in front of the team was embarrassing.

Strongly disagree	1	2	3	4	5	Strongly agree

18. I would rather have WIPDash displayed only privately.

Strongly disagree	1	2	3	4	5	Strongly agree

19. I found the following WIPDash view modes useful (*please explain when and for what purpose*).

- o Iteration overview ____
- o Opened in last 24 hours ____
- o Changed in last 24 hours _______________________________________
- o Sticky notes____
- o Other: (All, Unassigned, Person view)______________________________
- o None, because____

20. I found the following WIPDash filtering features useful (*please explain when and for what purpose*).

- o Iteration ____
- o Category (Feature, Bug, Spike etc.)_________________________________
- o State (Active, Closed, Resolved, Proposed)___________________________
- o Other:____
- o None, because____

21. I interacted with WIPDash (please explain with what view modes and for what purpose)
    - On the large display ____
    - On my own PC ____
    - Not at all, because____

22. I liked about WIPDash (please explain why, what view modes you liked and for what purpose)

____

____

____

23. I disliked about WIPDash (please explain why, what do you miss)

____

____

____

Extra comments:

You have finished the questionnaire. Thank you very much!

E: Glossary of Terms I

Awareness is the ongoing interpretation of representations of human activity and of artefacts (Chalmers, 2002).

Collaborative working environment is a collocated shared workspace that facilitates groups during meetings. The workspace is enhanced with multiple collaborative systems and media, such as private and shared displays, tabletops, touch screens, cameras and other devices.

Extreme collaboration refers to working within war room environments where teams work together synchronously in all phases using a variety of computer technologies to maximize communication and information flow.

Group awareness is the understanding of *who* you are working with, *what* is being worked on, and *how* your actions affect others, is essential to effective collaboration [Dourish and Bellotti, 1992].

Microarray experiment examines simultaneously the expression level of all genes of a specific organism, in a cell type in a specific growth or stress condition. Microarray technology is currently one of the most important methods in genomics and is usually applied to unravel complex cellular mechanisms or discover transcriptomics biomarkers: genes whose expression profile can be used for diagnostic purposes or to monitor and predict cellular processes [Stekel, 2003].

Omics experimentation is a research area in molecular biology that deals with omes: large or complete arrays of cell components, such as the genome (all genes) and the proteome (all proteins). For example, studies that encompass the whole genome are in general referred to as genomics studies, and studies that examine the expression level of all mRNAs (messenger RNA, which directs the synthesis of proteins) in a given cell population are called transcriptomics.

Peripheral awareness display is an information system or a graphical representation that resides in the user's environment and provides information or visual feedback in the periphery of the user's attention. Monitoring the peripheral display causes minimal shift from the user's current focus of attention, allowing users to garner information without being distracted from their primary task [Plaue et al., 2004].

Situational awareness is the perception of the elements of the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future, and the prediction of how various actions will affect the fulfilment of one's goals [Endsley, 1995, p.36].

Shared situational awareness is a reflection of how similar team members view a given current environmental situation. Thus, if a team has a high degree of shared situational awareness, one can assume they are perceiving, comprehending, and interpreting the situation's information requirements in a similar manner [Bolstad et al., 2005, p.1].

Task analysis is a domain-specific analysis of the current work situation, which combines such classical HCI techniques as contextual interviews, field observations, ethnography and interaction analysis [Jordan, 1996; van Welie and van der Veer, 2003].

F: Glossary of Terms II

Agents are individuals, groups, or systems, which take part and play certain *roles* in a work process.

Roles indicate certain subsets of *tasks* that can be performed by classes of *agents* to whom *the role is* allocated. More than one agents may perform the same role, and a single agent may have several roles at the same time.

Tasks is an activity performed to reach a certain *goal*. The distinction is made between (1) the *unit tasks*: the lowest task level that people consider in their work; and (2) the *basic task*: the atomic level of task delegation that is defined by the tool used in performing work. Several tasks can share the same goals, and complex tasks may be split up between *agents* or *roles*.

Goal is a desired state in the system or task world.

Actions can really be understood only in frame of a corresponding task, as they derive their meaning from the task. *Unit tasks* and *basic tasks* may be decomposed further into *user actions* and *system actions*. Actions

Events are things that happen in the task world, over which the *agent* does not always have direct control, and are used to model external dynamic aspects of the task. An event indicates a triggering condition for a task, even if the triggering could be caused by something outside the considered task domain.

Task environment is the current situation for the performance of a certain *task*. It includes *agents* with *roles* as well as conditions for task performance. The history of past relevant *events* in the task situation is part of the actual environment if this features in conditions for task execution.

Organization refers to the relation between *agents* and *roles* in respect to *task* allocation. Delegation and mandating responsibilities from one *role* to another is part of the organization.

Objects are the essential items that are used, modified or created by tasks. Objects can be owned by agents playing a certain *role*. Different roles have different rights in relation to different objects: create delete change inspect, etc. Objects may be physical things, or conceptual (non-material) things like messages, gestures, passwords, stories, or signatures (e.g. in microarray analyzes the software and visualizations used). Objects are used as an input and output when agents perform certain roles.

Workflow model is used to model external dynamic aspects of the *task*. Workflow model is used to show work in relation to time and *roles*, which tasks are performed and how different people are involved in them. It can show how people work together and communicate by exchanging *objects* or messages. Typically, a *workflow model* describes a small scenario involving one or more roles.

G: Observation coding scheme (Chapter 7)

Category	Classification
Communication	Advice
	Agreement
	Orientation/understand
	Collaboration request
	Disagreement
	Information/Bottleneck
	Disagreement
	Status
	Other
Shared display use	Load information
	Hook personal device
	Transfer control
	Visual scan
	TFS (Team Foundation Server) Reference
Collaboration type	Co-located/Visible (with shared visual workspace)
	Co-located /Not Visible (without shared visual workspace)
	Distributed
Collaboration configuration	Multiple personal devices
	Single device, single control
	Single device, shared control
	Shared display only
	Shared and personal devices used

H: Observation Protocol Train-of-Thoughts (TX Lab, Enschede)

Group(I/II):________ Condition: (Y/N)____________ Observer:________________

Train-of-Thoughts (T-O-T) Awareness Support for Group Decision Making in Multidisplay Environments

Research Goal: Measure the effect of shared awareness visualisation on: a) *team situational awareness* and b) satisfaction with the *group decision making* process in a multi-display environment

1 Observer:
Observer will be taking notes on the group behavior (dynamics, turn-taking, attention to the displays) and the use of the display and the T-O-T interface. An observer will switch tables and observe instances of **30 minutes in Y and N condition per each group**.

Observation Categories: *Please note the condition (Y/N)!!! (and the time stamp for the video syncing)*

- Warming-up:
- Group dynamics (turn-taking):
- Dominance:
- Attention (group members: active?):
- Awareness (attention to vertical/ horizontal display / laptop):
- Group strategy (ranking):
- T-O-T:
- Problems (lab setting, T-O-T):
- Other:

Lab Setting

This experiment will take place in VR-Lab (TXchange Cell). The Train-of-Thoughts interface will be projected on the right vertical projection display.

In case of **N** (**Without Train-of-Thoughts** interface), only MindMap, Carousel game and Sketching will be used.

In case of **Y** (**With Train-of-Thoughts** interface) participants will be given a sign (reminder from the Facilitator) to fill in the mid-results (2 times) of the discussion the group find most important via Train-of-Thoughts (T-O-T) interface, and the end results (1 time – 3 best ideas). MindMap, Carousel game and Sketching will be used as in the N condition.

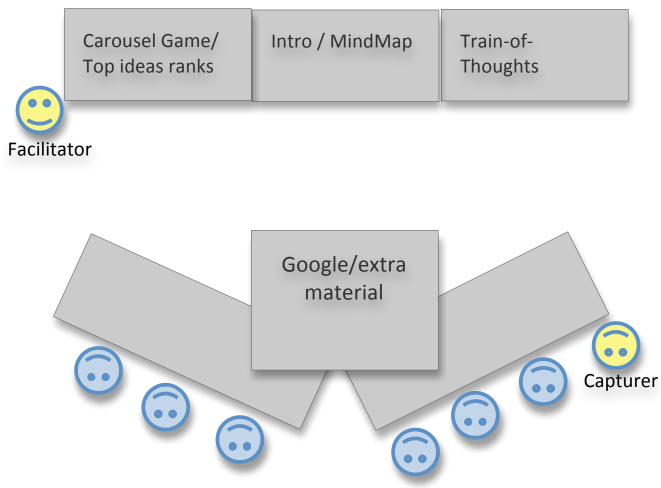


Figure 1. Screen space and sitting arrangement, T-Xchange Lab (University of Twente, Enschede, The Netherlands)

I: Train-of-Thoughts Questionnaire Outline

The purpose of this questionnaire is to access the perceived *group process* quality and *satisfaction* with the *decision making process* (A, B). An additional set of questions (c) addresses participants' subjective judgments about *satisfaction with and usefulness* of the 'Train-of-Thoughts' interface (including distraction and awareness).

Part I. Post-questionnaire 'Train-of-Thoughts' *(using 5-point Likert-scale: where '1' means 'Strongly agree' and '5' – 'Strongly disagree')*

A. Group process [Olaniran, 1996]
1. Team members work very well together.
2. There are disruptive conflicts.
3. Comments reflect respect for one another.
4. Team members get bogged down in petty arguments.
5. The teamwork process is not satisfying.
6. Team members reach agreements.
7. I dislike the discussion or interaction process.
8. People are friendly.
9. The quality of my own contributions to the discussions is very good.
10. The general quality of the team members' contributions is very good.
11. The evaluation of arguments is very thorough.
12. Team members bring a variety of perspectives to bear on the tasks.
13. The discussions are unorganized.
14. Important criticism is ignored.
15. Discussion procedures are clear.

B. Satisfaction with decision making process [Paul et. al., 2004] + *1 *additional question*
1. I participate extensively in the decision making process.
2. I am able to evaluate a number of alternatives during the decision making sessions.
3. I believe my contribution to be significant in our team arriving at final decisions.
4. I do not rush to provide my solutions.
5. I am not rushed by others in the discussion sessions.
6. Overall, as a member of our team, I am satisfied with the process I employ in arriving at final decisions.
7. Overall, I am satisfied with the solution process our team employs to arrive at final decisions.
8. *Overall, I am satisfied with the final decision of the group, in relation to my personal preference.

*Total: 23 questions; *-extra question*

Part II. Post-questionnaire 'Train-of-Thoughts' *(using 5-point Likert-scale: where '1' means 'Strongly agree' and '5' – 'Strongly disagree', and some multiple choice questions at the end)*

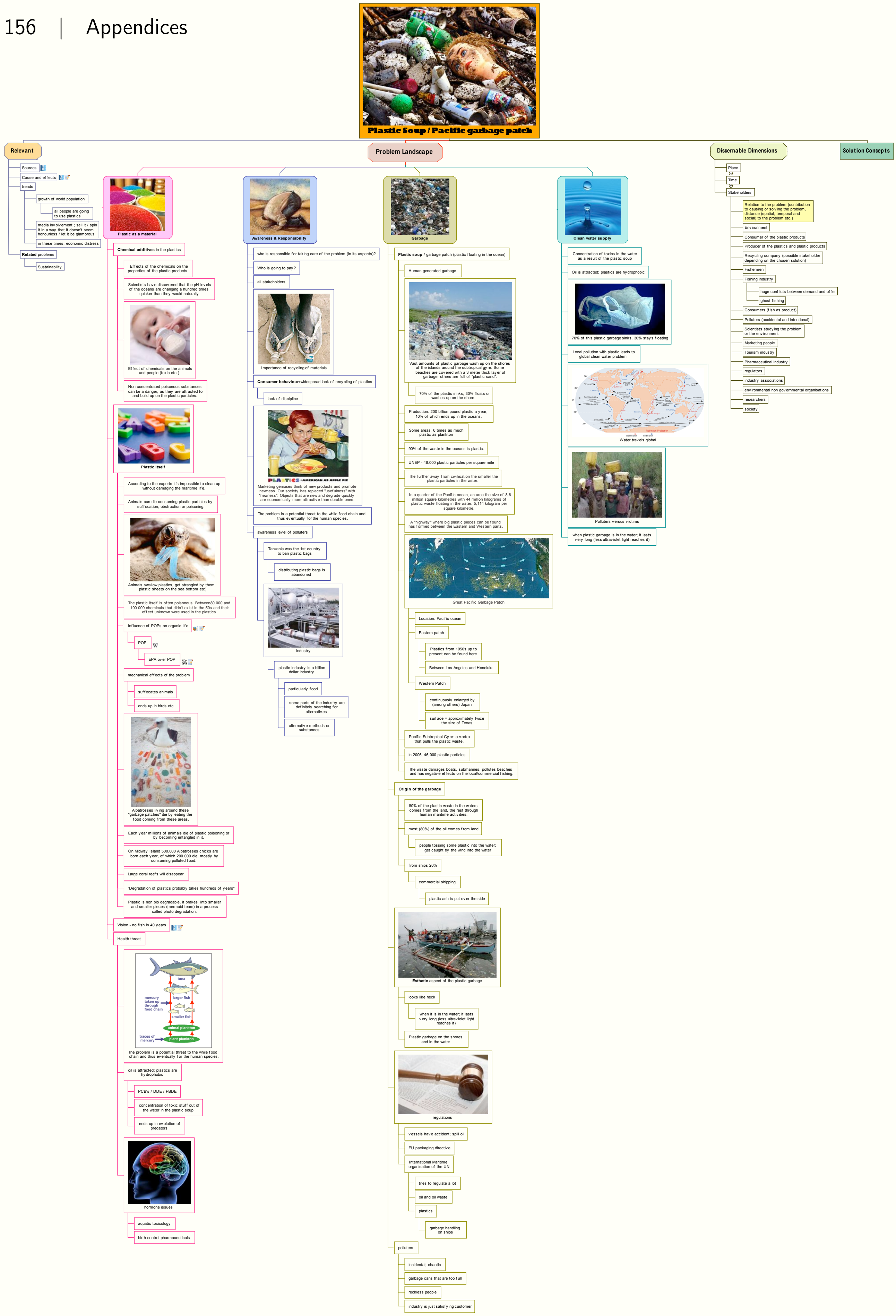
C. Satisfaction with system [Paul et. al., 2004]
1. I have difficulty understanding the Train-of-Thoughts interface.
2. The Train-of-Thoughts interface is easy to use.

3. The Train-of-Thoughts interface is reliable.
4. I have confidence in the information provided by the Train-of-Thoughts interface.
5. I need more training to understand the Train-of-Thoughts interface.
6. I find the information provided by the Train-of-Thoughts interface informative.
7. The information provided by the Train-of-Thoughts interface is comprehensible.
8. Overall, I am satisfied with the Train-of-Thoughts interface.
9. I would be happy to use the Train-of-Thoughts interface in the future.

Awareness and Distraction [Cadiz et al., 2002; Kulyk et al., 2006] + **additional question*

1. I find the Train-of-Thoughts interface distracting.
2. The Train-of-Thoughts interface helped to grab my attention at the right times.
3. The Train-of-Thoughts interface interrupted me during the group discussion.
4. The Train-of-Thoughts interface helped me to stay aware of information that's critical for me to keep track of during the discussion.
5. The Train-of-Thoughts interface helped me stay aware of the discussion process.
6. I would rather have the Train-of-Thoughts interface displayed only p*rivately*.
7. * I found the following features of the Train-of-Thoughts interface useful (*please explain when and for what purpose*): adding an image, adding the text, Train-of-Thoughts , other, none
8. * I prefer to interact with the Train-of-Thoughts interface (*please explain when and for what purpose*): on the vertical projection display, on the individual Tablet PC, via other means (e.g. gestures, speech, etc.)
9. * Things I liked about the Train-of-Thoughts interface (*please explain why, what you liked and for what purpose would you use it*)
10. * Things I disliked about the Train-of-Thoughts interface (*please explain why, what do you miss*)

*Total: 9 +10=19 questions; *-extra question*



Plastic Soup / Pacific garbage patch
Relevant
Sources
Cause and effects
trends
growth of world population
all people are going to use plastics
media involvement ; sell it / spin it in a way that it doesn't seem honourless / let it be glamorous
in these times; economic distress
Related problems
Sustainability
Problem Landscape
Plastic as a material
Chemical additives in the plastics
Effects of the chemicals on the properties of the plastic products.
Scientists have discovered that the pH levels of the oceans are changing a hundred times quicker than they would naturally
Effect of chemicals on the animals and people (toxic etc.)
Non concentrated poisonous substances can be a danger, as they are attracted to and build up on the plastic particles.
Plastic itself
According to the experts it's impossible to clean up without damaging the maritime life.
Animals can die consuming plastic particles by suffocation, obstruction or poisoning.
Animals swallow plastics, get strangled by them, plastic sheets on the sea bottom etc)
The plastic itself is often poisonous. Between80.000 and 100.000 chemicals that didn't exist in the 50s and their effect unknown were used in the plastics.
Influence of POPs on organic life
POP
EPA over POP
mechanical effects of the problem
suffocates animals
ends up in birds etc.
Albatrosses living around these "garbage patches" die by eating the food coming from these areas.
Each year millions of animals die of plastic poisoning or by becoming entangled in it.
On Midway Island 500.000 Albatrosses chicks are born each year, of which 200.000 die, mostly by consuming polluted food.
Large coral reefs will disappear
"Degradation of plastics probably takes hundreds of years"
Plastic is non bio degradable, it brakes into smaller and smaller pieces (mermaid tears) in a process called photo degradation.
Vision - no fish in 40 years
Health threat
tuna
larger fish
smaller fish
mercury taken up through food chain
animal plankton
plant plankton
traces of mercury
The problem is a potential threat to the while food chain and thus eventually for the human species.
oil is attracted; plastics are hydrophobic
PCB's / DDE / PBDE
concentration of toxic stuff out of the water in the plastic soup
ends up in evolution of predators
hormone issues
aquatic toxicology
birth control pharmaceuticals
Awareness & Responsibility
who is responsible for taking care of the problem (in its aspects)?
Who is going to pay?
all stakeholders
Importance of recycling of materials
Consumer behaviour: widespread lack of recycling of plastics
lack of discipline
PLASTICS - AMERICAN AS APPLE PIE
Marketing geniuses think of new products and promote newness. Our society has replaced "usefulness" with "newness". Objects that are new and degrade quickly are economically more attractive than durable ones.
The problem is a potential threat to the while food chain and thus eventually for the human species.
awareness level of polluters
Tanzania was the 1st country to ban plastic bags
distributing plastic bags is abandoned
Industry
plastic industry is a billion dollar industry
particularly food
some parts of the industry are definitely searching for alternatives
alternative methods or substances
Garbage
Plastic soup / garbage patch (plastic floating in the ocean)
Human generated garbage
Vast amounts of plastic garbage wash up on the shores of the islands around the subtropical gyre. Some beaches are covered with a 3 meter thick layer of garbage, others are full of "plastic sand".
70% of the plastic sinks, 30% floats or washes up on the shore.
Production: 200 billion pound plastic a year, 10% of which ends up in the oceans.
Some areas: 6 times as much plastic as plankton
90% of the waste in the oceans is plastic.
UNEP - 46.000 plastic particles per square mile
The further away from civilisation the smaller the plastic particles in the water.
In a quarter of the Pacific ocean, an area the size of 8,6 million square kilometres with 44 million kilograms of plastic waste floating in the water: 5,114 kilogram per square kilometre.
A "highway" where big plastic pieces can be found has formed between the Eastern and Western parts.
Canada
Japan
U.S.A.
Great Pacific Garbage Patch
Location: Pacific ocean
Eastern patch
Plastics from 1950s up to present can be found here
Between Los Angeles and Honolulu
Western Patch
continuously enlarged by (among others) Japan
surface = approximately twice the size of Texas
Pacific Subtropical Gyre: a vortex that pulls the plastic waste.
in 2006, 46,000 plastic particles
The waste damages boats, submarines, pollutes beaches and has negative effects on the local/commercial fishing.
Origin of the garbage
80% of the plastic waste in the waters comes from the land, the rest through human maritime activities.
most (80%) of the oil comes from land
people tossing some plastic into the water; get caught by the wind into the water
from ships 20%
commercial shipping
plastic ash is put over the side
Esthetic aspect of the plastic garbage
looks like heck
when it is in the water; it lasts very long (less ultraviolet light reaches it)
Plastic garbage on the shores and in the water
regulations
vessels have accident; spill oil
EU packaging directive
International Maritime organisation of the UN
tries to regulate a lot
oil and oil waste
plastics
garbage handling on ships
polluters
incidental, chaotic
garbage cans that are too full
reckless people
industry is just satisfying customer
Clean water supply
Concentration of toxins in the water as a result of the plastic soup
Oil is attracted; plastics are hydrophobic
70% of this plastic garbage sinks, 30% stays floating
Local pollution with plastic leads to global clean water problem
Robinson Projection
Water travels global
Polluters versus victims
when plastic garbage is in the water; it lasts very long (less ultraviolet light reaches it)
Discernable Dimensions
Place
Time
Stakeholders
Relation to the problem (contribution to causing or solving the problem, distance (spatial, temporal and social) to the problem etc.)
Environment
Consumer of the plastic products
Producer of the plastics and plastic products
Recycling company (possible stakeholder depending on the chosen solution)
Fishermen
Fishing industry
huge conflicts between demand and offer
ghost fishing
Consumers (fish as product)
Polluters (accidental and intentional)
Scientists studying the problem or the environment
Marketing people
Tourism industry
Pharmaceutical industry
regulators
industry associations
environmental non governmental organisations
researchers
society
Solution Concepts

K: Train-of-Thoughts Experiment: Participants Info

Dear all,

Thank you for your willingness to participate in a user study on visual awareness support for large display environments.

The topic of our discussion for tomorrow will be a problem of Plastic Soup. Enclosed you will find detailed information on the topic and whereabouts. We start at **9:00** o'clock **sharp**.

Date: **Wednesday, June 3**
When: **9:00-12:00**
Where: **TXchange Cell - De Horst** (WH224) : Enter **De Horst** building from the **left entrance**, take the stairs and follow '**TXchange cell'** signs.

See the **route attached!**

We will introduce you into the subject of Plastic Soup, into the interactive discussion support technology which will be used during the session and there is possibility to meet and discuss with the other discussion participants.

The entire session will be in English. During the session we will discuss the Plastic Soup problem along four perspectives:

1. **Plastic as a material**

   • Chemical additives in plastics are toxic: influence on organic life throughout the food chain: huge health threat
   • Plastic doesn't biodegrade very well
   • When plastic is in the water it lasts very long (less ultraviolet light)
   • A large number of substances of which we do not know the long-term effects
   • Huge powerful industry

2. **Garbage**

   • Human generated garbage (think of bottles, plastic bags, etc.)
   • On the islands around the subtropic gyre a lot of garbage washes ashore (beaches filled with 3 mtr garbage, plastic sand on beaches)
   • Effects on ecology: pollution, food-chain, hormones
   • Widespread lack of recycling of plastics
   • Damage to animals, boats, fishing industry
   • Small particles cannot be "fished out

Information on the issue of Plastic Soup:

http://www.plasticsoep.nl
http://www.plasticsoup.org
http://science.howstuffworks.com/great-pacific-garbage-patch-sources.htm

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Summary

Modern collaborative environments often provide an overwhelming amount of visual information on multiple displays. In complex project settings, the amount of visual information on multiple displays, and the multitude of personal and shared interaction devices in these environments can reduce the awareness of team members on ongoing activities, the understanding of shared visualisations, and the awareness of who is in control of shared artefacts. Research reported in this thesis addresses the situational awareness (SA) support of co-located teams working on team projects in multidisplay environments.

Situational awareness becomes even more critical when the content of multiple displays changes rapidly, and when these provide large amounts of information. This work aims at getting insights into design and evaluation of shared display visualisations that afford situational awareness and group decision making.

This thesis reports the results of three empirical user studies in three different domains: life science experimentation, decision making in brainstorming teams, and agile software development. The first and the second user studies evaluate the impact of the Highlighting-on-Demand and the Chain-of-Thoughts SA on the group decision-making and awareness. The third user study presents the design and evaluation of a shared awareness display for software teams. Providing supportive visualisations on a shared large display, we aimed at reducing the distraction from the primary task, enhancing the group decision-making process and the perceived task performance.

Part I focuses on the theory of situational awareness (SA). Chapter 2 gives an overview of the related studies on team collaboration and situational awareness support. We discuss how to afford situational awareness in scientific teams and present an overview of the state of the art on evaluation of visualisations in multidisplay environments. Part I also presents an overview of the related work on the role of shared large displays in supporting situational awareness.

Part II starts with an introduction of the three domains in which we performed empirical user studies presented in Part III. Chapter 4 presents the results of an exploratory user study and requirements elicitation in the first, life science experimentation domain. In situ observations, questionnaires and interviews with life scientists of different levels of expertise and various backgrounds were carried out in order to gain insight into their needs and working practices. The analyzed results are presented as a user profile description and user requirements for designing user interfaces that support situational awareness and group decision making in co-located multi-display environments. Life sciences is used as an example domain in this study. In chapter 4 we also discuss the results of the task analysis study describing the current

collaboration practices in life science experimentation.

The outcome of the requirements elicitation and the task analysis studies leads to the discussion of three new concepts for SA support, namely (**1**) *Highlighting-on-Demand*, (**2**) *Chain-of-Thoughts*, and (**3**) *Control Interface*. The purpose of these concepts is to explore various alternative solutions for SA support in multidisplay environments to enhance group decision making and to facilitate co-located group discussions.

Part III presents the results of the three empirical user studies in different domains, aimed at fostering *shared* situational awareness and accessing the effect of situational awareness support on team decision making and group process in co-located multidisplay environments.

Chapter 5 discusses the results of the first empirical user study on the effect of the Highlighting-on-Demand concept on the group decision-making process. The Highlighting-on-Demand interface enables a team member who is currently controlling the shared display to draw attention of the other team members by highlighting a certain visualisation using a touch display. The results show that when group members used the Highlighting-on-Demand interface during the discussion, the satisfaction with the final group decision increased.

Then, chapter 6 presents the results of the second empirical user study on evaluation of the Chain-of-Thoughts concept that enables group members to capture, summarise and visualise the history of ideas on a shared display to provide an awareness on the group decision making progress and status. Participants liked the fact that the awareness visualisation enables the group to summarize the enormous set of brainstorming ideas to general important solutions. The results indicate that the Chain-of-Thoughts visualisation presented on a shared large display had a positive influence on the participants' satisfaction with their contribution to the final group decision, and with some of the aspects of the group process and decision making. Team members reported that interacting via a shared display was beneficial for the awareness of the group about what is actually being put into the shared Chain-of-Thoughts visualisation.

In chapter 7 we discuss the results of the design and evaluation of an Awareness Display (WIPDash – Work Item and People Dashboard) of software teams' activities and project progress were discussed. This chapter includes **(1)** detailed findings about how software developers maintain awareness of ongoing team activities using existing techniques and tools, **(2)** a novel awareness visualisation based on developers' needs. The results of the study suggest benefits from providing awareness of teams' activities and project progress and give insights into the use of a shared display to support software teams' collaboration.

Finally, we present general conclusions, design implications for large display applications and visualisations for situational awareness support, and future work directions. We also discuss challenges in evaluation of merging collaborative workspaces.

List of Publications

Kulyk, O., de Kler, T., Leeuw, W., Veer, G. C., Dijk, E.M.A.G. Staying focused: Highlighting-on-Demand as situational awareness support for groups in multidisplay environments. In: *Human Aspects of Visualization*, A. Ebert, A. Dix, N. Gershon and M. Pohl., editors, Lecture Notes in Computer Science, volume 5727. Springer Berlin, 2010, *accepted for publication*.

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"Out of the strain of the doing, into the peace of the done."
–Julia Louis Woodruff

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