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Information Sharing Tools and Behavior in Collaborative Human-Centered Design Teams

By

Lora Ann Oehlberg

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

In

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in the

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of the

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Committee in Charge:

Professor Alice M. Agogino, Co-Chair

Professor Sara L. Beckman, Co-Chair

Professor Dennis Lieu

Professor Björn Hartmann

Fall 2012

Information Sharing Tools and Behavior in Collaborative Human-Centered Design Teams
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By
Lora Ann Oehlberg

Abstract

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By

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Doctor of Philosophy in Mechanical Engineering

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Developing innovative products and services benefits from collaboration within multidisciplinary design teams. Design teams gather and generate large quantities of data, including user research, information on competing products and applicable technologies, and new design ideas; however, teams often struggle to synthesize this diverse design information. Collaboration can break down if they cannot form a shared understanding of the design problem. This dissertation examines current design practices to construct theoretical models of the design process and to develop new tools to help design teams create, communicate, and collaborate. It explores how information tools are used to support collaborative design processes, and suggests forms for future tools. It presents a series of qualitative research studies, i.e., survey and interviews with professional and student designers as well as observations of face-to-face student design team meetings. The analysis of surveys and interviews with professional designers offer a descriptive characterization of how design teams use technology to share information with each other in practice. These studies also inform a new conceptual framework—the *sharing spiral*— that describes how information is shared throughout individual and collaborative design tasks, across user research and conceptual design phases. With this new framework guiding qualitative analysis of observations of face-to-face student design team meetings, nine challenges to information sharing are identified. This dissertation proposes design guidelines for new design collaboration technology, based on these challenges. Finally, it applies these guidelines to a new system, *Dazzle*. *Dazzle* is an information sharing tool for face-to-face design teams that allows teammates to share, log, and annotate shared design resources. This dissertation offers a new understanding of information sharing in design practice, and has implications for improving design practice and the development of future design tools.

For my brothers
Mark & Dan

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CHAPTER 1

INTRODUCTION

INTRODUCTION

The increasing complexity of today's engineering challenges require cross-functional collaborative design teams that follow a human-centered approach to design. For example, the Engineering Grand Challenges for the twenty-first century identified by the National Academy of Engineering (National Academy of Engineering 2008) include many challenges that require synthesizing technological innovations with insight into human behavior, culture, and society, such as *managing the nitrogen cycle*, *advancing health informatics*, and *advancing personalized learning*. A single designer does not have the expertise to fully understand both the technological and human dimensions of these challenges alone; these challenges must be taken on by a team. Indeed, team efforts are more likely to lead to innovations than individual efforts (Hargadon 2003), and companies thus rely on cross-functional teams to draw on a range of expertise to develop new innovations (Denison, Hart, and Kahn 1996). One type of complex work addressed by cross-disciplinary teams is *human-centered design*; designers employ human-centered methods to investigate and understand the social factors that influence technology design, and incorporate this understanding of people into the development of technical solutions. This improves the chances that the designed solution will address user needs, and reduces the product's risk of failure in the marketplace.

These cross-functional teams using the human-centered design process face the challenge of managing collaborative design work, as they must process a considerable amount of new information throughout the design process. Teams must gather and understand information about the rapidly changing problem space in order to address it—these types of problems are exemplified by volatility, uncertainty, complexity, and ambiguity (Johansen 2007). Collaborative design is also a social process (Bucciarelli 1994) performed through interpersonal interactions. New information is continually brought into the team, including user research, market research on competitor's products, information about applicable technologies, or new design ideas. As this information is introduced to the team, the team must socialize that information within the team and re-establish a shared understanding of the design problem. From there the team can make design decisions and re-strategize how it should proceed in the design process. Thus, design work is simultaneously driven by and hindered by the amount of information brought into the team.

Technology plays an important role in helping teams manage design information and mediate shared understanding. Traditional design methods and practices evolved to rely on physical information in paper form; however, digital information technology offers new, more powerful ways to create, manage,

and share design information. Designers incorporate quantitative and qualitative information in their designs, including market research, user and stakeholder interviews, background on existing technologies or competing products, new design concepts, and technical calculations for implementation. With both physical and digital sources of design information, it is important to understand how designers interact with technologies during collaborative design in order to develop new tools that help design teams create, communicate, and collaborate.

This dissertation explores how information tools are used to support collaborative design processes, and suggests guidelines for the design of future tools. It presents a conceptual framework that characterizes how design teams use information tools in practice and describes information sharing throughout individual and collaborative design contexts. This framework was developed through an analysis of interviews with professional and student designers and a survey of professional designers. This conceptual framework was then applied to observations of face-to-face team meetings in order to identify challenges that teams face when sharing and manipulating individuals' information as a team. Based on these research findings, a series of design guidelines are proposed for developing collaborative design tools that support information sharing in early stage design. Finally, these guidelines are implemented and evaluated via *Dazzle*, an information sharing tool designed based on these principles to facilitate face-to-face design teams to share, log, and annotate their shared design resources.

MOTIVATION

This dissertation focuses on how technology is used to support **human-centered design** as it is enacted by **cross-functional teams** during **new product development**. This section examines each of these elements individually.

NEW PRODUCT DEVELOPMENT

This dissertation focuses on new product development, which often “involve[s] radically different product or production technologies and may help address new and unfamiliar markets” (Ulrich and Eppinger 2011). Radical innovations are a greater departure from existing technologies and, therefore, higher-risk (Hage 1980).

There are many models that describe the new product development process. Some models are more cyclic, describing the iterative nature of design. One example of a cyclic model is Beckman and Barry's Innovation Process (Beckman and Barry 2007) (Figure 1), which has been adapted from design process models (Owen 1998) and experiential learning (Kolb 1984) to apply to the design process; this reflects the iterative nature of design thinking and designers' experiential engagement with design practice. In this model, designers transition from analysis to synthesis while cycling through abstract and concrete ways of thinking about the world. Other models focus more on describing how the design process unfolds over time. For example, Ulrich and Eppinger's model of the front-end market-pull product development process (2011) (Figure 2) describes a series of stage-gates (Cooper 1990) that continue the development of the product over time; this model also includes references back to iterate through previous stages.

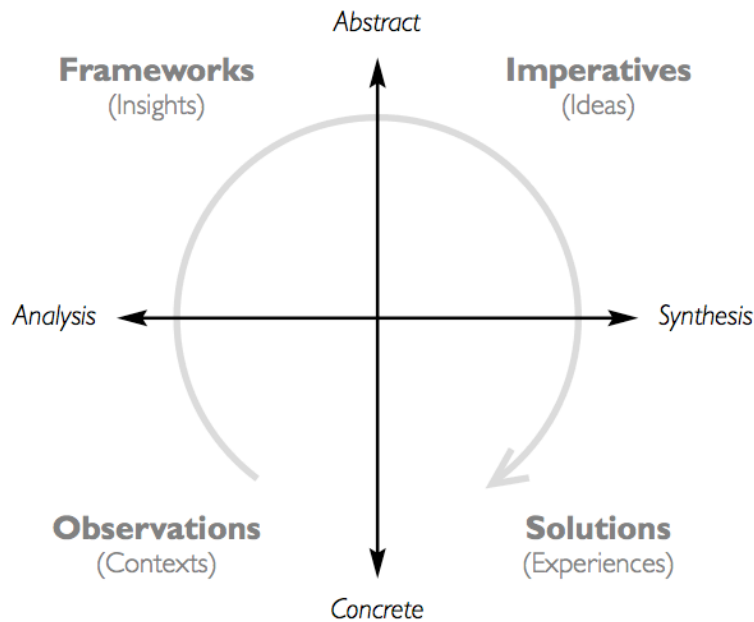


Figure 1: The innovation process (Beckman and Barry 2007), described in terms that integrate experiential learning (Kolb 1984), and design thinking (Owen 2001).

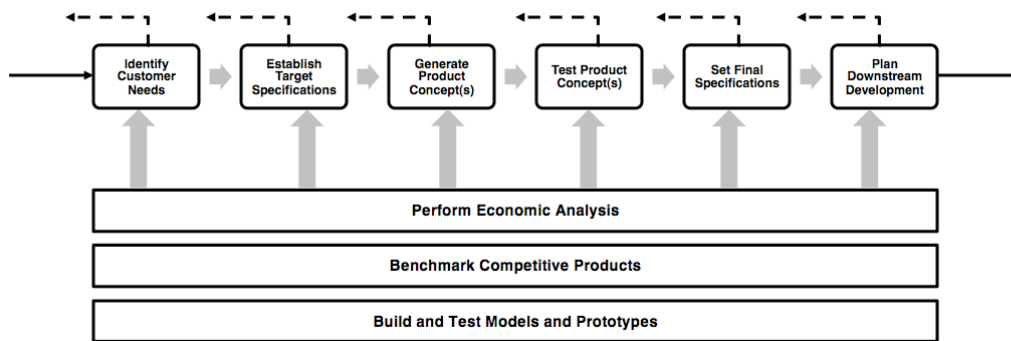


Figure 2: Ulrich and Eppinger's model of the front-end market-pull product development process (2011).

While there is a wide range of new product design and development process models, most share a similar set of activities at the front end of the process: understanding the design context and customers' needs, and initially defining the problem. This dissertation specifically focuses on these early stages of product development, i.e., *User Research* and *Conceptual Design*. It is in these phases that human-centered design takes the lead in guiding the design process.

HUMAN-CENTERED DESIGN

Research has repeatedly shown that successful new products are not necessarily driven by the availability of new technologies, but instead meet user or market needs and are valuable to the customer (Poolton and Barclay 1998). Several variant names and definitions have been proposed that reflect this design philosophy of placing high value on meeting user needs, including *market-pull*

(Ulrich and Eppinger 2011), *user-centered* (Sanders 2008), or *human-centered design* (Rouse 1991). All of these approaches are essentially “oriented toward integrating technology and other resources to support people in ways that are appropriate and conducive to their fulfilling the responsibilities associated with their roles” (Rouse 1991).

This thesis refers to **human-centered design** and defines it as:

A philosophy of design where the designer’s goal is to apply his or her expertise to serve the needs and desires of the product’s users and stakeholders. The designer selects a technology or set of technologies that acknowledges the greater context of that technological solution in its users’ lives.

A human-centered philosophy affects how a designer thinks and acts when faced with a design problem. While human-centered design philosophy influences decisions throughout all stages of the design process, it carries the strongest influence during early stages of problem exploration and definition. The human-centered design process is led by design research: the team first researches its users and cultivates a deep understanding of the design context before developing possible solutions (Sanders 2008; Laurel 2003). The focus of many early stage design team meetings is to discuss user research, reach a shared understanding of the design problem, and identify implications for possible solution directions.

CROSS-FUNCTIONAL TEAMS

Cross-functional teams represent the range of perspectives and expertise that are needed to solve complex socio-technical problems. Wenger describes participation in a cross-functional team as a boundary practice where, “members from a variety of communities of practice interact with each other across their respective boundaries” (Wenger 1999). Companies often form new product development teams of designers with multiple areas of expertise to benefit from diverse expertise and the team’s increased flexibility to respond to changing problems (Denison, Hart, and Kahn 1996; Ancona, Bresman, and Kaeufer 2002).

One of the main challenges of new product development teams is internal communication (Poolton and Barclay 1998). Much of early stage design communication is ambiguous, communicating imprecisely and articulating provisional ideas as the team initially fleshes out the scope of the design problem and solution (Bucciarelli 1994). Diverse teams particularly face communication challenges and interpretive barriers due to their disciplinary diversity (Dougherty 1992). Diverse teams are able to work cohesively by “addressing conflicts, reconciling perspectives, and finding resolutions” (Wenger 1999). The goal of this communication is to establish a shared understanding or common ground (Clark and Brennan 1991) of the design problem or solution. Shared understanding keeps the team on topic and on task and serves as the basis for future communication.

THESIS

This dissertation explores how human-centered design teams interact with technology to manage information during early stages—user research analysis and concept generation—of the new product development process. It examines how tools mediate the process of sharing information as a team, including how teams engage in information sharing, how the technology affordances influence team interactions, and how tools might be better designed to assist the process of reaching a shared understanding.

This offers several potential benefits to design practice:

- Individual designers are able to **contribute more of their gathered knowledge and integrate it into the team's shared understanding**. Acknowledging and integrating all voices from the team build on the team's wide areas of expertise and fulfill the promise of cross-functional teams.
- Design teams are **liberated from managing the details of communication logistics** and can focus more attention on exploring the problem space.
- Teams can **feel comfortable about their ability to integrate even more information into their design process and still establish common ground**. This results in solutions that are more innovative, take more risks, or address a more nuanced view of the problem space.

CHAPTER SUMMARIES

The following chapters address this research thesis.

Chapter 2 offers a literature review of why and how design teams exchange information and reach shared understanding in early stage design, and the role of information tools in that process.

Chapter 3 outlines the various research methodologies used in this research, including the theoretical frameworks used for analysis in the rest of the thesis—sharing semantics (Shen, Everitt, and Ryall 2003) and the formality spectrum (Yang, Wood, and Cutkosky 2005). It also introduces the research sources and user groups that were studied in this thesis.

Chapter 4 reviews the breadth of information tools currently used by practicing multidisciplinary design teams. It presents results from a series of surveys and interviews with both professional and student designers and user researchers. The range of design tools mentioned by interview participants led to a new schema for categorizing information tools. This chapter also examines the formality and sharing semantics associated with particular tools when used to support collaborative design tasks. A more nuanced analysis of sharing semantics transitions and a revised formality spectrum led to a *new framework*—the sharing spiral—a major contribution of this thesis. The sharing spiral is a conceptual framework that describes how designers gather and share information individually and as a team across early stage design phases. Some material from this chapter has already been published (Oehlberg, Roschuni, and Agogino 2011).

Chapter 5 presents video-recorded observations of student design team meetings, analyzed based on the phases of the sharing spiral that are present during co-located team meetings. The main contribution of this chapter is *nine identified challenges* that face-to-face teams encounter when trying to share information during user research and conceptual design tasks.

Chapter 6 re-examines the research findings from Chapters 4 and 5 and contributes *design guidelines* for how new technologies should support the process of shared understanding in user research and conceptual design. This chapter also reviews how existing design tools used by practitioners and developed by researchers address these principles. Some material from this chapter has also already been published (Oehlberg et al. 2012).

Chapter 7 introduces *Dazzle*, a collaborative design tool that helps individual designers share information with their collaborators, while also generating a record of the team's shared information from the meeting. This chapter outlines how Dazzle's features align with the design principles from

Chapter 6 and present scenarios to illustrate how Dazzle performs in its context of use. This chapter also contributes a description of an early implementation of Dazzle, and initial user evaluations of the system during collaborative user research and conceptual design tasks. Some material from this chapter has also already been published (Oehlberg et al. 2012).

Chapter 8 summarizes and synthesizes the findings of this dissertation, looking forward to how this dissertation might impact areas of design research and human-computer interaction.

This thesis offers contributions in the areas of design research and human-computer interaction. It offers the design research community new conceptual frameworks to illustrate how information sharing processes work in small design teams. The human-computer interaction community can benefit from design principles for new collaboration tools that stem from deep analysis of design teams at work, as well as Dazzle, a new system that illustrates a practical application of these principles.

CHAPTER 2

BACKGROUND

INTRODUCTION

This chapter reviews research literature on the design process, shared understanding, information sharing, and design information tools that form the backdrop for the research contributions of this thesis. First, it reviews a set of design process models that are used throughout this dissertation to specify which stages of the new product development process are within the scope of this thesis. It then discusses the type of unique information and individual perspectives that designers bring to their team, and the team's desired end point—shared understanding—that is formed by bringing together disparate points of view. Focusing on this process of information sharing and synthesis, this chapter discusses theoretical models that describe how collaborative design teams exchange information and identify this shared frame. Finally, this chapter discusses related research on the role of personal and collaborative design information tools in design practice. This includes the role of digital and physical artifacts in design communication within teams.

DESIGN PROCESS MODELS

There are many different process models that describe design activity (Dubberly 2004). This thesis references and refers to two models that each emphasize a particular aspect of design: Ulrich and Eppinger's design-phase model of the product development process (2011), and the innovation learning process (Beckman and Barry 2007) which is an integration of design thinking (Owen 2001) and experiential learning (Kolb 1984).

Ulrich and Eppinger's model of the product development process (see Figure 2 in Chapter 1) is an example of a sequential model, describing how a product development process might unfold linearly over time (Ulrich and Eppinger 2011). Product teams shepherd a product from problem formulation and conceptualization through manufacturing, distribution, and service, often with stage-gates (Cooper 1990) where teams deliver outcomes at the end of each phase. However, this model does not explicitly account for iterative or concurrent design activity. For example, some design teams simultaneously handle manufacturing and distribution, or iteratively alternate between problem formulation and conceptualization. This thesis focuses on the earlier phases of design—problem formulation, user research, and conceptual design—when it is critical for the team to agree upon a common understanding of the problem, its design goals, and solution concepts.

Design thinking has been described as a cycle alternating between abstract and concrete thinking and cycling between analytical and synthetic action (Owen 2001), describing the iterative nature of the

design process. Beckman and Barry integrated ways of thinking from experiential learning (Kolb 1984) that are critical at each step in the design thinking cycle: *diverging*, *assimilating*, *converging*, and *accommodating* (Beckman and Barry 2007) (see Figure 3). Beckman and Barry also use this model to describe designers' asymmetrical adeptness at each phase, noting that not all members of a cross-disciplinary team will have the same strength at each stage, but that a well-balanced team will have someone who can take a leadership role at each stage of design thinking. This thesis is concerned with the role of technology in collectively navigating through the design thinking cycle—how the group uses technology to help form a shared understanding at each stage of *diverging*, *assimilating*, *converging*, and *accommodating* thinking.

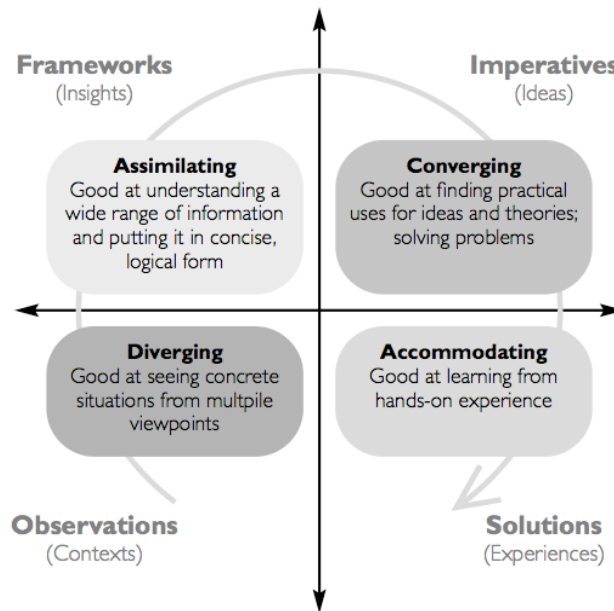


Figure 3: Learning styles from (Kolb 1984) that are relevant at each stage of the innovation process (from (Beckman and Barry 2007)).

DESIGN PROBLEMS

Early stages of product development—user research and conceptual design—involve gathering and synthesizing qualitative information from the unique experiences of product stakeholders and users, and generating a range of possible solution paths that may be appropriate for a particular context. These types of problems can be characterized as “wicked problems” (Rittel and Webber 1973), whose properties include:

- Wicked problems have no stopping rule.
- Solutions to wicked problems are not true-or-false, but good-or-bad.
- There is no immediate and no ultimate test of a solution to a wicked problem.
- Every solution to a wicked problem is a “one-shot operation”; because there is no opportunity to learn by trial-and-error, every attempt counts significantly.
- Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
- Every wicked problem is essentially unique.
- Every wicked problem can be considered to be a symptom of another problem.

- The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.

Cross-functional new product development teams are well prepared to respond to the complexity of wicked problems. A cross-functional design team can synthesize the designers' individual perspectives into a shared solution. This type of task can be considered *judgmental*—the team must come to a consensus on one of several possible answers—and a *hidden profile task*—only by incorporating the unique knowledge of each designer can the team realize a good decision (Mesmer-Magnus and DeChurch 2009). Thus, the information being gathered by the team is complex and cannot be solved or optimized. Instead, the team must synthesize its respective information and areas of expertise into a well-informed solution.

INDIVIDUAL PERSPECTIVES

Each member of a design team comes with his or her own set of assumptions, or *frame*, on the design problem; this guides his or her interpretations and actions moving forward. Frames have four features (Hey 2008):

- 1) A desired end state or goal;
- 2) Relative importance and relevance of features (prioritization of designers' attentions);
- 3) Boundaries to the design situation (problem scope, solution scope, resource constraints);
- 4) Criteria for evaluation (of new information, features, and possible solution concepts).

The designed object is a form of rhetorical communication often articulating the designer's personal attitudes, values, or design philosophy (Buchanan 1985). As such, the designer's frames are embodied in the final design. This frame can be influenced by both the designer's personal values, and by information from the particulars of a design problem.

PERSONAL PERSPECTIVES: PROFESSIONAL IDENTITY AND DESIGNER VALUES

A designer entering an empty room already has an intrinsic set of values that guides how he or she enacts design practice—how he or she would respond to fundamental questions about design. *What is good design? What does a good design process look like? What is a good designer?* This design identity represents the designer's "set of beliefs, attitudes, and values about design" (Kilker 1999) and influences the designer's role in a collaborative team, the process and procedures he or she chooses to follow, and how the designer chooses to evaluate the end product or goal. The designer's conceptions of design begin to form during design education (Oehlberg and Agogino 2011) and carry into professional practice (Mosborg et al. 2005). Design values also have roots in the designer's cultural background (Razzaghi, Ramirez Jr., and Zehner 2009).

There are few examples of what this space of possible design identities or perspectives might look like. Fallman describes three accounts of design—*conservative*, *pragmatic*, and *romantic*—which influence what design is to those designers and what those designers do (Fallman 2003). The *conservative* account views the designer as an information processor that follows a fully transparent, rational search process. The *pragmatic* account views the designer as a reflective, know-how bricoleur that engages in a reflective conversation to produce a product that is integrated into the world. The *romantic* account views the designer as a creative, imaginative genius that follows a mystical, opaque process to create a functional piece of art (Fallman 2003). Sanders' framework of design perspectives helps juxtapose different assumptions designers might have about the design process or the relationship between designers and

end-users (Sanders 2008). In her framework, the design process can be research-led or design-led, and the designer's relationship with the users may be as the expert (users are seen as subjects or reactive informants) or may represent a more participatory approach (users are seen as partners or active co-creators). For example, in this framework, human-centered design represents a research-led process with the designer as an expert. Such design values not only influence the final design, but also the process approach that the designer applies to develop their final design.

One famous example of how a design values might manifest themselves is in Dieter Rams' clearly stated ten principles of good design (Rams 1984):

1. Good design is innovative.
2. Good design makes a product useful.
3. Good design is aesthetic.
4. Good design makes a product understandable.
5. Good design is unobtrusive.
6. Good design is honest.
7. Good design is long lasting.
8. Good design is thorough, down to the last detail.
9. Good design is environmentally friendly.
10. Good design is as little design as possible.

These values provide a backdrop for new information and perspectives that form the specifics of a given design project as it unfolds.

CONTEXTUAL AND PROCESS-INDUCED PERSPECTIVES

Once designers encounter a design problem, their experiences inform their evolving understanding of the problem, which once again shapes their design values. Bardram describes design as a co-constructive collaborative activity, "in which the actors focus on re-conceptualizing their own organization and interaction in relation to their shared object" (1998). For example, a team of designers taking a human-centered, research-led approach (Sanders 2008) will understand the design problem by sending out individuals or pairs to conduct fieldwork with target users (Laurel 2003). Through their personal experiences of conducting design research, designers develop independent points of view. As each team member learns about different user perspectives, he or she diverges from the design perspectives of his or her collaborators (Hey, Joyce, and Beckman 2007).

SHARED UNDERSTANDING

It is imperative that design teams integrate individual perspectives and form a *shared understanding*. Valkenburg describes shared understanding as "a mutual view amongst the team members on relevant design topics and design activities" (1998). This dissertation defines "shared understanding" as the team's shared frame of the design problem. Extending Hey's definition of an individual frame (2008), the team's shared frame represents common goals, and the team's agreed-upon design priorities, problem boundaries, and criteria for evaluation.

High-performing teams benefit from both divergent individual perspectives and shared understanding. The team's divergent mental frames are a form of *task conflict* (Jehn and Mannix 2001) or *cognitive conflict* (Amason 1996). Jehn and Mannix (2001) found that high performing teams do have a lot of task conflicts, but these conflicts are resolved as the task comes to a close. Similarly, Song, Dong

and Agogino found that high-performing teams have high variation in their semantic coherence—common language used by individuals— throughout the design process, but these teams manage to reach high semantic coherence—using similar language—just before major stage gates (2003). One example of how diverse perspectives might be managed in practice is through a team’s approach to concept generation; designers typically brainstorm ideas both individually —to get quantity and a diversity of ideas—and as a team—to improve the team’s shared understanding of the solution space (Paulus, Larey, and Dzindolet 2001). While task conflict can be beneficial and enlarge functional perspectives, it also risks driving the team apart (Weingart, Todorova, and Cronin 2010). Thus, teams that are able to resolve conflicting points of view and reach a shared understanding are better able to avoid these destructive forms of team conflict.

Analogous concepts to shared understanding also exist in communication and cognitive science research. Clark (Clark 1996) defines *common ground* between two people as, “the sum of their mutual, common, or joint knowledge, beliefs and suppositions.” Similarly, *distributed cognition* theory uses the concept of a shared mental model, which is used by teams to coordinate action (Hutchins and Klausen 1998). Given that new product development can be interpreted as a knowledge management task (Madhavan and Grover 1998), these general theories on collaborative knowledge management are directly applicable to this thesis.

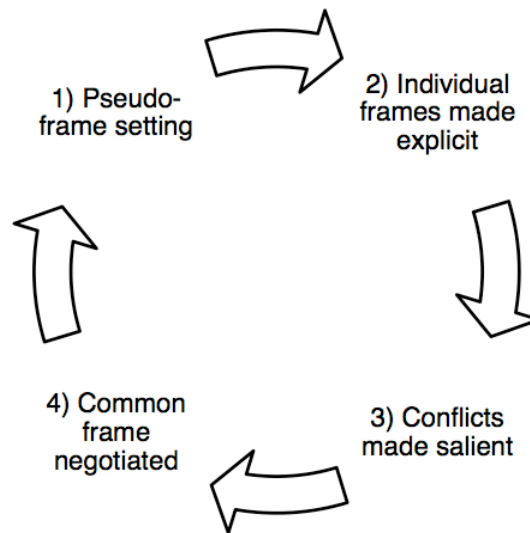


Figure 4: The framing cycle, from Hey, Joyce, and Beckman (2007). Teams assume that they start out with a common pseudo-frame, individual frames are made explicit, conflicts between frames are made salient, and a common frame is re-negotiated.

Previous research has developed theoretical models to describe the dynamics by which design teams reach a shared frame. Hey, Joyce, and Beckman propose the ‘framing cycle’ (2007)(see Figure 4). In the framing cycle, the team first starts with an assumed pseudo-frame. Next, individual frames are made salient as each individual shares his or her knowledge and point of view. Once conflicting frames between individuals are made salient, the team must negotiate a common frame based on individual experiences and points of view. With its newfound shared frame, the team can act from a shared set of assumptions and work towards the same goals. Each step in the framing cycle relies heavily on communication between individuals. By observing the paths that design teams take in reaching a

shared frame, Hey developed principles for how teams engage in the framing process and communicate their frames to each other (2008).

This dissertation focuses on how designers use information technology to communicate with each other, making their individual frames salient, and helping the team recognize conflicting frames (Hey, Joyce, and Beckman 2007). The next section discusses how various communication media, artifacts, and technologies support collaborative design practices, particularly in reaching a shared understanding.

INFORMATION SHARING AND USE IN DESIGN TEAMS

In order to reach a shared understanding, collaborating designers will engage in information sharing. In a meta-analysis of research on team information sharing, Mesmer-Magnus and DeChurch conducted a meta-analysis of research on team information sharing, particularly looking at the effect that information uniqueness and openness had on team performance (2009). The meta-analysis found that information sharing had a positive correlation with performance outcomes. Teams share more information when team members already know the information, when team members are already capable of making decisions independently, or when members are similar to each other (low team diversity).

Design teams build shared understanding by exchanging information that they have at hand about the design problem. Designers build upon individual data elements to construct formal and informal information, which is then interpreted through knowledge processes to construct knowledge elements, which then inform design decisions (Hicks et al. 2002). Engineering designers not only seek out information from documents but also from knowledgeable people—both within and outside their organization (Hertzum and Pejtersen 2000; Leckie, Pettigrew, and Sylvain 1996). Song asked student designers to rank the type of information they found most important after user research and conceptual design stages (Song 2004). She found that 45.5% of information sources were from personal communications with either collaborators or outside experts. She also found that designers exchange information with each other predominantly through face-to-face and email communication (more than 70%).

Will describes the engineering practices at Hewlett-Packard, particularly focusing on how new information from simulation and modeling is used to feed into early stage design (Will 1991). During user needs analysis, the product team applies the Quality Function Deployment (QFD) approach to transforming user needs into design quality, systematically enumerating the customer's needs and analyzing the current product for features that meet those needs. During ideation, Will notes that "human creativity rules the day" but also identifies that engineers' dominant needs are for quick estimators for back-of-the-envelope calculations, and easy access to prior designs with its design intent.

This thesis examines how co-located teams exchange information, supporting their process of reaching a shared understanding. It particularly focuses on how design information is exchanged through various information tools and media. The next section reviews existing literature on the range of boundary objects, information tools, and communication media relevant to early stage engineering design.

COMMUNICATION MEDIA AND BOUNDARY OBJECTS

There are several theories that discuss the role that information tools and artifacts play in communication. One such theory is the idea of *boundary objects*, information artifacts that “inhabit several intersecting social worlds [...] and satisfy the informational requirements of each of them” (Star and Griesemer 1989). Boundary objects allow two individuals to create an artifact that can communicate across a disciplinary or knowledge boundary; by making knowledge explicit and negotiating a shared representational system, both parties are able to engage with and draw information from the object. Carlile (2002) describes three types of boundaries: *syntactic* (establishing a common syntax or language), *semantic* (establishing a common interpretation), and *pragmatic* (understanding consequences between interrelated and dependent objects or concepts). Boundary objects help the team establish a “boundary infrastructure” (Bowker and Star 2000) or “boundary process” (Carlile 2004) that individuals then use to manage knowledge across that boundary.

The process of grounding (reaching a shared understanding) is heavily affected by the affordances of the particular boundary object or communication medium, as well as the social context. Clark and Brennan (1991) identify the following factors as influencing the quality of the grounding process: *copresence*, *visibility*, *audibility*, *cotemporality*, *simultaneity*, *sequentiality*, *reviewability*, and *revisability*. For example, users’ *visibility* of and *access* to others’ information define the boundaries between personal and private spaces (Greenberg, Boyle, and Laberge 1999; Shen, Everitt, and Ryall 2003). Information crosses these boundaries as designers interact with each other and share information, while the boundaries themselves dictate the extent to which that information is ‘shared’ with collaborators.

Boundary objects are abundant in engineering design practice. Sketches, drawings, and prototypes produced by engineering designers are one common example of boundary objects (Henderson 1991; Carlile 2002). Because sketching is both an interactive communication tool and an individual thinking tool, it is a particularly powerful means to communicate visual knowledge. Examples include designers’ technical drawings that communicate how machinists and manufacturers should build the object that the designers have socially constructed, and more informal sketches generated during a casual conversation between design engineers. Sketches and prototypes, however, are forms of design communication that can be manifested using a range of information tools.

DESIGN COMMUNICATION TOOLS

This thesis considers a wide range of tools that designers may choose to employ to support their efforts to reach a shared understanding. Several design researchers have focused on the use and content of specific design tools (e.g., logbooks (McAlpine et al. 2006), email (Wasiak et al. 2010), electronic files (Hicks et al. 2008)). Others have looked into how specific activities are supported by tools, such as sketching behavior in design journals (Song and Agogino 2004; Oehlberg, Lau, and Agogino 2009; Oehlberg, Lau, and Agogino 2009), or information scraps on Post-it notes or email (Bernstein et al. 2008). This research broadens the scope to consider all tools used to capture and share information in early stages of the design, rather than focusing on the specific content captured within particular tools. This section reviews previous research on existing practices surrounding:

- *Physical information tools*, including design sketchbooks and journals
- *Electronic information tools*, including wikis, electronic files and email

Related work on proposed new systems is addressed in Chapter 6. The next section defines each type of tool and reviews previous studies of how these types of tools are used in collaborative design teams.

PHYSICAL INFORMATION TOOLS

Physical tools, in this dissertation, refer to paper-based or handwriting-based tools. These systems are not reliant on electricity or computing. Examples include Post-it notes, paper sketchbooks or journals, or whiteboards.

The most compelling use-case for physical tools is for immediate sketching or drawing. Designers' sketches in design journals increase in conceptual detail and amount of annotation as the designer moves from problem formulation to concept generation to implementation (Song, Dong, and Agogino 2003; Oehlberg, Lau, and Agogino 2009; Oehlberg, Lau, and Agogino 2009). Designers also produce the highest quantity of sketches during concept generation, dropping off during implementation perhaps due to the increase of physical prototyping (Song, Dong, and Agogino 2003; Oehlberg, Lau, and Agogino 2009).

Many studies have addressed how engineers use design journals for sketching and graphical representation (Grenier and Schmidt 2007; Oehlberg, Lau, and Agogino 2009; Oehlberg, Lau, and Agogino 2009; Yang 2009) as well as for reflective practice (Currano and Leifer 2009). Personal tools, including design notebooks or journals, commonly exist as physical media. McAlpine et al. offered an extensive study of the use and content of the engineering design logbook (2006). These studies primarily focused on the personal relationship between designers and their design journals: the type of sketches and design information collected in these journals, how frequently they use their journals, and how the owner's project role affected the journal's content. The researchers also inquired about the collaborative implications of these logbooks, particularly with design reuse in mind. Some participants in this study reported that they would be happy to share logbook information with colleagues. However, it was also noted that sharing with colleagues would be difficult without help from the owner of the logbook, given that physical logbooks are primarily navigated through browsing and memory (McAlpine et al. 2006).

The reality is that design journals are part of a broader ecology of information tools. One design student from Oehlberg, Lau, and Agogino (2009) identified her set of information organization tools in this entry in her design journal:

"I didn't use my journal as much as some of my other team members. I have a few other habits for organizing my thoughts that I wasn't willing to change just for this project:

- email/wiki—this is where most of my communication takes place
- my own journal—where I track To-Dos and notes for ALL of my commitments in group meetings,
- [another team member] often took notes, so I always felt like she could refresh our memories."

Design journals also are trending towards including more than just physical media, including both digital documents and images. They also are increasingly extending beyond early stage design by including physical prototypes in the same artifact.

Large-scale physical media, such as whiteboards, are simultaneously used to support individual and collaborative work (Cherubini et al. 2007). Proximity to the whiteboard affects how groups collaborate around it. As users move through intimate, personal, social, or public proxemic zones from the whiteboard, they move from generating new content on the whiteboard, to discussing artifact details, to engaging in meta-discussion, to a peripheral awareness of the project (Ju et al. 2004; Ju, Lee, and Klemmer 2008).

DIGITAL INFORMATION TOOLS

Digital tools, in this thesis, rely on computers to capture or display information. This includes electronic files hosted on a local machine, email, and other forms of web-based communication such as wikis.

Hicks et al. studied professional engineers' management and use of electronic files, differentiating between file exchange and file sharing (2008). File exchange is the explicit transfer of personal files from one computer to another, whereas file sharing is done by posting files to a central server where they are made accessible to all collaborators. This distinction between exchange and sharing highlights two qualities of information sharing interactions between individuals: how accessible information is to others, and whether or not that action of making information accessible is made explicit to others. Hicks et al. found that engineers most frequently share and exchange files with their project team, and rarely share or exchange files with suppliers, customers, or subcontractors (Hicks et al. 2008).

While Computer-Aided Design (CAD) is an increasingly common way for designers to produce technical drawings, it also comes with failings as a boundary object. In one example from Henderson, machinists would find an error and suggest a quick change to the CAD drafters without consulting the design engineers; these engineers would have considered the impact a manufacturing change has on other aspects of the integrated design (Henderson 1991).

In a study of engineers' use of email, Wasiak et al. developed a coding scheme to describe "what topics emails discuss, why they are sent, and how their content is expressed" (2010). From applying this schema, they found that the majority of emails sent in engineering design teams are sent with the purpose of informing, as opposed to clarifying, exploring, or managing. The balance of emails pertaining to the project vs. the product also varied based on the sender's project role.

Newer online services are starting to be adopted by design teams, particularly ones involved in varying levels of distributed collaboration. For example, researchers have also looked at how wikis are used for reflection among design students (Chen et al. 2005) and to coordinate joint work in software development teams (Phuwanartnurak 2009). Researchers studying how teams adopt such new tools are able to better understand how technology features are meeting teams' latent collaboration needs. From there researchers can also develop emergent technologies to meet those needs.

CONCLUSION

This chapter reviewed research literature topics relevant to this thesis. Related research on design process models focus the scope of this thesis to relevant stages of design process—user research and conceptual design. This related work also helps define the starting point (individual information and frames) and end goal (shared understanding) of information sharing in teams. Related work on how information is shared and used within teams reviews the current understanding of the shorter-term goals and motivations of teams as they exchange knowledge. Finally, this chapter reviews mechanisms that teams use to communicate information to each other; this includes a theory review of boundary objects, as well as practical studies of specific physical and digital design tools.

The focus has been on literature that provides a foundation for the general subject areas described in this dissertation. Later chapters add to this literature review in addressing specific methods, frameworks, and research used in each chapter. The following chapter discusses the research methods used for the remainder of this thesis to investigate how technology supports information sharing in design teams and associated related literature.

CHAPTER 3

RESEARCH METHODOLOGY & ANALYTICAL FRAMEWORKS

INTRODUCTION

This chapter reviews the research methodology and analytical frameworks used throughout this dissertation. First, it presents the data collection methods—including surveys, interviews, document analysis, observation and user studies—and the rationale behind using these approaches. Next, the chapter discusses the research subjects, professional and student designers. Finally, it introduces two analytical frameworks that form the basis for analysis in the following chapter: sharing semantics and the formality spectrum.

DATA COLLECTION METHODS

This dissertation employs a range of qualitative data collection methods.

- **Surveys:** Our survey allows us to identify trends within the general design community. This dissertation discusses a survey conducted in spring 2012 of 29 professional designers. Details from this survey are described in Chapter 4.
- **Interviews:** Interviews offer insights into designers' attitudes and beliefs when it comes to technology and information use in design team meetings; it is important to note that any behavioral information is self-reported. This dissertation includes interviews with 17 professional designers conducted in spring 2010, and interviews with 17 design students conducted in fall 2009 and spring 2010. Further details from these interviews are described in Chapter 4.
- **Observations:** While interviews and surveys rely on self-reporting, first-hand observations of design activity allow for more detailed analysis of observed interactions. These observations were also supported by document analysis from shared team folders, and group interviews with the teams after the observed sessions. Further details from these observations are described in Chapter 5.
- **User Study Evaluation:** After developing design guidelines from our analysis of design activity in Chapter 6, those guidelines are evaluated by applying them to the design of a new

collaboration system—Dazzle—and evaluating that system in a user study. Dazzle’s evaluation consisted of a user study with five teams, with 3 novice designers per team. These teams came in for two sessions, one focused on research, the other focused on brainstorming and concept generation. In each of these sessions participants were given an individual task before they came together for a team task—this is to simulate work done outside of a co-located team context. Further details on Dazzle’s evaluation are included in Chapter 7.

Table 1 summarizes the data collection methods employed and research subjects studied in this dissertation.

Data Collection Method	Research Subjects	Year	Participants
Survey	Professional designers	Spring 2012	29 individuals
Interviews	Professional designers	Spring 2010	17 individuals
Interviews	Human-Centered Design students	Fall 2009, Spring 2010	17 individuals
Video Observation, Document Analysis	Graduate-level course, “Managing the New Product Development Process: Design Theory and Methods” (ME 290P)	Fall 2010	3 teams (14 individuals)
Team Interview	Graduate-level course, “Managing the New Product Development Process: Design Theory and Methods” (ME 290P)	Fall 2010	2 teams (10 individuals)
User Evaluation	‘Novice’ designers—architecture, human-computer interaction, and engineering students with less than 5 years of human-centered design experience	Fall 2011, Spring 2012	5 teams, 3 participants per team

Table 1: Summary of research subjects for each data collection method.

This dissertation uses both professional designers and design students as research subjects. Professional designers are the subjects for the survey and interviews in Chapter 4. Individual student designers also participated in interviews in Chapter 4. Student design teams from the fall 2010 semester of the UC Berkeley course ME290P, “Managing the New Product Development Process: Design Theory and Methods” participated in the observations in Chapter 5. Novice designers—architecture, human-computer interaction, and engineering students—were recruited to participate in the evaluation of Dazzle in Chapter 7.

One difference between different sets of research subjects is the level of participants’ design expertise, which does lead to some differences in how experts and novices handle design work. A comparison of student and professional design processes while addressing a design problem (Atman et al. 2007) found that expert designers spent more time solving the overall design problem, which translated to them spending correspondingly more time conducting problem scoping and information gathering. However, based on Atman et al.’s data, experts spend 24% of their time defining the problem, whereas students spent 18% of their time—a non-significant difference in the proportion of time spent doing the design activity.

Another differentiating factor between students and professionals is the reality of the design problem and its final deliverable. Ultimately, professional designers are working on real-world problems that result in produced products that are delivered to and used by real customers. While professional design projects and project-based design courses share similar properties, including project timelines and deliverables, there are ultimately dimensions where these settings differ, including the designers’ time

commitment to the project, project timeline constraints, and the resources available in educational and industry settings.

In the surveys and interviews for Chapter 4, students offer a counterpoint to professional designers; as they represent the next generation of designers, they also represent adopters of the next generation of design tools. Student design teams offered an accessible and targeted research subjects for the observational studies in Chapter 5. By timing observations to correspond with user research and concept generation team assignments on the course syllabus, the observations focused on meetings that were relevant to these early stage design activities.

ANALYTIC METHODS & FRAMEWORKS

This thesis focuses on qualitative data gathered from designers and design activity. Analysis of this data was guided by applying the following frameworks, and by inductive qualitative techniques. The qualitative analysis in Chapter 4 is initially guided by two frameworks in order to understand design information sharing and tool use: *sharing semantics* and *formality*.

SHARING SEMANTICS

The sharing semantics framework describes the various modes of information sharing employed by face-to-face design teams. In a discussion of face-to-face collaboration that occurs around tables, Shen, Everitt, and Ryall define a gradient of sharing semantics of private, personal, and public (2003) (see Table 2). Each state is defined by the visibility and accessibility of that information to collaborators. Their proposed UbiTable executed this vision by separating visibility and accessibility to create the “personal” shade of sharing semantics.

Sharing Semantics	Definition
Private	Not visible or accessible to others.
Personal	‘On-my-side-of-the-table’ data, semi-private (it is visible but not accessible by others).
Public	Allows shared visibility and access

Table 2: Levels of sharing semantics, from Shen, Everitt, and Ryall (2003).

FORMALITY

Designers employ a range of information formality to support design communication to a range of audiences. In their discussion of design information for possible reuse, Yang, Wood, and Cutkosky propose a “spectrum of formality” to differentiate between the types of information created throughout a project (2005). This spectrum has three defined points: informal, semi-formal, and formal design information—these are outlined in Table 3. Yang, Wood, and Cutkosky’s spectrum takes into account how information is generated, captured, and structured.

Information Formality	Definition
Informal Design Information	Unstructured text, captured as it is generated, e.g., information captured in design logbooks.
Semi-Formal Design Information	Informal information with a limited amount of structure imposed, e.g., design rationale systems or case studies.
Formal Design Information	Highly structured, detailed documents, e.g., final reports, patents, and CAD drawings.

Table 3: Points along the Information Formality spectrum, according to Yang, Wood, and Cutkosky (2005).

Hicks et al. also discuss information formality in their framework for understanding the information and knowledge management requirements of engineers (Hicks et al. 2002). In their schema, formal information:

“provides a specific context and measure. It provides a structure or a focus so that individuals exposed to it may infer the same knowledge from it, such as formal education, where the content and order is prescribed. In order to achieve this, formal education is structured and sufficiently decomposed to describe all the necessary information, which includes facts and relations, upon which the inferred knowledge is based.”

Hicks et al. sub-classify formal information into three categories based on how the information is conveyed: textual, pictorial, and verbal.

Hicks et al. consider informal information to:

“encompass unstructured information. The majority of which is either personal information or information that is developed through the interaction between two or more individuals. Here the subjects and predicates may not be clearly defined; the information may change dynamically as content is altered or added. Indeed this varied and dynamic information set provides for the generation of various knowledge perspectives for the individuals taking part, and it is this variation that both simulates and develops the creative and decision-making processes.”

It is important to consider the levels of formality that are supported by various design tools, as they dictate the expressive range of those tools. Chapter 4 describes how information evolves from one level of formality from the next as it is translated to different tools or collaborative environments.

INDUCTIVE QUALITATIVE ANALYSIS

While applying existing frameworks to qualitative data can help frame how observed qualitative data fits in the context of previous work, there still remain questions that cannot be answered through existing frameworks. As a result, this dissertation also employs an inductive approach to qualitative analysis to identify and develop emergent frameworks from the data.

An inductive approach involves careful reading of the qualitative data— transcripts from interviews or video from observations—and breaking up that data into segments and “condensing categories that make sense in terms of [...] relevant interests, commitments, literatures, and/or perspectives” (Lofland 2006). Data is then revisited for focused coding where the initial codes are analyzed—e.g., identifying commonalities or contradictions—to help the researcher “sort, synthesize, and conceptualize large amounts of data” (Charmaz and Belgrave 2012).

In the case of this thesis, qualitative findings from one chapter are applied to later chapters to support a more structured analysis. For example, the nine design challenges that emerge from qualitative analysis of team observations lead to seven design guidelines. Six of these design guidelines are then used to structure the analysis of qualitative data from the user studies of Dazzle, to determine the effectiveness of those guidelines.

CONCLUSION

This chapter reviewed the research data collection methods and analysis frameworks used throughout this dissertation. Qualitative data collection methods include surveys, interviews, observation and document analysis, and user study evaluation. The main analysis frameworks for this thesis are sharing semantics and the formality spectrum. The analysis of qualitative data through these frameworks allow for a clearer definition of the range of technologies available to designers, and the construction of new conceptual models that describe how designers use technology throughout a collaborative project.

CHAPTER 4

FRAMEWORKS FOR ANALYSIS: DEVELOPING THE SHARING SPIRAL

INTRODUCTION

During user needs research and conceptual design, engineers and designers use a variety of design information tools to gather, create, explore, sort, and act on design information. These tools capture, archive, and present information; they are used personally or collaboratively; they represent a range of information formality and sharing semantics.

This chapter examines the spectrum of tools available for use during user needs research and conceptual design phases of the design process. Research questions include:

- What is the range of design information tools in use by today's engineers and designers for user needs and conceptual design?
- How do designers manage and share information over time as they transition between individual and collaborative work in user needs research and conceptual design?

This chapter presents an analysis of data gathered through a survey of professional engineering designers and design researchers and interviews with both professional and student engineering designers and design researchers. The survey results illustrate the range of information technology currently in use and how that technology is used in a range of collaborative contexts. The various design tools mentioned in these interviews are analyzed based on where they fall along the spectrum of formality, and how they support various transitions between private, personal, and public sharing semantics. Finally, this chapter presents the *sharing spiral*, a proposed framework for describing how designers work with information during individual and collaborative work, across user research and conceptual design.

RELATED WORK

Previous chapters in this dissertation have already addressed several areas of related work. Many researchers have studied specific design tools—for a more in-depth literature review of these studies, see Chapter 2. The starting points for the analysis frameworks are the formality spectrum (Yang,

Wood, and Cutkosky 2005) and sharing semantics (Shen, Everitt, and Ryall 2003); a more in-depth review of these frameworks is in Chapter 3.

In addition to these general areas of related work, this chapter specifically builds on previous surveys of design tool adoption and use. Yang conducted a survey of 107 mechanical engineering design professionals (2007) and asked them about which evaluation metrics, design methods, and tools they use in the design process. Yang’s survey asked designers about: *paper logbooks*, *electronic logbooks/wikis*, *sketching by hand*, *computer-aided drawing and design tools (CAD)*, *prototyping or mockups by hand*, *rapid prototyping (e.g., layered manufacturing)*, *software simulation of designs*, *Internet research tools (the Web)*, *communication tools (email, chat, conferencing)*, *external consultants (such as design firms or factories)*, *project costing tools*, and *project management or planning tools*. Of these tools, *computer-aided design tools* were rated as used most frequently, followed by more general *communication* and *Internet research tools*.

Myers et al. surveyed trends in interaction design practice, including tools used by interaction designers (2008). They found that all participants used paper and whiteboards for ideation sketches; however collaborative designers determined tool use based on the tool’s ease of use and ability to combine multiple designers’ efforts.

While the survey utilized in this chapter had fewer respondents than Myers et al. and Yang’s previous surveys, it asks more detailed questions about the context of use of design tools and technology, such as tool use in distributed and co-located team communications, or in communications with direct collaborators or clients and management. This research also uses interviews to identify broader categories of design tools.

RESEARCH SUBJECTS

This research draws from a survey and interviews with practicing and student designers. Table 4 includes a summary of the research subjects, including the number of student and practicing designer participants in each data collection method.

Research Subjects	Practicing Designers	Design Students
Interviews	17	17
Survey	29 complete (32 incomplete)	0
Total	46	17

Table 4: Summary of research subjects, including interview participants and survey respondents.

INTERVIEWS WITH PRACTICING DESIGNERS & DESIGN RESEARCHERS

The qualitative data includes interviews with 17 practicing user researchers and designers. The interviewees were from the San Francisco Bay Area, Chicago, New York, and London. The interviews were with mechanical engineers (3), industrial designers (3), user experience (software) designers (2), designer researchers (7), a project manager, and a mechanical design professor. The interview data includes notes from interviews with two practicing designers, conducted by an undergraduate student team. The interviews inquired about what tools they use, what information they choose to share (and choose not to share) with their collaborators, as well as how they select tools or methods to use in their design process.

Six interviewees were recruited after responding to a brief questionnaire, which included the question, “What types of information tools do you use as part of your job? For example: paper notebook, mobile

phone, software, whiteboards, web applications.” These interviewees were asked specific follow-up questions on the tools mentioned in their questionnaire response.

INTERVIEWS WITH STUDENT DESIGNERS

We interviewed four students from the fall 2009 semester of ME290P, a graduate-level multidisciplinary course on new product development. Two of the students interviewed were MBA students, while the other two were trained in software engineering and interaction design. The analysis also included notes taken from interviews of 13 student designers recorded by an undergraduate student design team conducting user research on design information capture. These students were from various disciplines, including engineering, architecture, and interaction design. In total this analysis includes 17 interviews with student designers.

SURVEY OF PRACTICING DESIGNERS & DESIGN RESEARCHERS.

The interviews were followed by an in-depth survey of design professionals, asking details about the types of information tools they used in a range of collaborative environments. The survey used for this study is listed in Appendix A. The survey begins with demographic information about the professional designer—asking for information about the number of years of experience, what type of company he or she works for, how his or her company is structured with respect to design, the types of roles he or she has in their design team, and which aspects of the design process he or she touches. The survey then asks, generally, which types of design tools they use. The survey then asks which types of design tools they use for early phases of the design process (conceptual design and user research), in specific collaborative contexts (either among collaborators or with clients). The median time to complete the survey was 30 minutes, with one outlier taking 8 hours to complete the survey.

The survey was distributed through professional connections in the design community via snowball sampling—asking key members of the design community to take the survey themselves and then broadcast the survey via their own professional networks (e.g., Twitter, LinkedIn, etc.). The survey was also broadcast among professional societies and professional groups (e.g., LinkedIn groups on Design Thinking and User Research, AnthroDesign Yahoo! Group). Sixty-one (61) participants started the survey; thirty-two (32) participants did not complete the survey, while 29 participants completed the survey in its entirety.

The participants of this survey represented a cross section of professional design practice. The survey included questions on the type and size of company/organization, amount of work-related experience, types of design problems worked on, and the types of job functions that the participant performs.

ANALYSIS METHODOLOGY

First, two analysts—both design researchers studying design team communication—read through transcripts of the interviews, identifying each time a designer mentioned using a particular information tool. This list of tools was then categorized based on their media. During a second pass through the interview data, the analysts counted the number of unique individuals reporting use of each particular information tool. This categorized list of tools was used to develop the survey, and is included along with additional detailed data in the Appendix.

Each tool mentioned in the interviews was then coded with the stage in the process when it was being used, as well as whether or not it was used in an individual or collaborative setting. Each instance of tool use was coded for where it fell on the gradient of formality (based on Yang, Wood, and Cutkosky (2005), see Table 3) and sharing semantics (based on Shen, Everitt, and Ryall (2003), see Table 2).

Finally, concrete quotes and examples from the interviews detailing tool usage were analyzed to understand which features and tools were adopted, in what contexts, and why. This emergent analysis led to the sharing spiral.

The following sections present the results of qualitative analysis of the interviews and survey. First, the range of tools mentioned by the interview participants is introduced and categorized. Next, results are presented on how tools were used by interview participants in the context of the spectrum of formality and sharing semantics. Then, a new framework, *the sharing spiral*, is proposed and detailed through examples from the emergent analysis of interview transcripts. Finally, results from the survey are presented, describing the design activities when categories of tools are used, as well as which tools are used in a range of collaborative contexts.

RANGE OF TOOLS

Designers use a wide range and variety of information tools; 53 design tools were mentioned by interview participants. The Appendix includes a summary of all tools mentioned by interview participants, with a count of the number of unique individuals during these interviews who mentioned using a particular tool aggregated for each subcategory. Analysis of the tool media mentioned in the interviews led to the following four categories of tools: *Physical Tools*, *Digital Hardware*, *Software*, and *Online Tools*.

PHYSICAL TOOLS

Physical Tools are tangible, non-electronic information tools. These tools include often paper-based information tools that designers handwrite or hand sketch with. These tools include small-scale, medium-scale, and large-scale tools, as well as physical prototypes.

- *Small-scale* physical tools, including Post-it notes, index cards, and paper scraps, are lightweight and mobile. This affords the ability to easily reconfigure and combine these pieces of information.
- *Medium-scale, bound* physical tools include various formats of paper notebooks (e.g., hardcover bound, spiral-bound), which are used as design journals or engineering logbooks (McAlpine et al. 2006). These formats afford implicit chronological use, as consecutive sheets are often filled out in chronological order.
- *Medium-scale, unbound* physical tools, such as loose-leaf paper, as well as tools that organize loose-leaf sheets of paper such as folders and binders. These additionally afford later reconfiguration or reorganization.
- *Magazines and books* are also medium-scale, but they are not generated by the designer and are used as an informational reference.
- *Large-scale* physical tools, including whiteboards and large-format paper, are used for collaborative tasks that require a shareable, viewable representation that is easily malleable by a team of designers.
- *Physical prototypes* may exist at a small, medium, or large scale, depending on the concept. As prototypes are embodied concepts, they often afford a richer, more visceral representation than a sketch on paper.

DIGITAL HARDWARE

Digital Hardware includes both hardware platforms for software or web applications and standalone capture devices.

- *Mobile Computing Devices* include smart phones and digital pens and paper. These tools are mobile and afford interaction while standing or walking. As a result, they are often taken into the field for user research.
- *Portable Computing Devices* are platforms that, while portable, necessitate a workspace in order to operate. While laptops can be taken into the field, they were more often shuttled between desks and other meeting spaces within a design studio. Unlike mobile computing devices, portable computing devices have larger displays and can run most software. As a result, they are the hardware platform of choice for most software and web services.
- *Digital Capture Devices* include audio recorders, video recorders, or digital photography, and are primarily used to capture user research data, but may also be used in creating prototypes.

SOFTWARE

Where digital hardware is able to multitask, software generally has more specialized functionalities that allow its users to accomplish particular tasks.

- *Prototyping software* helps the designer actualize a digital representation of his or her concept. Depending on his or her design domain, this may include solid or surface modeling CAD tools for product designers, wireframing tools for interaction designers, or desktop publishing for graphic designers. Designers used the full range of office suite software throughout the design process.
- *Word processing software* was often used to transcribe user needs interviews.
- *Spreadsheet software*, however, stood out as a non-specialized tool used by designers to manage and analyze user research data. These spreadsheets afford quick tagging and sorting of data.
- *Presentation software* is used to present ideas internally within a design team, or to external audiences like managers or clients. It also affords a linear and hierarchical structure to information.
- *User Research capture and editing software* is used in the capture and manipulation of user research data (e.g., screen capture, video editing, custom-built qualitative analysis software). This includes screen recording and qualitative coding tools. Some design firms will use custom software.
- *Note-taking software* applications are text editors used to take notes during a meeting, or during a user interview. While most afford text input, some augmented systems can synchronize audio recordings with the text input.

ONLINE TOOLS

Online tools are either web-hosted services or web-dependent applications that require Internet access for full functionality. Since much of the data for online tools exist “in the cloud,” it affords the peace of mind that files are safe on an external server.

- *Online User Research Tools* are used to communicate or capture interactions with users. User research participants are recruited from public-facing online tools like Twitter, Mechanical Turk, Mailing Lists, and User Forums.
- *Online File Management* tools are used to coordinate files or tasks across collaborators. Web-hosted applications like Google Docs are used to collaboratively co-create documents or artifacts.
- *Online Communication Tools* are used to communicate with collaborators, either asynchronously (e.g., Email) or synchronously (e.g., Instant Messaging, Web conferencing). Web conferencing tools afford the widest range of features, including audio, video, and text chatting, and shared desktops.
- *Online Note-taking/Journaling* tools are similar to note-taking software but afford access on any web-accessible device and extra peace-of-mind. Individuals use many of these tools, but some afford multiple accounts to contribute to a single archive and therefore allow collaboration between teammates.

COMPARING STUDENT AND PROFESSIONAL TOOL USE

There were two main differences between the student and professional designers that were interviewed.

Practicing designers mentioned using a broader range of tools than students. This could be because practicing designers in industry have resources that make using any given tool a more accessible, viable option. For example, professionals have consistent access to studio space where large-scale physical tools can be posted on the walls. Professionals also have larger budgets that can be spent on digital capture devices, specific prototyping software, or online user research services.

However, students exceed designers in their use of online note-taking tools. This may be due to increased comfort with new technologies, or evidence of exploration as new habits are being formed. One of the interaction design students experimented with using a Tumblr blog for his design journal. He found that many of the features not only benefitted himself (for example, using his iPhone to take pictures of sketches so that he could never lose his ideas) but also his collaborators (for example, posting links to relevant technologies and competing products that could be viewed by his collaborators online).

Otherwise, students and designers reported very similar behaviors in how they used technology in their design projects.

SHARING SEMANTICS

As teams progress through the design process, they continually share and capture design information within the team, and then with people outside the team, such as managers or clients. As such, the participants were asked to discuss when and how they shared different design information. Their responses were then assessed using Shen, Everitt, and Ryall's three-level framework for sharing semantics (2003). This analysis found examples of each category in the context of design teams:

Private information is not visible or accessible to other people. For the interview participants, most private design information was kept in design journals—designers' personal archives of information relevant to a design project. As noted earlier, this was often a medium-sized physical information tool

such as a paper notebook, or collection of loose-leaf paper. There were also instances of digital design journals which made use of information tools that afford single-user access such as software tools connected to a specific digital hardware device, or password-protected online note-taking tools.

Personal information is visible but inaccessible to others. Among the interview participants, personal design information was most often stored in design journals that they reviewed during meetings. These personal design tools were brought to face-to-face meetings where collocated collaborators may observe these tools in use. While visible, collaborators needed to ask permission in order to access that information. Similarly, digital tools may be considered personal if software is seen in use on personal digital hardware.

Public information must be visible and accessible to all collaborators. In physical tools, large-scale tools like whiteboards or butcher paper allow everyone to see public design information and have access to manipulating it. In digital tools, online software can afford collaborators access to a shared information space. One interesting example of public information was students who kept their design journals using online tools such as a Tumblr blog. In this case, information is not only accessible to collaborators, but also to the general Internet audience. These types of online tools afford an ambient awareness by a public audience, making what is generally a “private archive” public as it is created.

TRANSITIONING BETWEEN SHARING SEMANTICS

Though Shen, Everitt, and Ryall (2003) focus on the status of information in different situations, it is important to consider the transitions between sharing semantics.

Private to Personal

Information becomes personal as designers begin to collaborate and previously private information is now visible from across the table. Some of the designers attempted to keep information private in order to protect their collaborators from irrelevant or unnecessary detail. However, one of the interaction design students preferred paper to laptops because of its visibility to his peers:

“Like, the notes I’m taking in the meeting. I can be, like, ‘Okay so now we have three things. Which ones do we agree with?’ So, everybody can see it because, you know, if you have a laptop I don’t really know what you’re doing.”
(student)

Personal to Public

Public information often comes from personal sources. Personal information is made public when individuals make contributions to the material anchor of the team’s conceptual blend (e.g., everyone contributes Post-it notes with ideas towards a larger representation of the prioritized ideas of the entire team) (Hutchins and Klausen 1998). Personal information may also be made public as a reference to inform the team’s direction as they focus on another task.

Some designers keep two parallel tracks of information: 1) the main storyline they are developing as a deliverable and 2) the additional detail that may or may not be relevant to the primary message. In an effort to include the full extent of detail available, extraneous information will be pushed to less-direct methods of communication. One practicing design researcher at a consultancy commented on how he decides what goes into the report (primary message) versus the appendix (additional detail) presented to the design team:

“Putting together PowerPoint, there’s stuff that doesn’t fit. Though it seems interesting or important, it’s not a part of the story because it doesn’t fit in the story. It goes in an appendix, but not in the final report.”
(professional)

The risk of not sharing information directly in a face-to-face manner is that, despite being public, it will remain unread or misinterpreted through a mere skimming. One of the participants noted that if she did not present her designs to her manager in-person, there was no guarantee that her manager had actually seen anything that was sent to her.

However, much like design journals and notebooks act as extended memory for an individual (Hutchins and Klausen 1998), information shared indirectly is available to the group despite the fact that it may not be immediately relevant to the current thinking on the design problem.

Public to Private

Information that has been made public to the team may be transformed into private design information by being recorded into individuals' private archives. This recording may be notes from meetings, reflections on the team's ideas, or new concepts based off the public information. For example, some students reported using smartphones to take pictures of collaborative whiteboards—these representations of public information become part of the designer's private collection of information and are neither accessible nor visible to teammates.

Personal to Private

At the end of a meeting, a designer withdraws his or her personal information from view. Though collaborators are aware of an individual's personal information, its lack of visibility returns it to the private realm.

SHARING SEMANTICS: FROM USER RESEARCH TO CONCEPTUAL DESIGN

When looking at different stages of design, sharing semantics fundamentally changes due to different between user research and conceptual design due to the shift of design information ownership from individuals to the team. In the user research phase, an individual designer collects information about the user on behalf of the team, conveying the user's story back to his or her collaborators. On the other hand, initial concepts and ideas implicitly belong to the designer who generated those ideas. One practicing designer described this implicit ownership of concepts and learning to let go of that attachment:

“Though we're really attached to this idea, because you have some sort of, I don't know where that emotional attachment comes from, maybe it's your idea, maybe it's just pretty, literally. You just have to remind yourself, 'No, no, no. I have this information here that we've worked really hard to get and we know what the consumer wants or we need to have X. so don't go in this direction, go here'. So it happens every iteration, essentially. It happens when you're reviewing with the group, it happens when you're sitting down with the designer, and you're talking about things like where can this go, where can that go.” (professional)

Thus, while teams share user research data to reach the same frame as their users, teams share conceptual design information in order to reach a shared frame with each other on what the solution should be pursuing (Hey, Joyce, and Beckman 2007).

While the sharing semantics framework alone indicates three separate spaces where information may live, the transitions between sharing semantics offer examples of the range of interactions that designers have with their information, and with each other. It also begins to show how sharing semantics change over the course of team collaboration, responding to the team's changing information needs.

SPECTRUM OF FORMALITY

Two primary aspects of Shen, Everitt, and Ryall's framework are visibility and accessibility (2003). However, implied in visibility and accessibility is the increased formality required to guide the

audience through the information presented. The act of sharing forces the designer to prepare a more formal embodiment of information or orally contextualize the information to highlight what he or she believes is most interesting and relevant to his or her audience.

During the initial coding of the data using Yang, Wood, and Cutkosky's formality spectrum (2005), there were some information or documents that were less formal than semi-formal, yet not informal. In response, a distinct difference was identified between formal documents to be used in the immediate context of the design task, such as formal presentations, and even more formal documents used to archive and document a design for future reference. This thesis proposes the addition of two additional categories of formality to modify the formality spectrum (see Table 5).

Formality	Description	Example
Informal	Captured in the moment	Notes, Jottings
Semi-Informal	Sorting of informal, adding some structure	Clustering of concepts, features, needs, etc.
Semi-Formal	The beginnings of formalized structure	First drafts, working documents
Formal	Major components, but not fully fleshed out and finalized	Presentation slide deck requiring presenter for additional context
Archival	Stands alone, detailed	"Slideument" (presentation that stands on its own without a presenter), final reports, patents

Table 5: Revised spectrum of formality.

Informal information remains defined as "without structure," and requires fluent documentation of observation or thinking on to some medium. This takes the form of hand-sketched or handwritten notes on physical tools, or captured audio, digital, or video data from digital capture tools. It is particularly important to highlight that the audio, video, and photographic data collected by digital capture tools are still highly informal, despite being high fidelity. Though it includes a great amount of detail, the lack of structure to that detail puts it on the informal end of the formality spectrum.

Semi-informal includes documents that capture the beginning of a formalized structure. This may be annotated field notes and concept sketches, or the butcher paper resulting from a team meeting putting up Post-it notes—often the results of the reflection phase of the sharing cycle.

We redefine *semiformal* as including semi-structured documents as they are being further refined—first drafts, fleshed out frameworks, or concepts that still require further detail. These semi-formal tools allow for some fundamental structuring and often afford iterative refinement into a formal form. As a result, software tools for prototyping or presentations are used for semi-formal and formal documents.

Formal documents, such as formal presentations, refer to fully analyzed information, but may still require someone present to contextualize within the immediate design context. Formal information is the most refined version of semi-formal documents.

Archival documents are meant for future consumption beyond the immediate design process, such as CAD documents and final reports. Particularly for archival information, designers prefer digital tools (e.g., CAD, desktop publishing, presentation software, etc.) that not only can be easily polished and refined, but also distributed across a wider audience and digitally archived for future reference.

Given these definitions, formality is constantly shifting throughout the design process; as captured information is formalized and shared, the next stage is often to restart with informal representations again. For example, the formalized, synthesized results of user research shared within a group will lead

to informal concept sketches in the conceptual design phase. These sketches will once again be gradually formalized into CAD drawings or even an archival form, such as a patent application.

This parallels the converging-diverging model of the design process—just as the team must converge, informal information must be synthesized into a cohesive vision for the team’s design priorities, which in turn leads to identifying divergent paths forward and capturing these potential paths in an informal format. It is therefore unsurprising that software and web service tools—particularly those that afford formalized representations or shared work—are commonly used in converging phases of the design process.

The anticipated audience makes a big difference on the required formality of the shared information—if a designer is discussing with collaborators, less formality is required than if talking to someone who is a spectator to the design process, such as a client or manager.

NEW FRAMEWORK—THE SHARING CYCLE

Design process models (e.g., Ulrich and Eppinger’s New Product Development Process (2011)) describe how teams progress through different phases or stages of the product development process. Roschuni (2012) proposes a model that describes how user research teams communicate their research findings to design teams, as these two types of teams may be separate in an organization. However these models for the design process and communication do not necessarily describe what happens within those stages as teams collaborate with each other—particularly as individuals begin to share information with the rest of their team. Sharing semantics and the formality spectrum offer glimpses of what design information and support tools could look like. However, these models do not necessarily indicate how information media changes over time to adapt to the team’s collaborative work.

To describe the transition from individual to team information, across user research and design, a common sharing cycle was identified—one that applies across the situations recounted in the interviews with students and practicing designers. The model of *Capture*, *Reflect*, and *Share* is proposed to better describe and understand how individuals and collaborators share information over time during both user research and conceptual design stages of the design process. An illustration of this model is provided in Figure 5.

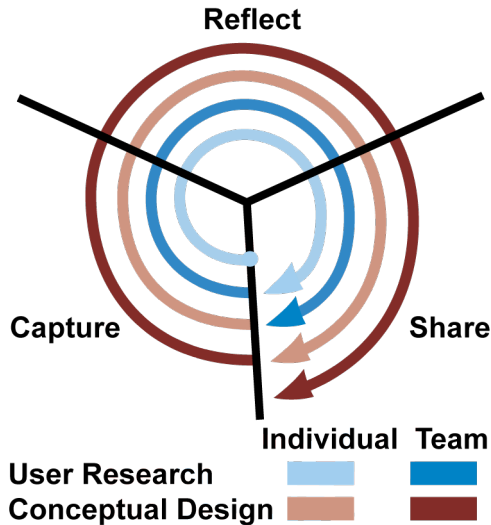


Figure 5: The Sharing Cycle.

- **Capture:** Designers individually or collaboratively gather information that may be of use in the design process. During user research, this consists of capturing raw data such as photos, videotapes, audio recordings, and transcripts; in conceptual design, this includes capturing concept sketches and possible design directions.
- **Reflect:** Reflection involves evaluating captured data and prioritizing, adding additional structure, and making decisions as to which data should be pursued further in the design. These reflections may or may not be recorded in a design tool.
- **Share:** The designer elects to share his or her prioritized information with his or her collaborators, or the design team elects to share its progress with people outside of the team, either upper management or an outside client.

This cycle is conducted *individually* as team members prepare to share their findings and ideas with each other, and *collaboratively* as the team prepares to share with outside audiences. The cycle also repeats as each stage of the design process progresses and as the team iterates and integrates new information. After user research information is captured, reflected, and shared both individually and collectively, conceptual design information is then captured, reflected, and shared individually and collectively, again through multiple iterations.

Figure 6 illustrates an example of how the sharing cycle may look in practice for a team working through user research. For example, a user research team may capture insights with an informal representation (e.g., Post-it notes); reflect on those raw insights by organizing them into a semi-informal representation (e.g., clustered on a whiteboard); or share its synthesized user research findings internally via a semi-formal representation (e.g., a persona) or externally via a formal representation (e.g., user research findings presentation slides). The following sections step through each phase of the sharing spiral, comparing how designers enact that phase during user research and conceptual design.

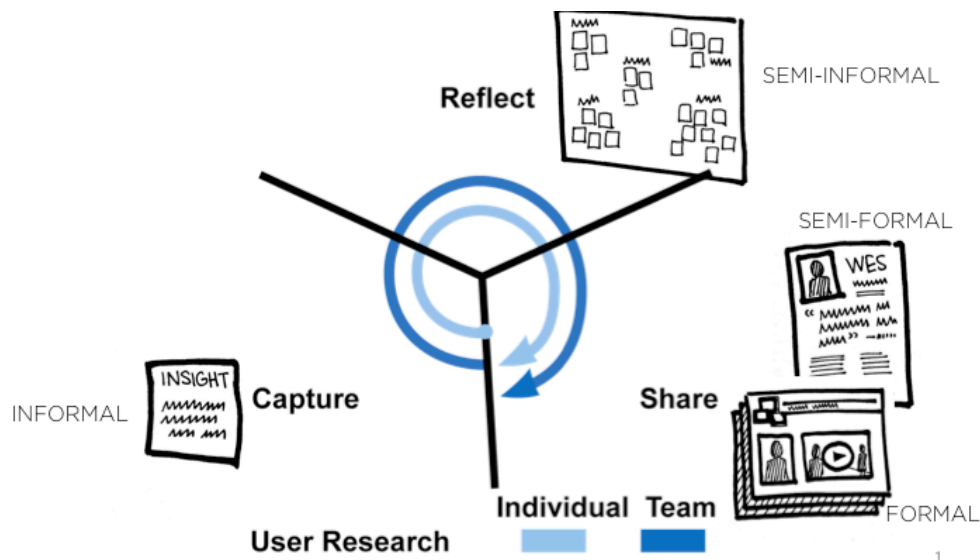


Figure 6: The types of tools and information formality change throughout the sharing spiral. For example, a user research team may capture insights with an informal representation; reflect on those raw insights by organizing them into a semi-informal representation; or share its synthesized user research findings via a semi-formal or formal representation.

CAPTURE: USER RESEARCH

Information must be captured before it can be sorted or shared. One of the most basic ways to capture is to experience through the human senses and refer back to the memory of that experience. In an effort to better record these experiences, information can also be captured through tools that allow for better recall and more objective validity. In addition to personal notes, designers will also employ capture tools (e.g., audio, photo, and video recording devices). One of the participants, a practicing design researcher at a consultancy, described his efforts at doing user research alone:

“Video camera on tripod, and then a plastic folder and paper for taking notes, and field guide. And I’m holding the camera, put the camera down, do this octopus thing, take still pictures, have a video camera, take notes, have a conversation.” (professional)

While these tools can be individually operated, most of the participants conducted field research as a team. Few physical tools are used besides private note-taking. The owners of these personal archives have a fear of their loss (Kaye et al. 2006); however they are more often used as a memory aid (Yeo 2008) that allow designers to offload some of their cognition onto this artifact and allow their thoughts to stay focused on the task at hand (Hutchins and Klausen 1998). This is also true for when teams capture information from individuals—lightweight, informal tools such as Post-it notes are used, allowing continuous social engagement within the team.

Online tools and web services are sometimes used to capture user behavior (e.g., card sorting, surveys, design games, Mechanical Turk), as web accessibility allows for remote observation and research, capturing user behavior in a manageable and accessible format for the rest of the design team. Newer digital tools, including Pear Note and Anoto-based digital notebooks and pens, are being used to integrate different media into the same representation (e.g., audio with text or handwritten notes).

CAPTURE: CONCEPTUAL DESIGN

During conceptual design, individuals capture their ideas in small-scale personal, and often-physical tools that allow for hand sketching. The digital exceptions include tablet laptops, which afford the direct capture of hand sketching, or CAD tools that are used in later stages of design. Designers will also capture ideas, both nascent and developed, through the building of physical or digital prototypes. One professional designer told about capturing ideas as rough prototypes she called “Frankensteins” while interviewing a potential user:

“When we go into a session, sometimes with Frankensteins, I can think of a couple times where one person will be like, ‘Oh, you’re using it that way, let’s do it like this,’ and they’ll take one part off and screw another part on.” (professional)

REFLECT: USER RESEARCH

During user research, field notes generally begin as private to each individual. Once data has been collected, individual designers or researchers must reflect on what is pertinent to their research goals. These reflections may be recorded in notes as annotations or reflections or simply tagged in their minds as important to consider and perhaps shared with peers. After the pertinent information has been identified, it is themed, clustered, and filtered in order to make sense of the data. This may occur on an individual level or as a group. Tools to support reflection and organization activities included spreadsheet software (e.g., Excel) or large-scale physical tools (e.g., butcher paper). These tools can accommodate individual contributions by breaking down into smaller units, either cells within a shared spreadsheet or the accumulation of smaller physical tools (e.g., Post-it notes).

In either case, the outcome is a record of the reflections, discussions, and decisions in the form of a digital or physical representation. As these representations are being created, designers reference the raw data (e.g., user research transcripts, video, audio, photographs, or conceptual designs). The choice of representation media may affect how the designer or group of designers is able to structure or synthesize their captured data. For example, one user researcher described her use of informal, physical tools to synthesize results:

“What we do is read them, make notes, and talk about them. It’s pretty low-fi, there’s Post-it notes everywhere; we’re clustering, debating, identifying patterns. If you’ve been doing this for years, themes emerge in the field and you get instincts and know where you’re heading. Analysis is checking that, giving things weight and priority, figuring out how they relate to each other. Then it’s piles of Post-it notes, putting stuff together.” (professional)

Her coworker, however, preferred the linear structure offered by presentation software:

“PowerPoint for me is a good thinking tool because it’s linear in a certain way, bit by bit by bit.” (professional)

REFLECT: CONCEPTUAL DESIGN

During conceptual design, additional documents are often referenced to help structure or filter ideas. These documents are often more formal than the rough concepts (e.g., product specifications, results from usability testing, etc.). Introducing these external sources may also open the designer to previously unconsidered options or constraints, and inspire further creative idea generation.

Either as an individual or as a team, design directions and concepts must be evaluated and decided upon. Individuals decide what concepts to share or to combine, while teams discuss possibilities, build off each other’s ideas, and draw in new ideas during the reflective discussion.

SHARE: USER RESEARCH

To create sharable, formalized representations, designers will curate the raw user research data or conceptual designs into a representation that supports a particular point of view. For example, one of the practicing designer researchers created a set of video “trailers” or short “edu-mercials” to inform different members of his consultancy’s client company about user insights and design imperatives arrived at through the user research. From hours of interview and observation footage, the project team carefully selected and edited together clips that supported its conclusions in an engaging and memorable way, both to facilitate buy-in and stimulate curiosity about what else was learned.

Not all sharing is done solely for the sake of information transfer—some of the user researchers chose to engage designers in activities or workshops where conceptual design stems directly from the communicated synthesized research results. They saw these workshops as increasing the likelihood that the information was immediately useful in the next stage of design, concept generation. This was reported from design researchers at consultancies:

“Presentations are when we’re telling you what we learned, it’s our download to them. The mode of the workshop or ideation session is very different—we’re now facilitating, we’ve a specific process we want them to go through, we’re taking these opportunity areas that are trailheads.” (professional)

In-house design researchers were also encountered who found value in hands-on workshops with their designer coworkers:

“Anyone who’s really interested will come to the meeting later to review and talk about the next activity, which might be to create a persona to personify the voice if we’re looking for a human voice in the software.” (professional)

As designers take this formalized information from the user research phase, they return to an individual, informal capture mindset as they create new ideas, and the sharing cycle continues.

One insight from the interviews, surveys and document analyses was the changing interplay between levels of formality and sharing semantics in the early stages of the design process. As information is captured, reflected upon, and shared, its formality gradually increases as synthesis and decision-making impose additional structure.

SHARE: CONCEPTUAL DESIGN

Once designers have reflected on what is pertinent, interesting or valuable, they may share the results of those reflections in the form of synthesized user research findings, concepts, mock-ups, or prototypes. As these artifacts are shared, they are refined to include increasing amounts of detail. To accommodate this detail while maintaining their comprehensibility to an outside audience, these shared documents require increased structure and formality, eventually becoming the formalized documents as identified by Yang, Wood, and Cutkosky (2005).

Due to their ability to iterate on high fidelity, polished concepts, digital tools such as CAD, publishing software, and presentation software are often used to create and share many types of refined representations. The amount of embedded detail increases significantly when the designer or designers are anticipating sharing with a future audience or archiving information for future reference.

DESIGN TOOLS IN CONTEXT

Following the interviews, the research team developed and deployed a survey to gather broader and more consistent data on which tools are used in which collaborative contexts, and to what end. The initial questions in the survey offer insight into the professional lives of the respondents. The amount of experience among survey respondents is skewed towards more years of experience—most respondents have over 13 years of experience in the design field (11 respondents, 38%). The respondents relatively evenly represent most organization types—Corporate or Enterprise (7 respondents, 24%), Design Consulting Firm (8 respondents, 27.5%), Freelance or Independent (8 respondents, 27.5%), Academia (7 respondents, 24%)— with the exception of only few respondents working at Startups (4 respondents, 14%). The most common job functions among the respondents were the phases of design most relevant to this research: planning design/user research studies (26 respondents, 90%), conducting generative or exploratory research (24 respondents, 83%), and ideation and generating design concepts (24 respondents, 83%). While few respondents worked on designing buildings and environments (4 respondents, 14%) and public sector products and services (9 respondents, 29%), there is relatively even representation from other areas of design—business and services (16 respondents, 55%), physical products (15 respondents, 52%), software (17 respondents, 59%), and websites (17 respondents, 59%).

In the main section of the survey, respondents indicated which tool categories within the above schema they used frequently, occasionally, or not at all. Respondents noted which physical, digital hardware, software, and online tools they used to *Capture Information about the Design Problem* (see Figure 11) and perform *Information Analysis and Synthesis* (see Figure 12). These particular activities address how individual designers Capture and Reflect during early stage user research and problem framing.

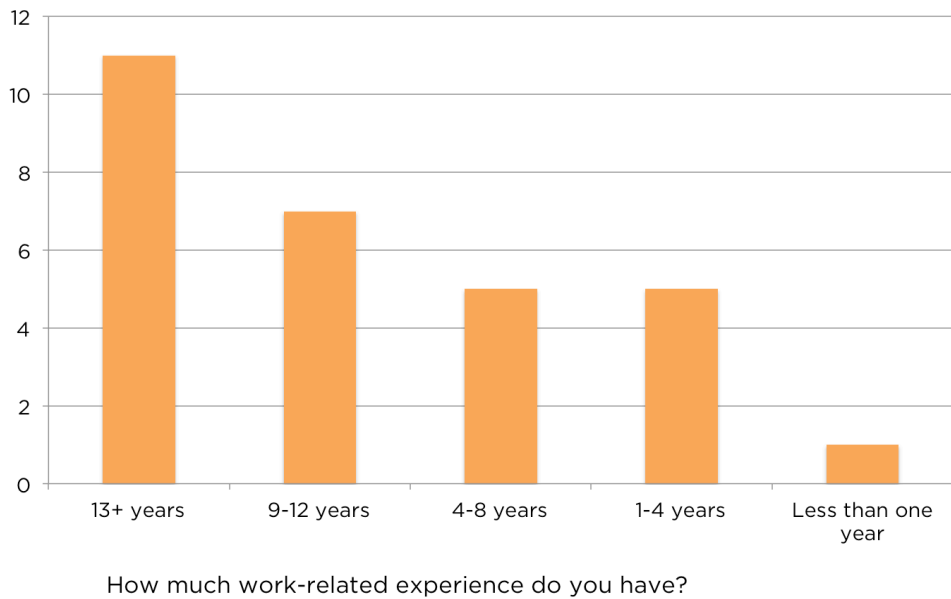


Figure 7: Number of respondents with each range of work experience. The respondents of the survey skewed towards veteran professional designers and design researchers who had over 13 years of experience.

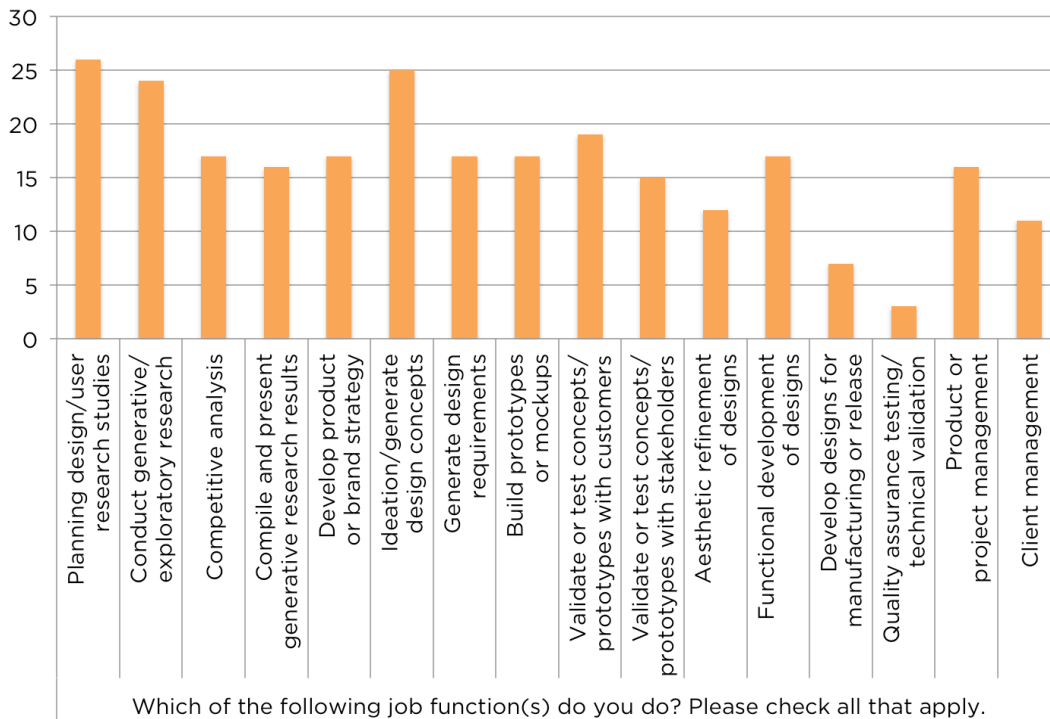


Figure 8: Number of respondents who reported having a given job function. Note that respondents could select as many job functions as were applicable to their professional practice.

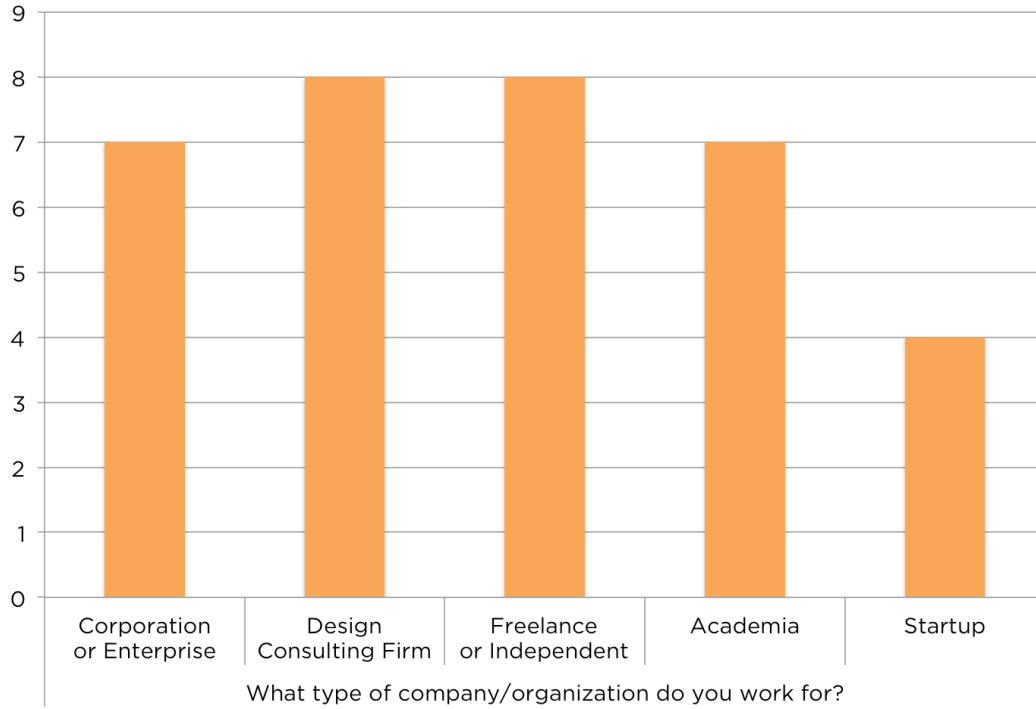


Figure 9: Number of respondents working for each type of company or organization. Note that respondents could select as many types of company or organization as were applicable to their professional practice.

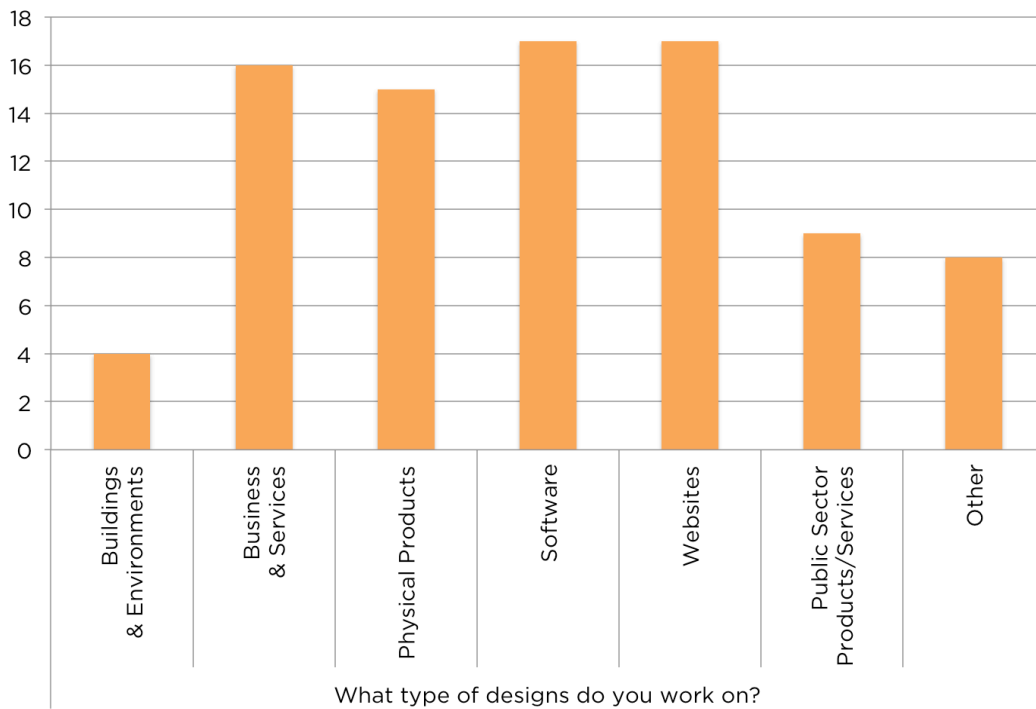


Figure 10: Number of respondents working on each type of design. Note that respondents could select as many types of design as were applicable to their practice.

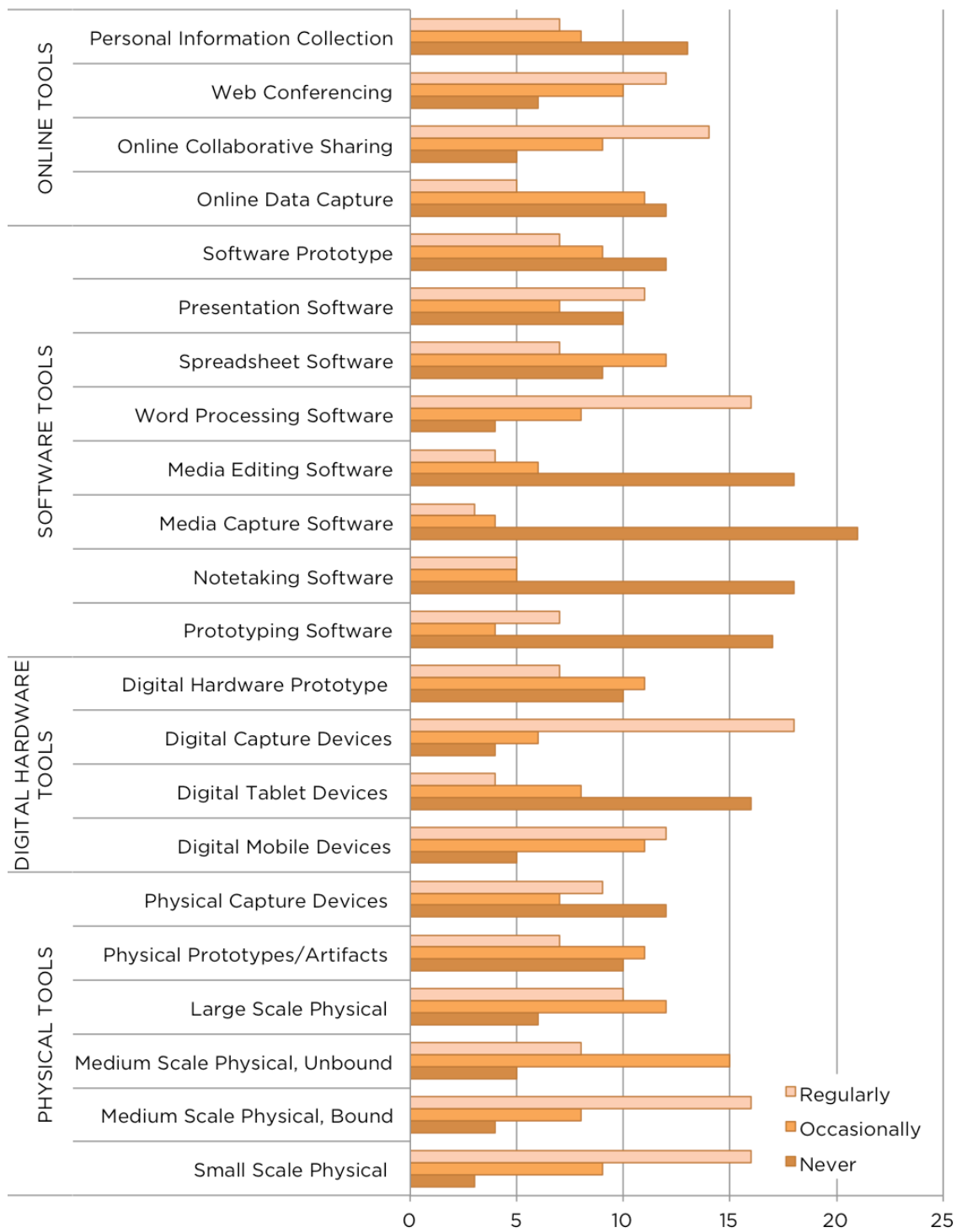


Figure 11: Number of respondents that reported using physical, digital hardware, software, and online tools either regularly, occasionally, or never while *Capturing Information about the Design Problem*.

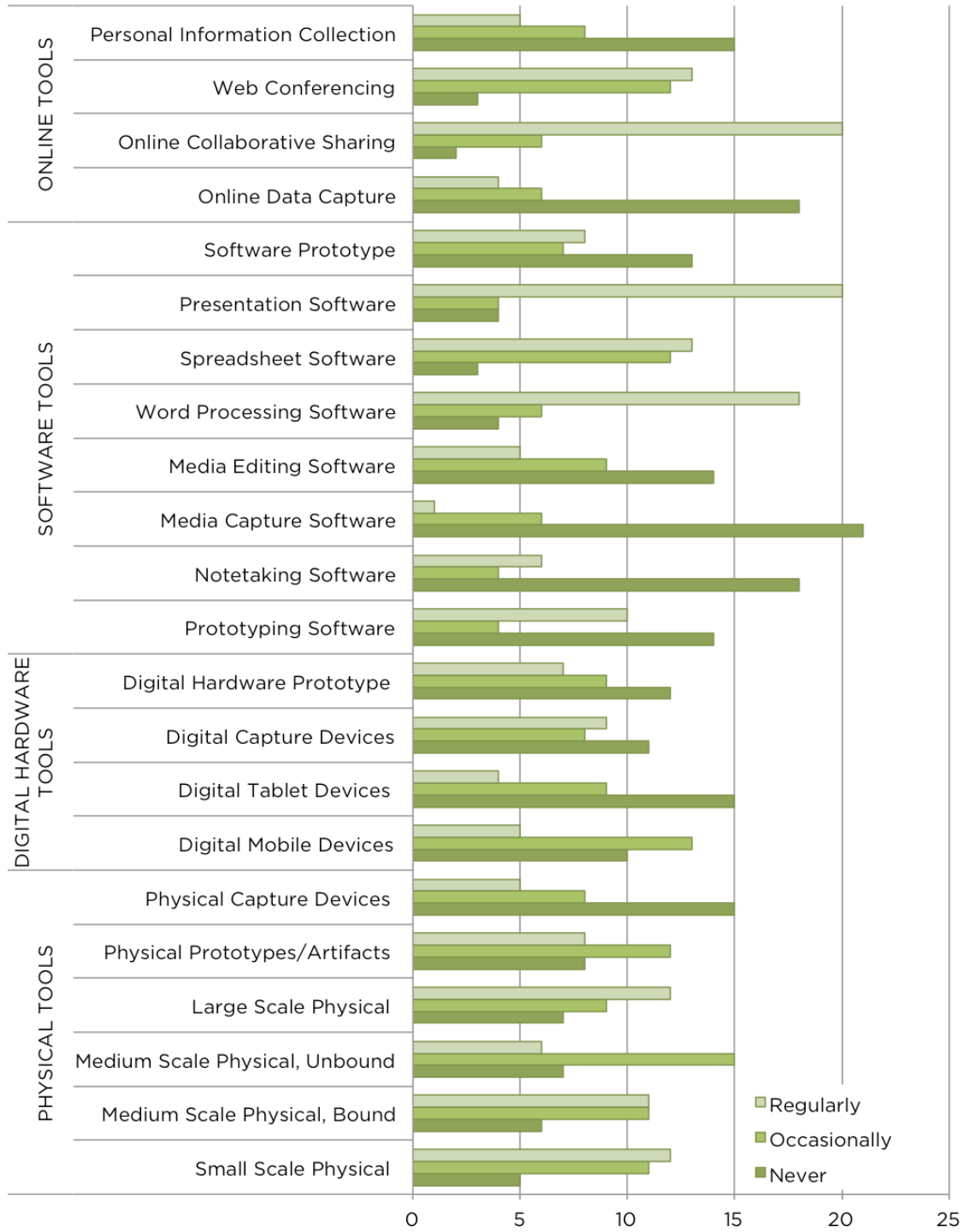


Figure 12: Number of respondents that reported using physical, digital hardware, software, and online tools either regularly, occasionally, or never during *Information Analysis and Synthesis*.

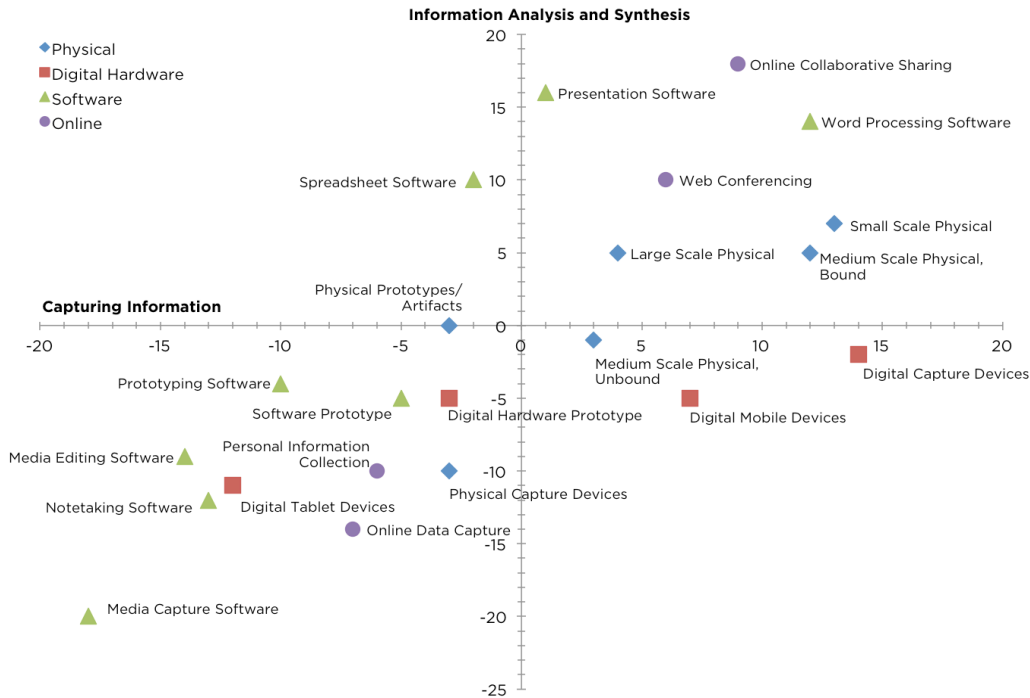


Figure 13: Relative usage of tools during Information Analysis and Synthesis, and Capturing Information about the Design Problem. Relative usage of each tool is calculated by scoring based on how frequently respondents reported using the tool: +1 for each “Regularly” response, +0 for each “Occasionally” response, and -1 for each “Never” response.

We created an additional visualization (see Figure 13) to identify which tools are versatile (used for both *Information Analysis and Synthesis* and *Capturing Information about the Design Problem*), specialized (used for either one activity or the other), or rare (not used regularly for either activity). The y-axis represents the relative usage of each tool for *Information Analysis and Synthesis* and the x-axis represents the relative usage of each tool for *Capturing Information about the Design Problem*. The relative usage of each tool was calculated by scoring it based on how frequently respondents reported using the tool: +1 for each respondent who reported using a tool “Regularly,” +0 for each respondent who reported using a tool “Occasionally,” and -1 for each respondent who reported “Never” using a tool. By plotting the scores for *Information Analysis and Synthesis* and *Capturing Information about the Design Problem* against one another, which tools are commonly used for both activities (upper-right quadrant) or are generally less-commonly used (lower-left quadrant). Tools in the upper-left and lower-right quadrants are used asymmetrically and are preferred for one activity over the other.

The most ubiquitous technologies for the survey respondents are small-scale, medium-scale bound, and large-scale physical tools, word processing and presentation software, and online collaboration services for video chat and file sharing. It is interesting to note that few tools were exclusively used for only *Information Analysis and Synthesis* or only *Capturing Information about the Design Problem*. Digital mobile devices and capture devices are primarily used to capture design information; spreadsheet software is primarily used for information analysis. All other tools mentioned in the survey, including specialized tools such as prototyping software, media editing software, and online data capture, did not have as resounding use rates for either activity.

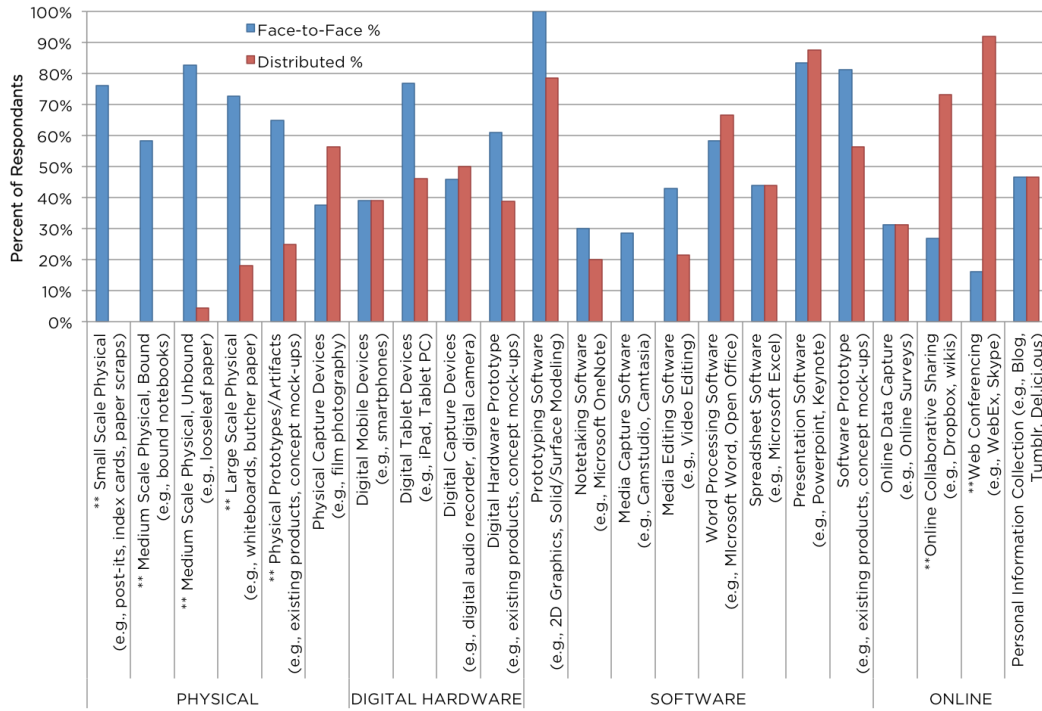


Figure 14: Percent of respondents who reported using given tool “frequently” or “occasionally” that used a tool for face-to-face or remote collaboration. Items denoted with ** have a statistically significant difference between the proportion that use that technology for face-to-face and remote collaboration.

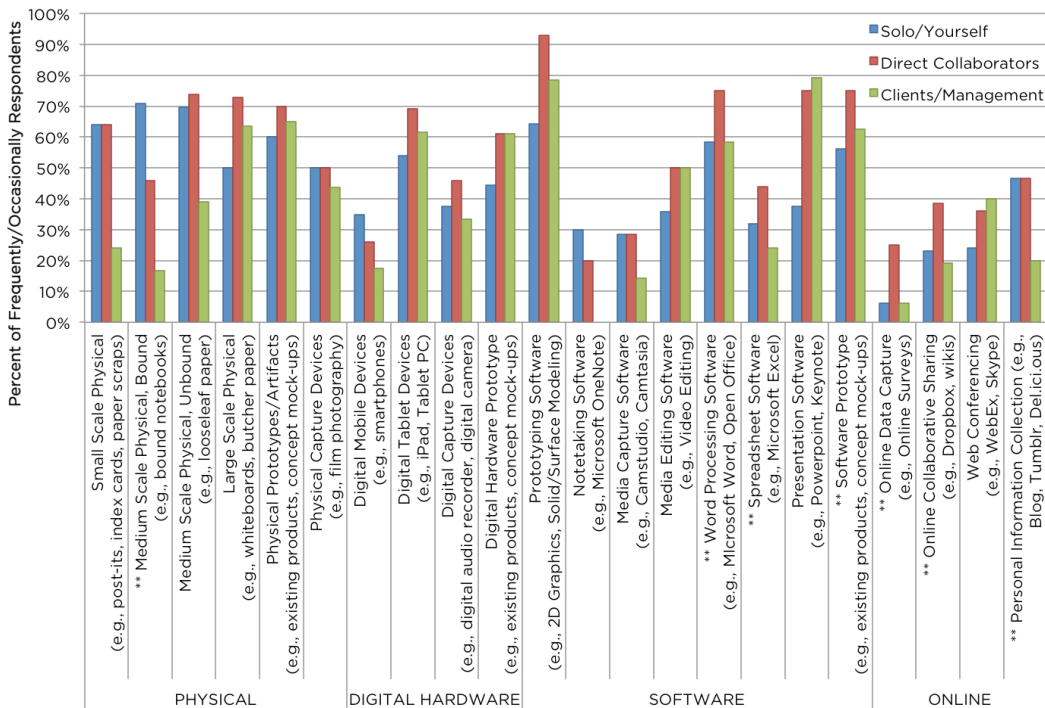


Figure 15: Percentage of tools used to communicate with him or herself, with direct collaborators, or with clients or management. Items denoted with ** have a statistically significant difference between direct collaborators and clients/management.

Figure 14 reports on the percentage of individuals using a given tool that reported using it for face-to-face and distributed collaboration. Our respondents reported using physical tools primarily for face-to-face collaboration, whereas Online Collaborative Sharing and Web Conferencing (both online tools) were primarily used for distributed collaboration. It is interesting to note that these specialized tools for face-to-face and distributed collaboration are also the most popular tools to use for both *Information Analysis and Synthesis* and *Capturing Information about the Design Problem* (from Figure 13). Digital hardware and software were used consistently in both face-to-face and distributed collaboration.

Figure 15 represents which tools each respondent used to communicate design ideas to him or herself, to direct collaborators, and to clients or management. When asking which tools were used in a range of collaborative contexts, most designers used tools individually and with direct collaborators for the same amount. The one exception to this is bound medium-scale physical tools—commonly used as design journals. When comparing the types of tools used with direct collaborators and clients, however, there were far more differences in the percent of respondents that reported using a given tool. A significantly higher percentage of designers reported using medium-scale bound physical tools, spreadsheet software, software prototypes, online data capture, online collaborative sharing, and online personal information collection with direct collaborators compared to clients/management. However, one possible reason for this difference is that designers communicate more frequently with direct collaborators than they do clients/management.

These survey results demonstrate the range of today's diverse design tools—many are specialized to cater to the particular needs of a designer's collaborative context. As a set, however, they are able to manage *Capturing Information about the Design Problem* and *Information Analysis and Synthesis*, face-to-face and distributed collaboration, as well as a range of audiences (both direct collaborators and external clients).

CONCLUSION

This chapter presents a categorization schema for the range of design information tools in use, and uses the existing concepts of the formality spectrum and sharing semantics to develop a new framework. The data for this chapter was gathered through a survey of 29 professional designers and design researchers and interviews with 17 professional and 17 student designers and design researchers.

We introduced a categorization scheme for design information tool media—*Physical*, *Digital Hardware*, *Software*, and *Online Tools*—and applied this to the 53 design tools mentioned in the interviews. The survey of professional designers found that while there are distinct differences in which design tools are adopted and used for information capture and analysis, there are actually few differences in which tools are used individually and in a team setting. Direct collaborators, however, are exposed to a much larger set of design tools than clients.

Through analysis of the interviews with students and professionals, the formality spectrum was revised to include more defined points along the spectrum. These include *Informal*, *Semi-Informal*, *Semi-Formal*, *Formal*, and *Archival* information. This additional definition helps describe how information formality changes over time, within a tool or across different tools. This chapter also examined how design tools enable designers to transition between different sharing semantics—private, personal and public.

Finally, a new framework was proposed to describe how designers negotiate information both individually and as a team, across user research and conceptual design. The sharing spiral notes that designers cycle through capture, reflect, and share, both as individuals and as teams, during user research and conceptual design.

Of particular interest to this thesis is how individuals share information and teams capture and use that information. The following chapter applies the sharing spiral to observation data from face-to-face team meetings, identifying some of the challenges teams face in managing design information.

CHAPTER 5

SHARING SPIRAL IN THE WILD: INSIGHTS FROM OBSERVATIONS

INTRODUCTION

The sharing cycle, which describes how information flows from individuals to teams during user research and conceptual design, was introduced in the previous chapter based on self-reports of designers' uses of technology and tools for sharing information in face-to-face team meetings. This chapter focuses on the challenges of enacting the sharing cycle in real-world design team meetings.

This chapter enters “the wild” of design practice and reports on observations of design team interactions during face-to-face meetings about user research and conceptual design. This vantage point clarifies how real-world teams move through the sharing spiral, a conceptual framework that describes how information flows from individuals to teams during research and conceptual design. It is also possible to identify challenges that the teams face as they move through each stage of the cycle.

These observations of face-to-face student design team meetings lead to the identification of four major goals for teams, which correspond to applicable stages of the sharing cycle. These goals are:

- *Transfer individuals' information to the team.*
- *Synthesize individual information into the team's shared frame.*
- *Record current design activity for future reference.*
- *Build on past team activity in the present moment.*

Teams face a series of challenges to meeting each goal, summarized in Table 6.

Sharing Cycle	Goal	Challenges
Individual/Share Team/Capture	Transfer individuals' information to the team.	C1. Identify individual information that is relevant to the team. C2. Translate from personal preferred formats into a common format. C3. Efficiently share rich information with collaborators C4. Control how information is interpreted by the team.
Team/Reflect	Synthesize individual information into the team's shared frame.	C5. Ensure that shared decisions reflect individual contributions.
Team/Share	Record current design activity for future reference.	C6. Negotiate how information is recorded, and by whom. C7. Decide what to record in the present moment.
Team/Capture	Build on past team activity in the present moment.	C8. Find relevant information from previous sessions. C9. Present past information in a format that is useful to the team's current activity.

Table 6: Summary of goals that collaborating designers are trying to address at three key points in the sharing cycle. Also, corresponding challenges that teams face when trying to accomplish each goal.

These challenges were observed in video data from a series of student design team meetings, particularly in the student designers' interactions with each other and with available information technology and tools. This chapter examines each goal and identifies the challenges associated with each goal.

RELATED WORK

There are many examples of previous work that analyze direct observations or video of design team behavior to understand team coordination (Brereton et al. 1996), management of information (Milne and Leifer 2000), and manipulation of communication artifacts (Edelman 2011). In addition to face-to-face settings, researchers have also studied the mobile practices of design collaboration to better understand how ad-hoc design work happens (Bellotti and Bly 1996). Researchers have also observed design teams' collaborative behavior with the goal of developing systems for computer-supported collaborative work (Tang 1991).

This work examines collaborative work in a naturalistic setting—student design teams working on an open-ended project, selecting their own tasks, tools, and processes. This chapter focuses on understanding the team's current collaboration challenges; the following chapter discusses the implications that these challenges have on new technologies for design teams.

ANALYSIS METHODOLOGY

For the qualitative analysis, two research analysts reviewed transcripts and video from observations of student design team meetings. As the analysts viewed the video, they added notes on the team's gesture and movement to the transcript. The analysis started with an open coding of the video

transcripts, including verbal utterances, gestures and actions. These open codes included notes on team process management, relationship management, and discussions that contributed to the conceptual development of the team's design.

Each instance of technology use was coded with the type of technology in use and how it was being used. All team discussions that directly addressed the technology that they were using were also noted. The research analysts exchanged research memos and compared open codes, ultimately focusing on the challenges that teams faced and how these challenges were handled via information technology or interpersonal communication. This analysis led to the nine identified design challenges.

This chapter focuses on the stages of the sharing spiral that represent the interactions that design teams have with technology during face-to-face team meetings. This includes: Individual/Share, Team/Capture, Team/Reflect, Team/Share. Figure 16 illustrates the segment of the sharing cycle that is addressed during face-to-face team meetings.

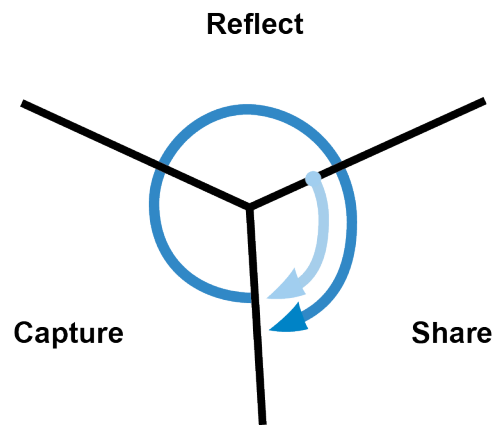


Figure 16: Section of the Sharing Cycle that is relevant during face-to-face team meetings.

By analyzing the video observations with the sharing cycle in mind, the research team identified team goals that correspond to particular phases of the sharing cycle (see Figure 17):

Individual/Share & Team/Capture: *Transfer individuals' information to the team.*

Team/Reflect: *Synthesize individual information to the team's shared frame.*

Team/Share & Team/Capture: *Record current design activity for future reference.*

Build on past team activity in the present moment.

The following section focuses on each of these sharing cycle stages and how the teams attempt to meet these goals. This section highlights particular quotes and images that reveal the challenges faced by teams as they attempt to reach these goals (see Table 6). A detailed analysis is included in the Appendix.

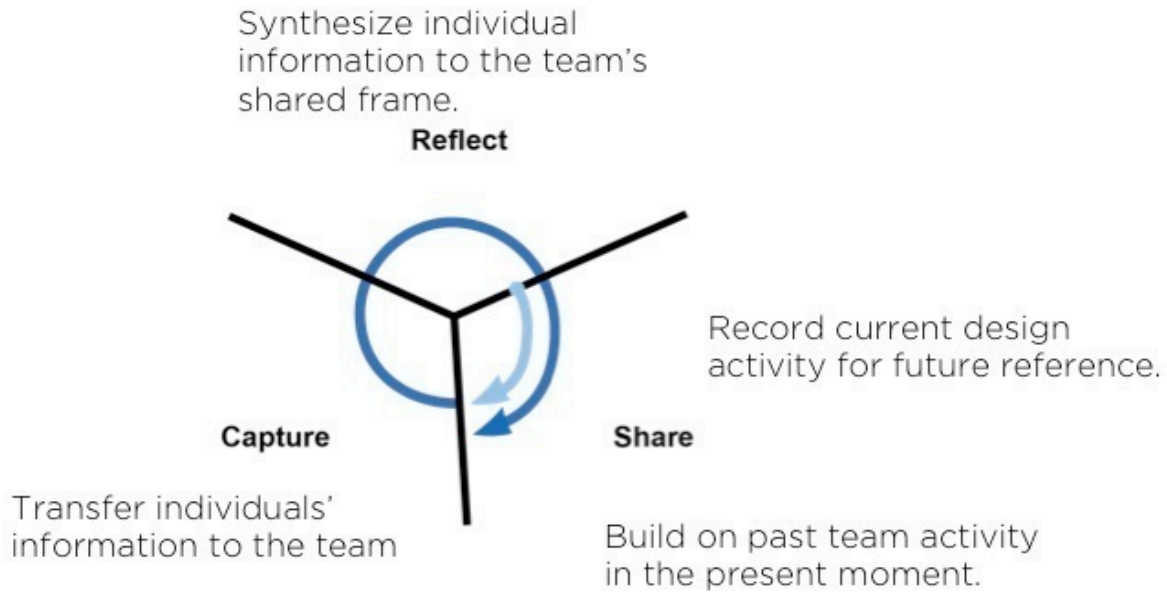


Figure 17: Design team goals that correspond to stages of the sharing cycle relevant during face-to-face team meetings.

TEAM OBSERVATION OVERVIEW

This chapter is based on video-recorded observations from three teams from UC Berkeley's ME290P "Managing the New Product Development Process" class during the fall 2010 semester. In this graduate-level course, students work in cross-disciplinary teams on semester-long human-centered design projects. The course was structured around individual assignments that often implicitly contributed towards team deliverables. The course instructors set up Dropbox accounts to help teams manage files. Dropbox is an online file sharing service that allows multiple users to maintain synchronized shared files and folders on multiple machines.

Meetings were video and audio recorded from three teams, designing along the themes of Working Women's Wardrobe (4 members), Household Water Conservation (6 members), and Accessible Public Transportation (4 members). Each team represented a different type of collaboration and technology use. Each observed meeting was focused on building on individual assignments to produce an upcoming team deliverable. The research team also had access to documents produced during these meetings that were shared through the course Dropbox account. Due to scheduling constraints, only one team's conceptual design meeting was observed (Household Water Conservation).

A summary of these research subjects, including the technologies used at each meeting setting, is in Table 7. None of the teams met in dedicated design studios—all teams were nomadic, setting up in temporary spaces such as conference rooms, student group work lounges, or classrooms. While some professionals have the luxury of working in a dedicated design space, it is very common for professionals to conduct collaborative work in conference rooms or other temporary workspaces.

The following section describes each team's makeup, design problem, meeting context, and the technologies used during each meeting.

Team	Individual	Discipline	Technology Used	
			User Research	Conceptual Design
Working Women's Wardrobe			Whiteboard	N/A
	ALF	MBA	Laptop (PC)	
	BRA	ENG	Laptop (tablet PC)	
	CHA	MBA	Laptop (PC), notebook	
	DEL	MBA	Laptop (PC)	
Household Water Conservation			Whiteboards (3)	Whiteboard
	ECH	ENG	Laptop (Apple), smartphone	Laptop (Apple)
	FOX	ENG	Laptop (PC), smartphone	Laptop (PC)
	GOL	MBA	Laptop (PC), notebook	<i>[not present]</i>
	HOT	ENG	Laptop (Apple), notebook, smartphone	Laptop (Apple)
	IND	ENG	Laptop (Apple), notebook, smartphone	Laptop (Apple), smartphone
	JUL	MBA	Laptop (PC), notebook	Laptop (PC), notebook
Accessible Public Transportation			Large display	N/A
	KIL	CCA	<i>[via videoconferencing]</i>	
	LIM	MBA	Notebook, mobile phone	
	MIK	ENG	Laptop (PC)	
	NOV	ENG	Laptop (PC)	

Table 7: Summary of design teams and research subjects from NPD 2010, including discipline and technology used.

TEAM A: WORKING WOMEN'S WARDROBE

The Working Women's Wardrobe team has four members: KGB, CHA, and DEL are all MBA students; BRA is an engineer. The team's mission statement at the time of the observed meeting is:

"A branded, comfortable, high-quality, new pair of pants that fits well and offers an innovative design for urban professionals."

The observed meeting takes place in a small meeting room inside the Haas School of Business Computing Center. At this point in the semester, each student has already performed initial interviews; the team is now synthesizing those findings to identify a research direction.

The most prominent, consistent use of technology throughout the meeting is ALF extensively using her laptop to take notes; these meeting minutes show up on Dropbox after the meeting. BRA occasionally uses a stylus to interact with a tablet laptop, but does not appear to directly reference content from this tablet laptop during the meeting. DEL regularly glances at his laptop, occasionally reading aloud relevant user interview notes or deliverable guidelines from the course syllabus during the meeting.

CHA also has a laptop and a notebook, but only occasionally refers to them—he checks email on his laptop and pulls out his paper notebook to specifically reference an analytical framework mentioned in class. All laptops remain open when not in use.

The room has a large whiteboard on one side of the wall; the whiteboard is nearest to CHA, who writes on this whiteboard during the meeting, using it to outline an email to the team's coach, to note the main needs that the team has identified, and to support an impromptu explanation of a possible way for the team to structure and prioritize its needs. The room also has a large display in the room; while the team initially expresses some interest in figuring out how to connect the display to KGB's laptop, they quickly elect not to use it due to its perceived complexity.

TEAM B: HOUSEHOLD WATER CONSERVATION (USER NEEDS)

The Household Water Conservation team has six members: GOL and JUL are MBA students; FOX, IND, ECH, and HOT are engineering students. The team was observed during two meetings, one week apart: the first meeting is focused on user needs research, the second on concept generation. The team's mission statement at the time of the observed meeting is:

“A solution that helps reduce environmental impact from the American household bathroom by reducing water use, changing usage behavior, or by reusing waste water.”

User Research Meeting

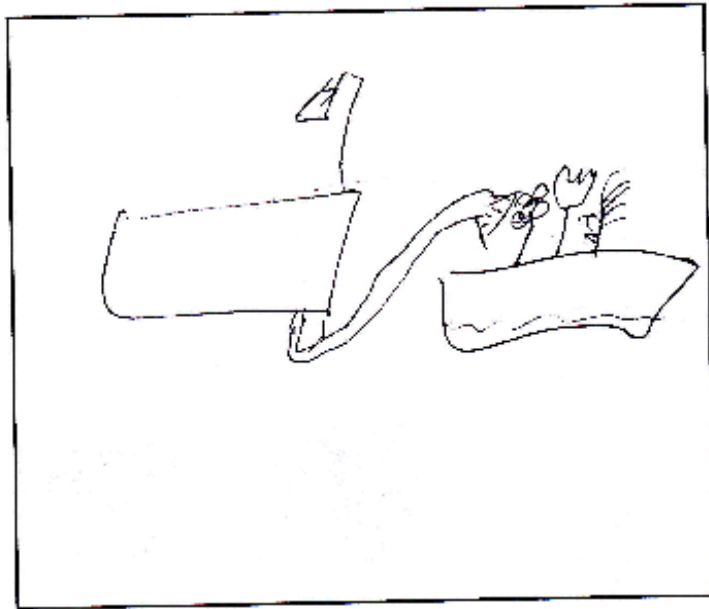
For the user research meeting, the team members come together in an open meeting space and lounge at the School of Information. The team pulls up chairs around a small table, which is surrounded by several nearby whiteboards. All six members of the team are present. The team is continuing to develop and share its user needs with each other. At this meeting, team members have already conducted interviews individually and are trying to synthesize their qualitative research findings into frameworks. The team comes up with a list of questions that they still need to ask its users. The team also begins to leap ahead to brainstorm a few ideas.

ECH, HOT, FOX, and JUL have laptops that they refer to throughout the meeting. These laptops are half-shut when not in use. At first, everyone uses their laptop computers, but eventually GOL, HOT, IND, and JUL also utilize paper notebooks. The whiteboards surrounding the table are used during the meeting; JUL and GOL write on them, drawing the rest of the team's attention to these whiteboards. Four members of the team (ECH, FOX, HOT, IND) have cellphones on the table or in their bags. During the meeting, they use their phones to capture the whiteboards that the team has been working on.

Concept Generation Meeting

The following week, the Household Water Conservation team meets again to generate concepts and discuss possible solution directions. Earlier that week, each student submitted an individual assignment to brainstorm ten ideas. The assignment was to document individual concepts on half-sheet concept templates provided by the course instructors (see Figure 18) and to submit the concepts by scanning the sheets and uploading them to the team's Dropbox folder. The team meets in a classroom at the Haas School of Business. This classroom has a large whiteboard in the front of the room, and a projection screen that hangs in front of the whiteboards. There is a semi-circle of tables in the front (left, middle, right) and a pedestal table in the center of the semi-circle that is easily moved out of the way (see Figure 19).

Name [redacted]
Title Greenhouse Plants
Description
A garden/assortment of plants that are planted in bathroom & can use the greywater to filter through
What are its features & attributes? (adjectives)



New

Figure 18: Example concept half-sheet from the Household Water Conservation team.



Figure 19: The Household Water Conservation meets for their concept generation meeting in a classroom at the Haas School of Business. Note the whiteboard at the front of the room, and the small, movable white table.

GOL is not present at this meeting. Throughout the meeting, the team discusses how they will go about making a decision with GOL not present at the meeting for the team's discussion. From the user needs meeting, it is clear that GOL is instrumental in facilitating decision making for the team. Thus, the team adjusts its process to accommodate his input, deciding to postpone any final decisions until GOL is able to weigh in.

HOT, JUL, FOX, and ECH each have laptops open at the beginning of the meeting. However, the team switches into a concept clustering task; at this point, JUL, HOT and FOX walk away from their laptops. They occasionally refer back to these laptops as a reference later in the meeting, particularly in reference to the mission statement and prioritized user needs from the previous meeting. IND opens up his laptop halfway through the meeting, and sits to work at it in the front of the room. He looks at his laptop while mentioning email updates from their coach to the rest of the team. JUL refers to his paper-based design journal/notebook throughout the meeting.

Much of the concept generation meeting is spent manipulating pieces of paper laid out on the floor. IND, HOT, JUL, and FOX pull out stacks of paper that already have sketches; ECH redraws his scanned concept images from his laptop on to slips of paper that are more manipulable by the rest of the team. The stacks are labeled using Post-it notes. The whiteboard is briefly used to write down the team's prioritized user needs from the previous meeting. FOX and IND have smart phones that are used during the meeting to photograph images of the stacks of concept half-sheets.

TEAM C: ACCESSIBLE PUBLIC TRANSPORTATION (USER NEEDS)

The Accessible Public Transportation team has four people: LIM, an MBA student; MIK and NOV, both engineering students; and KIL, an industrial design student. The team's mission statement around the time of the meeting is:

“To enable a safer and more comfortable bus transit experience for passengers of short stature.”

For their user research meeting, three out of four team members (LIM, MIK, and NOV) are co-located in a conference room in the Haas School of Business library. They begin a conference call/Skype session with KIL, who is based in San Francisco. There is a large display on the wall, available for them to use.

Over the course of the team's meeting, they extensively use prepared PowerPoint slides to support their discussions. They take turns reviewing secondary market research on various public transportation systems around the world (LIM, NOV, KIL), and statistics about safety on public transportation and the lives of shorter people (MIK). They also take turns reporting back on user interviews that they conducted, as well as direct observations from their own first-hand experiences on public transportation. However, the reports back on user interviews were primarily verbal and were not supported by PowerPoint slides.

The co-located team drives the large display in the room via a laptop computer owned by LIM but operated by MIK. NOV has her laptop on the table, which is half-open when not in use. LIM has a stack of papers and a pen in front of him as well as a mobile phone, which he periodically references. KIL is heard but not seen, as she is calling in from San Francisco—however, it can be assumed that she is using a computer to videoconference with the rest of the team.

RESULTS

This section examines the teams' activity at specific phases of the sharing cycle, when the design team is addressing particular collaboration goals:

- *Transfer individuals' information to the team.*
- *Synthesize individual information into the team's shared frame.*
- *Record current design activity for future reference.*
- *Build on past team activity in the present moment.*

However, as teams attempt to perform these goals, they encounter challenges that make this work more difficult. Each section below identifies each goal's challenges.

GOAL: TRANSFER INDIVIDUALS' INFORMATION TO THE TEAM

As individuals share information with the team, the team captures that information into its shared knowledge. Thus, the goal for individuals is to transfer his or her information to the team.

First, *individuals need to identify personal information that is relevant to the team (C1)*. Not all information is important enough to share with the team, or relevant to the current conversation. While this occurs seamlessly during most meetings, technology can get in the way of this step. For example, the Accessible Public Transportation team only had one person (MIK) who was able to control the shared display. As a result, the rest of the team had to explicitly instruct MIK to navigate to the items that they wanted to show to the team. For example:

LIM So can you go to Dropbox again?
MIK Okay.
LIM Go up one. Walking. Can you go to Walking from this? And 'Shorter Person Questionnaire'... that one.

Another aspect to this challenge is keeping collaborators peripherally aware of personal information such that relevant information can be requested if needed. For example, JUL looked over GOL's shoulder during the Household Water Conservation team's user research meeting, and was able to request that GOL share his idea with the rest of the team.

Second, *individuals need to translate information from their preferred communication mode to one that is standardized within the team (C2)*. Chapter 4's research findings demonstrate the variety and diversity of information tools adopted by student designers and design researchers. However, when it comes time to share information with the entire team, individuals must convert their information from their personal preference into a mode that the entire team can adopt and work with. One way that teams handle this is to prepare visual communication materials in advance (e.g., PowerPoint slides, photos, physical concept sketches). However, when an individual arrived unprepared or the team's communication took an unpredictable turn, students resorted to ad-hoc methods of translating information. For example, in the Household Water Conservation team's concept generation meeting, ECH forgot to bring his concept sheets in the previously agreed-upon paper form—a format critical for the shared task of physically organizing the team's ideas.

ECH I don't have them, but I know what they are if that helps.
HOT That helps.
IND We need to have physical things.
HOT We need to reorganize and stuff.
IND Do you have extra blanks, so we can write them out real quick?
JUL I do.

Because there was no immediately available printer, ECH manually copied his ideas from where they were digitally backed up through the bulk of the meeting, disengaging himself from the rest of the team discussion. Another approach is to directly display personal sources of information to the rest of the team. In several instances, individuals turned their physical notebook or laptop towards the rest of the team to briefly show its contents to their peers (see Figure 20). While this accomplished the goal of transmitting information to collaborators, not everyone was able to see the details or context of the information.

Third, *individuals need to efficiently “share richly” with their collaborators (C3)*. While teams primarily communicate orally with each other, Hey et al. note the value of including rich media in team framing conversations (Hey 2008). However, sharing richly and going into detail also requires more time and technology resources than a team may have available. For example, members of the Working Women’s Wardrobe team primarily shared high-level findings from their research orally; while efficient, it lacks the descriptive richness of other forms of communication. One approach that teams currently use is to physically re-enact situations from user research and interviews. In Figure 21, GOL re-enacts a scene from his user research (using a bucket to collect shower water) for his Household Water Conservation teammates. These reenactments not only potentially build empathy for users, they also allow the team to ask follow-up questions of the simulated user, given the additional context of the gestured action. However, such a reenactment may not be entirely accurate to the original user’s experience compared to sharing a primary source.

Finally, *individuals need to control how information is transferred to the team (C4)*, often prioritizing and highlighting their information or directing the team’s attention to convey a rhetorical position. After the designer identifies personal information that is relevant to the team (C1), he or she still needs to interact with that information in order to properly convey its intended meaning. Some of the observed students offered a synthesis of their user research in order to guide the team towards their particular interpretation; however, such summaries often lack valuable rich description. Other students built an argument by going through data in detail and orally, physically, or virtually highlighting whatever information is most relevant. This is particularly evident in the Accessible Public Transportation team, where only MIK is able to directly control the public display and others must gesture in order to direct the group’s attention. In Figure 22, NOV points to one of the images on a PowerPoint slide to direct the team’s focus to a particular image.

However, there are two notable exceptions to the need to control others’ interpretations. One is when sharing raw user research information with teammates—when sharing images from observations of how people stand on busses, all members of the Accessible Public Transportation team were able to identify details and offer interpretations of user behavior. The second exception is during concept generation meetings, where incorrect interpretations of a concept reflect additional points in the possible solution space. In the Household Water Conservation team’s concept generation meeting, new ideas were generated through others’ alternate interpretations of concepts. While user research needs to be accurately presented to convey the users’ framing of the design problem, solution concepts are far more flexible and can benefit from ambiguity (Gaver, Beaver, and Benford 2003).

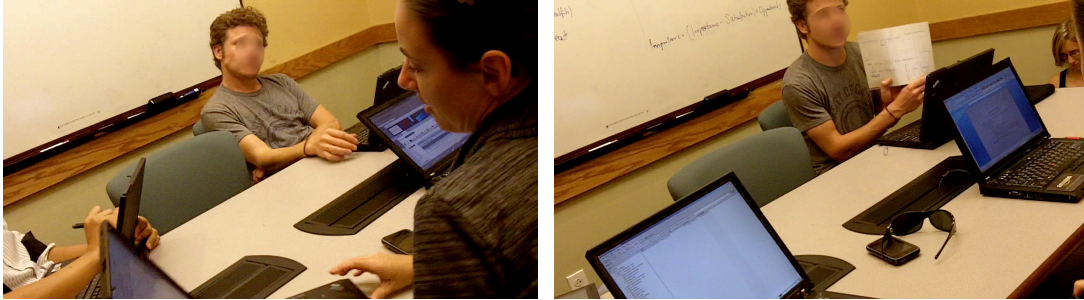


Figure 20: ALF turns her laptop to show her team agenda for their feedback meeting with their industry coach. CHA shows the team his notebook to remind them of an analysis framework mentioned in class.

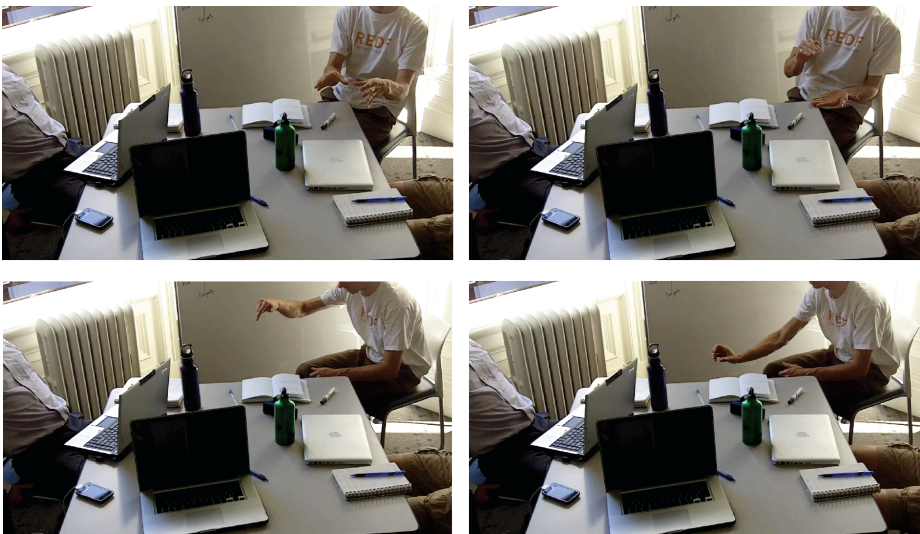


Figure 21: GOL re-enacts a scene from his user research for his teammates, when a user put a bucket into a shower as the temperature adjusted to collect water.

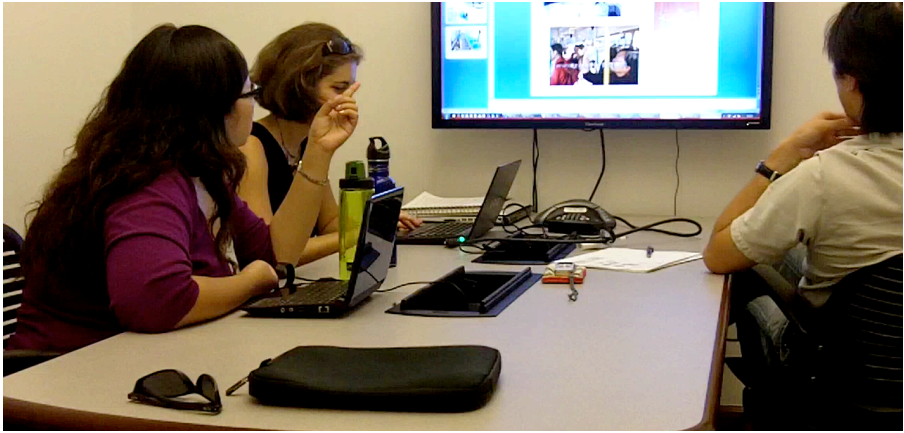


Figure 22: NOV gestures to PowerPoint slides on the shared display. Because she cannot control the slideshow directly, she orally or physically highlights information from afar.

GOAL: SYNTHESIZE INDIVIDUAL INFORMATION INTO THE TEAM'S SHARED FRAME

As the team reflects on its collective data, it must then reflect on that individual information and incorporate it into a shared frame for the team. . However, while individuals may share information with the team, the team will not necessarily incorporate that information into the team's shared frame.

The team's challenge in reaching this goal is to *ensure that shared decisions reflect individuals' contributions (C5)*. As the team shares stories and scenarios that summarize the experiences of individual users or the team's high-level progress, it is unclear if or how these summaries reflect the entire team's contributions or intended meaning. While not all perspectives need to be taken into account, the new frame should at least be grounded in the team's ongoing discussion of the design problem. New articulations of the team's shared frame must be verified with the team.

One way that teams address this is by visualizing information together, comparing diverse data points, and systematically creating a shared abstraction of that data. The teams that had access to a whiteboard (Working Women's Wardrobe, Household Water Conservation) used this space to visualize the entire team's contributions and information on a single canvas. In its concept generation meeting, the Household Water Conservation team spread out its ideas on the floor, sorting through the piles, grouping them together, and assigning category names to each group (see Figure 23). None of the observed teams used digital media or technology to create a shared representation. These shared representations help direct the team's conversation and allow the team to directly compare items to each other. These comparisons may be with an already proposed concept or idea, a related existing product, or a non sequitur. The team will then develop a shared abstraction that represents the relationships between information—identifying commonalities.



Figure 23: The Household Water Conservation team spreads out its ideas on the floor in order to identify patterns across each other's concepts. IND (far right) takes pictures of each cluster using his smartphone.

GOAL: RECORD CURRENT DESIGN ACTIVITY FOR FUTURE REFERENCE

One of the most common audiences for teams as they prepare to share information is the team itself, in the future. To do this, the team must first record current design activity for future reference.

When recording activity from the current meeting, the team must first *negotiate how information is recorded, by whom, and using which media* (C6). In the Working Women's Wardrobe and Accessible Public Transportation teams, the role of the recorder is established at the beginning of the meeting; however this role often compromises that person's ability to contribute otherwise during the meeting. Another approach is to redundantly assign the role of recording information to the entire team. For example, during its user research meeting the Household Water Conservation team had four members of the team (ECH, HOT, IND, FOX) simultaneously taking photos of the same final whiteboard (see Figure 24). In the concept generation meeting, the Household Water Conservation team had multiple members photographing the clusters on the floor (IND, FOX, HOT). After the meeting, HOT emailed out a .zip file with images from the meeting to the rest of the team—in their end-of-semester interview, the Household Water Conservation team noted that they often would email these images of notes to the team, either during or after the meeting. Distributing the role of the recorder, however, may make it ambiguous who captured information and how, such that it is unclear what was recorded and if it can be found later on.



Figure 24: Four Household Water Conservation team members take pictures of the same whiteboard using personal smart phones. Whiteboard contents include the meeting's agenda, prioritized needs, criteria for evaluation, and frameworks for understanding needs.

The team must also *decide what to record in the present moment (C7)*. Sometimes the recorder will reiterate what he or she is writing down so that others on the team can contribute additional or alternate suggestions for what to record. If the role of the recorder is distributed, individuals on the team can also make a general request for someone to record a whiteboard if they are unable to do so themselves. However, sometimes the rate of conversation is constrained by the team's ability to record the results, or the quality of the record suffers due to the speed of the conversation. In the Accessible Public Transportation team, KIL begins to describe her interviews in detail while MIK attempts to type continuous notes. Frustrated with her inability to capture the fast-paced descriptions, MIK buries her head in her hand (see Figure 25) and lets KIL know that she is unable to keep up with the conversation. KIL then offers to upload her interviews directly. While this provides the entire team with her fully detailed interviews, they will not necessarily highlight the same qualities that KIL prioritized and brought up during the meeting.

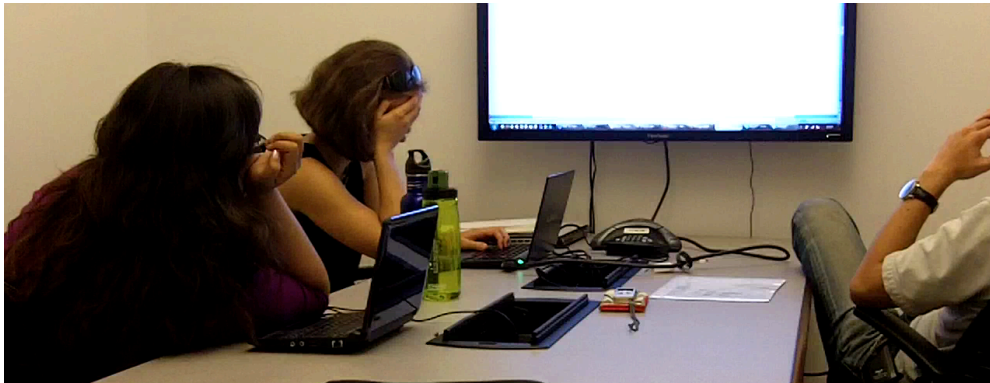


Figure 25: At the Accessible Public Transportation team meeting, MIK buries her head in her hand when she can no longer keep typing at same fast pace of the conversation.

GOAL: BUILD ON PAST TEAM ACTIVITY IN THE PRESENT MOMENT

Ultimately, recorded information is intended to be used by the team in the future. In order to utilize that information, someone on the team needs to first *find relevant information from previous sessions (C8)*. If that information was recorded by a distributed set of people, this may be difficult. In the Household Water Conservation team's concept generation meeting, ECH reminded the team that they could refer back to the mission statement and prioritized needs that they had agreed upon the previous week as criteria for evaluating concepts. JUL asks ECH to find that information while the rest of the team continues its conversation. Two minutes later, ECH is still unable to find the mission statement, and the team's conversation is unable to proceed without that information. At this point, four out of five people in attendance start to look for the information, each finding a different piece of the puzzle. In the end, JUL finds part of the needs in his personal notebook, while FOX and ECH find different documents on their laptops that were archived in the Dropbox. These types of distractions are not uncommon—the Accessible Public Transportation team also ran off track for one minute while the team collectively searched online for images and more information about the TransStrap, a benchmark concept that had been previously discussed and used in team members' interviews.

The team must also *present past information in a way that is useful for the team's current activity (C9)*. Many references to past information occur in passing, under the assumption that everyone on the team is fully aware of all information that had been synchronously or asynchronously shared in the team.

However, individuals often need to subtly revisit past information to refresh their memories and stay up to speed with the rest of the team. Teams also want to revisit and represent past information as a shared reference to the current conversation. For example, after the Household Water Conservation team had unearthed its mission statement and prioritized needs, they were immediately written back on a whiteboard such that it is publicly visible to the entire team again.

CONCLUSION

First, this chapter identifies the segment of the sharing cycle that

- *Transfer individuals' information to the team.*
- *Synthesize individual information into the team's shared frame.*
- *Record current design activity for future reference.*
- *Build on past team activity in the present moment.*

Next, this chapter introduces three teams from a graduate-level new product development course. These teams were observed during face-to-face meetings on user research and concept generation. Observations of these teams led to the identification of several challenges individual designers and teams faced as they tried to reach the above collaboration goals:

- C1. Translate from individuals' preferences into a common format.
- C2. Identify relevant information for the team.
- C3. Efficiently share richly with collaborators.
- C4. Control how information is interpreted by the team.
- C5. Ensure that shared decisions reflect individual contributions.
- C6. Negotiate how information is recorded, and by whom.
- C7. Decide what to record in the present moment.
- C8. Find relevant information from previous sessions.
- C9. Present past information in a format that is useful to the team's current activity.

There are also several parallels between what happens when individuals share information that the team must capture, and what happens when the team shares information with its future self. For example, *present past information in a format that is useful to the team's current activity* is analogous to *efficiently share rich information*—both ensure that whatever information that the team is handling, regardless of its source, is of the best quality and in a form that is useful to the team. Similarly, *identify information that is relevant to the team* and *decide what to record in the present to communicate with the future* are parallel.

The following chapter proposes design guidelines for future technologies based on these challenges.

CHAPTER 6

DESIGN GUIDELINES FOR

NEW DESIGN

COLLABORATION TOOLS

INTRODUCTION

Thus far, this dissertation has focused on describing how designers use tools and technology to manipulate information during early stage design work. Chapter 4 explored the types of tools that designers use, and in which collaborative contexts. It also introduced the sharing spiral, a conceptual model that describes how individuals and teams work through design information across user research and conceptual design stages, and across individual and collaborative work. Using the sharing spiral as a guide to our analysis of design team meeting observations, Chapter 5 introduced nine challenges for design teams as they negotiate individual and shared information during face-to-face meetings:

- C1. Translate from individuals' preferences into a common format.
- C2. Identify relevant information for the team.
- C3. Efficiently share richly with collaborators.
- C4. Control how information is interpreted by the team.
- C5. Ensure that shared decisions reflect individual contributions.
- C6. Negotiate how information is recorded, and by whom.
- C7. Decide what to record in the present moment.
- C8. Find relevant information from previous sessions.
- C9. Present past information in a format that is useful to the team's current activity.

These research findings have implications for how new design tools could better support design activity, particularly in how these tools help human-centered design teams integrate diverse individual perspectives in collaborative, early stage design work. Table 8 connects each challenge from Chapter 5 to design guidelines that help address those challenges, which are introduced and discussed in this chapter.

Challenge		Design Guideline	
C1	Identify individual information that is relevant to the team.	G0	Maintain a personal space where materials can be prepared for public view.
C2	Translate from individuals' preferences into a common format.	G1	Support heterogeneous clients and media.
C3	Efficiently share richly with collaborators.	G2	Support focused sharing of "rich" media.
C4	Control how information is interpreted by the team.	G3	Offer collaborative ways to organize and structure information from disparate sources.
C5	Ensure that shared decisions reflect individual contributions.	G4	Record all activity in the background, but also let individuals record items explicitly.
C6	Decide what to record in the present moment.	G5	Make the record of the team's activity navigable by individuals.
C7	Negotiate how information is recorded, and by whom.	G6	Make the team's past activity visible and actionable by the team.
C8	Find relevant information from previous sessions.		
C9	Present past information in a format that is useful to the team's current activity.		

Table 8: Connections between challenges identified in Chapter 5 and the design guidelines.

First, this chapter briefly reviews insights on design technology use and behavior from the previous chapter, and sets out goals for the design of new technology. Next, seven design guidelines are introduced and discussed, highlighting relevant examples from our observational data. These guidelines are compared to previous guidelines offered by researchers from the computer-supported collaborative work (CSCW) and human-computer interaction communities. Finally, emergent technologies from industry and academic research are compared based on these guidelines.

DESIGN GUIDELINES FOR COLLABORATIVE DESIGN TOOLS FOR SHARED UNDERSTANDING

Research from the previous chapters exposes challenges in sharing, control, attention, and recall, as well as the challenge of connecting disparate information sources together into a shared reference. They also expose opportunities for new technologies to improve teams' abilities to reach a shared understanding.

The following section describes specific examples from our past research, particularly highlighting observations from the NPD 2010 teams discussed in further detail in Chapter 5—Household Water Conservation, Working Women's Wardrobe, and Accessible Public Transportation. Based on these examples, design guidelines are identified for collaborative design tools that support building shared understanding from individual perspectives in face-to-face team meetings.

GUIDELINE 0: MAINTAIN A PERSONAL SPACE WHERE MATERIALS CAN BE PREPARED FOR PUBLIC VIEW

The idea of *maintaining a personal space where materials can be prepared for public view* (G0) stems from Shen, Everitt, and Ryall's sharing semantics (2003). In each of the design teams, designers had a personal space for their ideas (e.g., laptop, paper notebook) that was separate from the public canvas (e.g., whiteboard, shared display). When individuals no longer have a personal space where they can prepare

materials for public view, the entire team is burdened with the individual's information search. For example, the Accessible Public Transportation team primarily worked around a large display that was controlled by MIK. Most of the team prepared materials in advance and posted them on Dropbox to be shared during the meeting; however, navigating to find these items or deciding to share something ad-hoc became an awkward task of orally directing MIK to the correct item as the rest of the team waits.

The same principles from general-purpose applications such as UbiTable (Shen, Everitt, and Ryall 2003) and SharedNotes (Greenberg, Boyle, and Laberge 1999) can and should apply to tools for design teams: separating privacy and visibility, providing a gradient of sharing semantics, enabling control of what is made personal and public, and leveraging the existing roles and affordances of mobile devices and shared displays. However, it is important to acknowledge how these transitions need to be tailored based on the particular nature of early stage user needs research and conceptual design work. This guideline is numbered zero because of its prevalence in so many collaboration systems from both industry and research.

GUIDELINE 1: SUPPORT HETEROGENEOUS CLIENTS AND MEDIA

In the interviews with professional and student designers, there was no consistent personal technology preference across collaborators; therefore, groupware systems should not assume a standardized input format. Each designer preferred a different set of platforms and software tools to support his or her practice. In all observed team meetings, everyone entered with their own set of personal information tools—including laptops, notebooks, or mobile phones. Even with shared infrastructure (e.g., file sharing using Dropbox (2012)), design team members differ in their note-taking practices (McAlpine et al. 2006; Oehlberg, Lau, and Agogino 2009; Oehlberg, Roschuni, and Agogino 2011). While some companies may formally mandate specific information infrastructures, student team members or freelancers may not share any infrastructure beyond Web access. Therefore, this dissertation focuses on flexible groupware systems that can run on a variety of computing platforms, and practices that are compatible with a range of media.

Just as design journals are increasingly taking a hybrid form between physical and digital media (Oehlberg, Lau, and Agogino 2009), design teams use an ecosystem of design tools to support their individual and collaborative information needs (Lee et al. 2006). Designers use rich ecosystems of physical and digital tools to ease the process of capturing, reflecting upon, and sharing diverse media with their team. Future tools need to be able to *support heterogeneous clients and media (G1)* to accommodate different medium preferences at various stages of the design process.

GUIDELINE 2: SUPPORT FOCUSED SHARING OF RICH" MEDIA

Designers must be able to select relevant information from their own individual tools to share with the team. This includes controlling of how design research is presented to others, and supporting best practices, such as using rich media. While richly sharing media is valuable (Hey 2008), it also can result in an overwhelming amount of information for the team to process. The distributed group (Accessible Public Transportation) had three co-located members and a Skype call with the fourth member. The group had a shared display, which was also screen shared over Skype with the remote participant. This shared display was locally controlled by one team member. As a result, any time someone wanted to show information, the files had to first be uploaded to a shared file space (e.g., Dropbox (2012)). They then had to orally instruct the student controlling the public display to open the correct file, or navigate to the relevant information at the right time. Despite not having direct control over the shared display, individuals on Accessible Public Transportation managed to share rich information with each

other—often sharing photo slideshows or primary sources with the team. Thus, new systems should *support the focused sharing of “rich” media (G2)*.

GUIDELINE 3: OFFER COLLABORATIVE WAYS TO ORGANIZE AND STRUCTURE INFORMATION FROM DISPARATE SOURCES

When teams share information with each other, their goal is to not only learn from others' experiences but also to find patterns and connections between individuals' divergent points of view. For example, during the concept generation meeting, individual members of Household Water Conservation contributed their paper concept sketches to a clustering exercise of everyone's concepts on the floor. As the team discussed the concepts, they also labeled the clusters to understand the overall direction of the team's summative efforts. After individual designers share their information contributions, the team must collectively understand, analyze, and prioritize information to make shared decisions. This analysis should be supported and documented by collaborative design tools.

Both co-located teams, Household Water Conservation and Working Women's Wardrobe, used whiteboards throughout their meetings to record their shared decisions; each time the meeting ended with a team member taking a photograph of the whiteboard. However, these images do not necessarily capture who contributed which items to the whiteboard, which may be needed later on for clarification or further detail on a specific point. At the end of Household Water Conservation's concept generation meeting, two team members photographed each cluster of ideas—not only capturing the individually contributed paper concept sheets, but also how the team chose to juxtapose and thematically cluster their collective set of concepts. Co-constructed artifacts reflect the team's shared understanding. New technology should *offer collaborative ways to organize and structure information from disparate sources (G3)*; gathering co-constructed artifacts together with the information that individuals brought to the team's attention creates a centralized, coherent team resource.

GUIDELINE 4: RECORD ALL ACTIVITY IN THE BACKGROUND, BUT ALSO LET INDIVIDUALS RECORD ITEMS EXPLICITLY

By using technology that can *record all activity in the background but also let individuals record items explicitly (G4)*, designers can both consciously document important items and be relieved from constant documentation responsibilities. Both MIK (from Accessible Public Transportation) and ALF (from Working Women's Wardrobe) were consumed by the task recording the team's activity throughout the meeting. When MIK found out that KIL had posted her interview on the website and stopped taking as many notes, the team lost the opportunity to have a MIK's record of what KIL prioritized to mention to the team.

Throughout the design process, everything from informal to archival documentation is produced; it is important that future tools allow for these various formalities to exist side-by-side. For example, a tool should allow designers to simultaneously reference shared formal information (e.g., synthesized user research results) while creating informal information (e.g., initial concept sketches).

GUIDELINE 5: MAKE THE RECORD OF THE TEAM'S ACTIVITY NAVIGABLE BY INDIVIDUALS

Ultimately, information that has been captured in an archive needs to be accessed later on; in the case of teams that have distributed the responsibilities of recording information, the person who captured information may not be the same person accessing it later on. For example, during a concept generation meeting, Household Water Conservation needed to decide which concepts to pursue based on its user research. ECH and JUL asked about a previous shared decision—“Let's put up the needs and maybe

mission statement”—to help guide the criteria for the team’s solution. The meeting halted for three minutes, losing all momentum of the discussion, while half of the team searched through individual notes, team emails, and shared files to locate the correct information. In their previous user research meeting, several team members took photos of the whiteboard with these top needs; no one could recall these images at the later meeting. The team’s top user needs were eventually found in an individual’s design journal, not on the team’s shared, centralized information repository (Dropbox). Had the team been able to automatically centralize and organize its team records, particularly information of collective importance, then this recall action could have occurred far faster and more seamlessly with the rest of the team’s conversation.

Co-created artifacts reflect team decisions and design rationale, and therefore a shared frame. This archive of shared information should be accessible to both individual designers and the team as a whole. Technology should *make the record of the team’s activity navigable by individuals (G5)*, regardless of who originally documented that information.

GUIDELINE 6: MAKE THE TEAM’S PAST ACTIVITY VISIBLE AND ACTIONABLE BY THE TEAM

Once past team information has been found, it still needs to be in a format that is useful to the team’s current activity. For rich media, this means not only making the information visible to the team, but also interactive or revisable. Once the Household Water Conservation team had found its top user needs, these needs were then written on a whiteboard for the rest of the team to reference peripherally throughout their discussion. If new technologies can *make the team’s past activity visible and actionable by the team (G6)*, the team archive can become a better resource; the team can then properly build upon past progress and continue to develop its ideas.

DESIGN GUIDELINE COMPARISON

This section looks at design guidelines, principles, and recommendations offered by previous researchers in human-computer interaction, particularly those focusing on creative collaborative work (Hunter et al. 2011; Wigdor et al. 2009; Hailpern et al. 2007) and design knowledge management (Ju et al. 2004; Sharmin et al. 2009; Carlile 2002). Several sources (Hunter et al. 2011; Sharmin et al. 2009; Hailpern et al. 2007) include guidelines that re-emphasize the importance of the social aspects of design and knowledge work. As it is known that design is inherently a social process (Bucciarelli 1988), this thesis focuses on guidelines that offer specific advice on how to handle creative, collaborative interactions.

Some sources of guidelines are from studies of design work, resulting in recommendations for effective technology or practices. Ju et al. (2004) offer lessons learned about technologies for knowledge capture and information reuse based on captured observations of physical design workspaces. In a study of design knowledge management and reuse, Sharmin et al. (2009) uncovered key findings which connected to implications for the design of a new Design Knowledge Management System (DKMS).

	Proposed Guideline	Guidelines from Related Work
G0	Maintain a personal space where materials can be prepared for public view.	<p>Allow the use of their laptops (Wigdor et al. 2009).</p> <p>Protect the privacy of users by only recording explicit actions (Hunter et al. 2011).</p> <p>Allow multiple levels of sharing (Hailpern et al. 2007).</p> <p>Provide clearly delineated personal and group spaces (Hailpern et al. 2007).</p>
G1	Support heterogeneous clients and media.	<p>Support heterogeneous types of input during group meetings for different contexts and user styles (Hunter et al. 2011).</p> <p>Support the coexistence of physical and digital content as much as possible (Hunter et al. 2011).</p> <p>Integrate the content generated at the table with existing personalized software accessible offline (Hunter et al. 2011).</p> <p>Be integrated with commonly used tools for the particular design domain (Sharmin et al. 2009).</p>
G2	Support focused sharing and directing attention of "rich" media.	<p>Maintain interactivity of existing applications (Wigdor et al. 2009).</p> <p>Support egalitarian and visible input (Wigdor et al. 2009).</p> <p>Retain user control over their own data (Wigdor et al. 2009).</p>
G3	Offer collaborative ways to organize and structure information from disparate sources.	<p>Provide a shared display (Wigdor et al. 2009).</p> <p>Keep multiple design ideas visible simultaneously (Hailpern et al. 2007).</p> <p>Allow designers to proactively flag artifacts for each other (Sharmin et al. 2009).</p> <p>In addition to search [...] support rapid visual foraging (Sharmin et al. 2009).</p> <p>Cannot assume or impose the use of consistent naming schemes or folder hierarchies (Sharmin et al. 2009).</p> <p>Shared ideas should always remain in the collective consciousness (Hailpern et al. 2007).</p>
G4	Record all activity in the background, but also let individuals record items explicitly.	<p>Use of implicit capture vastly increases adoption and usefulness (Ju et al. 2004).</p> <p>Knowledge capture tools need to accommodate both passive and active users (Ju et al. 2004).</p> <p>Design teams have real-time and near-term knowledge capture needs (Ju et al. 2004).</p> <p>Provide a lightweight means for capturing stories with artifacts (Sharmin et al. 2009).</p> <p>Design the interface to be efficient and consistent as possible, with a minimal number of steps to input and recall information from the system (Hunter et al. 2011).</p> <p>Record the context of events: who, what, and when something is created and modified for subsequent recall (Hunter et al. 2011).</p>
G5	Make the record of the team's activity navigable.	<p>Allow rapid access to personal and shared designs (Hailpern et al. 2007).</p> <p>Speed of data browsing is more important than data density (Ju et al. 2004).</p> <p>Design the interface to be efficient and consistent as possible, with a minimal number of steps to input and recall information from the system (Hunter et al. 2011).</p>
G6	Make the team's past activity visible and actionable.	<p>Provide a record/work product at the meeting (Wigdor et al. 2009).</p> <p>Provide a means for conveying the overall design process associated with the artifacts in a lightweight and informal manner (Sharmin et al. 2009).</p> <p>Captured knowledge can be adapted to many design needs (Ju et al. 2004).</p> <p>Design oversight benefits from richer data and adjustable levels of detail (Ju et al. 2004).</p>

Table 9: Overview of proposed guidelines, compared with guidelines from previous work.

Other sources of guidelines were design principles that guided the development of specific systems for collaborative, creative work. WeSpace (Wigdor et al. 2009), a collaborative workspace with a large data wall and an interactive tabletop surface, is intended to support scientists conducting collaborative cross-disciplinary research during impromptu meetings. Similarly, the Memtable (Hunter et al. 2011) was designed to support collaborative group work based on previous research on interactive tables as well as observations from groupware systems. TEAMSTORM (Hailpern et al. 2007) is a system designed to facilitate a group as it generates concepts and works with multiple ideas during creative group activity. Based on observations of group work, discussions with users, and a review of literature, the authors developed a list of design requirements.

Table 9 gathers other design guidelines and recommendations from these sources, and structures them based on their similarity to the proposed guidelines. Previous guidelines have primarily focused on specific aspects of information sharing, collaborative information analysis, and design documentation. The proposed list of design guidelines aims to inform the design of technologies that seamlessly integrates with design practices. It does so by examining the information needs of design teams during face-to-face meetings holistically—considering how individuals' gathered information feeds into the team's discussion, which in turn feeds into future team processes.

It is also important to recognize that implicit in all design rationale and reuse systems is the idea of a singular place where information from the team is gathered. This mitigates the issues that arise when a team is distributing the role of the recorder and the role of the person accessing that information in the future.

BENCHMARKING WITH EXISTING TECHNOLOGY & RESEARCH

The list of guidelines can be embodied into information technology systems using a range of approaches. This section compares existing systems from research and practice, using the design principles as criteria for comparison. The systems that are compared are all emergent or existing systems from industry and research that support information sharing during synchronous, face-to-face collaborative work in early stage design teams. Three types of systems that work towards this goal were identified: *individual tools*, *public tools*, and *multi-surface environments*.

- *Personal tools* (e.g., augmented notebooks) have features that allow others access to those materials. These tools focus primarily on personal sharing semantics, and extend outwards into the public sphere.
- *Public tools* (e.g., digital whiteboards) are shared assets that are collectively owned and authored. These tools primarily focus on public sharing semantics and sometimes emphasize being able to capture and recall previous states for the sake of the rest of the team. Their form can be vertical surfaces (whiteboard, wall display) or horizontal surfaces (table, floor).
- *Multi-surface environments* include both personal (e.g., laptops or allocated sections of larger interfaces) and shared spaces (e.g., vertical displays, interactive tables, or both). These environments are often the most complex, simultaneously handling sharing individual information, creating a shared space for collaborative analysis, and documenting progress in an archive or record.

Within each category there are examples that focus on the specific needs of design teams. This comparison excludes project management (e.g., Basecamp (2012)) services, as they are generally used

for asynchronous, distributed information sharing. Instead, this comparison benchmarks against commonly used tools in face-to-face meetings, including file sharing (e.g., Box (2012), Dropbox (2012)), VGA cables, and physical whiteboards. It also includes screen sharing, as it is also a common tool in web conferencing systems such as (Cisco 2012; Skype 2012), albeit primarily in distributed collaboration. However, this comparison is primarily focused on rich collaborative environments, particularly those that go beyond general groupware to support the specific needs of designers. These include systems that include shared displays and screen sharing, whiteboard capture and reuse, and the more-tailored design information sharing systems, and design rationale and activity logs.

Each system was evaluated against the list of design guidelines, with specific criteria to understand the nuanced differences between the systems in detail. Table 10 lists each of the design guidelines, and the corresponding questions used to guide the comparative analysis. Table 11 shows how each of the technologies mentioned below compare to the design guidelines.

	Guideline	Comparative Analysis Question
G0	Maintain a personal space where materials can be prepared for public view.	Does the system offer separate personal and public space?
G1	Support heterogeneous clients and media.	Does the system support heterogeneous media (physical and digital)? Does it support heterogeneous clients (cross-platform)?
G2	Support focused sharing of “rich” media.	Does the system offer a way to focus the audience’s attention? Can the system control others’ view of the information?
G3	Offer collaborative ways to organize and structure information from disparate sources.	Does the system offer a way for the team to collaboratively organize & structure their information (e.g., through categories or annotation)?
G4	Record all activity in the background, but also let individuals record items explicitly.	Does the system automatically capture information and design activity? Does the system allow the team to explicitly capture information?
G5	Make the record of the team’s activity navigable by individuals.	Does the system keep a shared record that is easy to access and navigate?
G6	Make the team’s past activity visible to and actionable by the team.	Does the system keep a shared record that is easy to visualize and use?

Table 10: Proposed design guidelines, and corresponding evaluation questions for the comparative analysis.

SYSTEM		DG0	DG 1	DG2	DG3	DG4	DG5	DG6			
		Personal and Public Space	Supports Heterogeneous Media	Supports Heterogeneous Clients	Focuses audience's attention (e.g., same view, interaction)	Controls others' view of information	Collaborative organization & structuring	Automatic capture	Explicit Capture	Easy to individually access and navigate team record	Easy to collaboratively visualize and use team archive
	File Sharing (e.g., Dropbox) (common)	yes	no	yes	no	no	yes	no	yes	yes	no
	Screensharing (e.g., Skype) (common)	yes	no	yes	yes	yes	no	no	no	no	no
	Display Cable (common)	no	no	yes	yes	yes	no	no	no	no	no
	Analog Whiteboard (common)	no	no	no	yes	yes	yes	no	no	no	no
Personal	Personal Electronic Notebook with Sharing (Hong et al., 1995)	no	no	yes	no	no	no	yes	yes	no	no
	iDeas (Lee, 2008)	yes	yes	yes	no	no	no	no	yes	no	no
Public	Dabbleboard (2012)	no	no	yes	yes	no	yes	yes	yes	no	no
	Stixy (2012)	no	no	yes	yes	no	yes	yes	yes	no	no
	Mimio (2012)	no	yes	yes	yes	yes	yes	yes	yes	yes	no
	eBeam (Luidia, 2012)	no	yes	yes	yes	yes	yes	yes	yes	yes	no
	Collaborage (Moran, 1999)	no	yes	yes	yes	yes	yes	no	no	no	no
	ReBoard (Branham, 2010)	no	yes	no	yes	yes	yes	no	yes	yes	yes
	Clear Board (Ishii and Kobayashi, 1992)	no	yes	no	yes	yes	yes	no	no	no	no
	TRACES (Van Dijk and Vos, 2011)	no	yes	no	yes	yes	yes	no	no	no	no
	Affinity Table (Geyer et al., 2011)	no	no	yes	yes	yes	yes	no	no	no	no
Multi-surface	media:scape (IDEO, 2012)	yes	no	yes	yes	yes	no	no	no	no	no
	WeSpace (Wigdor et al., 2009; Jiang et al., 2008)	yes	no	yes	yes	yes	yes	no	no	no	no
	Teamspot (Tidebreak, 2012)	yes	no	yes	yes	yes	yes	yes	no	yes	no
	Semi-Public Display (Huang and Mynatt, 2003)	yes	no	yes	no	yes	yes	yes	yes	yes	no
	IMPROMPTU (Biehl et al., 2008)	yes	no	yes	yes	yes	no	no	no	no	no
	M-Draw (Rekimoto, 1998)	yes	no	yes	yes	yes	yes	no	no	no	no
	Team Storm (Hailpern et al., 2007)	yes	no	yes	yes	yes	yes	no	yes	no	no
	Messy Desk/Messy Board (Fass et al., 2002)	yes	no	yes	yes	yes	yes	no	yes	no	yes
	WILD Room (Beaudouin Lafon, 2011)	yes	no	yes	yes	yes	yes	no	no	no	no
	Envisionment and Discovery Collaboratory (Arias et al., 2000)	no	yes	no	yes	yes	yes	no	no	no	no
	Pictionaire (Hartmann et al., 2010)	yes	yes	no	yes	yes	yes	no	yes	yes	no
	Memtable (Hunter et al., 2011)	yes	yes	no	yes	yes	yes	yes	yes	yes	yes

Table 11: Comparative analysis of personal tools, public tools, and multi-surface environments.

PERSONAL TOOLS

Personal tools are primarily for individual and not public use (G0). The ones included in this comparison also include features that allow for easy sharing. For example, pages from a digital notebook can be automatically shared (Hong, Toye, and Leifer 1995) or explicitly contributed towards a virtual “group notebook” (Lee 2008).

These systems do not offer support for the collaborative tasks that occur around individual data, such as collaboratively adding additional structure (G3) or creating a shared archive (G5, G6). However, they are often effective at capturing information in digital and physical formats and sharing individuals' ideas.

PUBLIC TOOLS

Public tools primarily offer a space where the team has shared-authorship over what is created. These systems only offer a public space for the team to work on, and not a personal space (G0). Whiteboards are a classic example of such a tool; they are often used in collaborative teams to synthesize information in a shared artifact (Cherubini et al. 2007). Physical whiteboard capture and reuse systems have been investigated both in research prototypes (Branham et al. 2010; Moran et al. 1999), and commercial systems (Luidia Inc. 2012; Mimio 2012). On digital whiteboards or collage walls—either hosted online (Dabbleboard Inc., 2012; Stixy 2012) or on a shared display (Fass, Forlizzi, and Pausch 2002)—teams co-create annotated collages, with each annotation or image contributed by individuals on the team.

Previous research systems have displayed this shared information in face-to-face meetings on vertical wall displays (Li et al. 2012), interactive tabletops (Geyer et al. 2011; Hartmann et al. 2010), and even floor projections (van Dijk and Vos 2011). Pairs of linked digital whiteboards can also facilitate distributed collaboration (Ishii and Kobayashi 1992).

All of these public tools focus on establishing a shared view (G2) and allowing for collaborative organization and restructure (G3). However, these systems do not accommodate individual work, and thus rarely involve a record of the team's activity that can be individually navigated (G5).

MULTI-SURFACE ENVIRONMENTS

Muti-surface environments support more complex information sharing, in that they allow for both public and personal tools to coexist and connect. Several systems have explored how teams can exchange information on shared displays, e.g., by sharing pointer and keyboard access to desktop applications on a single computer (Tidebreak Inc. 2012); by providing a video cable to each meeting participant (IDEO 2008); or by leveraging screen-sharing software to mirror a local display on a larger, public display (Wigdor et al. 2009).

Other researchers have used individual screens (e.g., tablet PCs) as an individualized input mechanism for large-scale displays that act as virtual whiteboards (Rekimoto 1998; Beaudouin-Lafon 2011) including sharing digital sketches during brainstorming or concept generation meetings (Hailpern et al. 2007). Multi-surface environments are far more complete in addressing the range of challenges faced by designers in face-to-face meetings. However, there are still a few gaps in whether or not a multi-surface environment is open-platform, or if it allows the right set of interactions with the shared archive.

Some public tools or multi-surface environments focus on recording design activity for later use (G4, G5, G6); these are often examples of design rationale systems. Design rationale systems capture the history of how something was designed (Regli et al. 2000), and are used to not only record concepts and capture the design process, but also forage for inspiration and facilitate storytelling (Sharmin et al. 2009). Some groupware systems also provide history (Hunter et al. 2011) or focus on capturing co-created meeting artifacts, e.g., video of the team's dialogue, or whiteboard content (Cutler et al. 2002). One notable example of a design rationale system is the MemTable (Hunter et al. 2011), a system that records and reflects group work during team meetings, acting as a shared memory for the team.

Multi-surface environments are the most promising in satisfying all design guidelines—particularly when such systems borrow from features in personal and public tools.

DISCUSSION & CONCLUSION

This chapter introduced a series of design guidelines for new tools that support information sharing and shared understanding in face-to-face design teams based on research findings from Chapters 4 and 5. It also presents a comparison of these guidelines against other design guidelines proposed or followed by other research systems. While previous guidelines have focused on specific aspects of information sharing in design teams—integrating individual information, collaborative information analysis, or design documentation—the proposed list of guidelines addresses the challenges faced by designers before, during, and after face-to-face meetings. By taking a holistic approach, these guidelines aim to inspire technologies that more seamlessly integrate with design practices. This chapter also presents a comparative analysis evaluating personal, public, and multi-surface tools against the proposed guidelines. Of these types of systems, multi-surface environments are the most comprehensive in addressing the needs of both the individuals that are sharing information, and the teams that are making sense of that information. However, even multi-surface environments have difficulty capturing use activity and offering that activity record to the design team in a useful way. Developers of new design collaboration tools can also draw lessons from how personal information tools incorporate heterogeneous, “rich” media, and how public tools focus the team’s attention and enable collaborative re-structuring.

It is also important to prioritize which guidelines are most important moving forward with this thesis. Guideline 0, “*Maintain a personal space where materials can be readied for sharing,*” is directly descended from sharing semantics (Shen, Everitt, and Ryall 2003), and aims to separate between private, personal, and public spaces in groupware systems. This principle has already been applied and explored by many other researchers (Wigdor et al. 2009; Hunter et al. 2011; Hailpern et al. 2007; Greenberg, Boyle, and Laberge 1999). While this is admittedly a very important guideline to address, it is not explicitly included in the design and evaluation of the new collaboration system in Chapter 7.

As a result, the remaining guidelines are the primary focus in the following chapter:

- G1. Support heterogeneous clients and media.
- G2. Support focused sharing of “rich” media.
- G3. Offer collaborative ways to organize and structure information from disparate sources.
- G4. Record all activity in the background, but also let individuals record items explicitly.
- G5. Make the record of the team’s activity navigable by individuals.
- G6. Make the team’s past activity visible and actionable by the team.

The following chapter applies the proposed design guidelines to Dazzle, a collaborative design tool to support face-to-face meetings as designers reach shared understanding in early stage design activity.

CHAPTER 7

SHOWING IS SHARING: BUILDING SHARED UNDERSTANDING IN HUMAN-CENTERED DESIGN TEAMS WITH DAZZLE

INTRODUCTION

The guidelines from the previous chapter (Table 12) are embodied in Dazzle (Figure 26), a creativity support tool that helps human-centered design teams share perspectives and reach a shared understanding. Dazzle is a collaborative shared display system for co-located design team meetings. Dazzle associates the action of showing information on the shared display with granting the rest of the team access to that information: *showing is sharing*. Users drag files into the client to begin screen sharing and show the files on the shared display. Dazzle makes these viewed files accessible to collaborators, and records the act of showing to others in a shared activity log. The shared activity log can later be searched, tagged, or annotated by everyone on the team. Dazzle can also capture images of the whiteboard and add them to the shared activity log for future reference. Dazzle also records a history of shown files. Team members can annotate this log using cross-platform synchronized clients.

	Design Guideline	Dazzle Feature
G1	Support heterogeneous clients and media.	Cross-platform application (Adobe AIR)
G2	Support focused sharing of “rich” media.	Showing is sharing
G3	Offer collaborative ways to organize and structure information from disparate sources.	Annotation & tagging
G4	Record all activity in the background, but also let individuals record items explicitly	Shared activity log Whiteboard camera
G5	Make the record of the team’s activity navigable by individuals.	Annotation & tagging, Search
G6	Make the team’s past activity visible and actionable by the team.	Showing is sharing

Table 12: Dazzle’s features address six design guidelines for collaborative tools that support building shared understanding from individual perspectives.

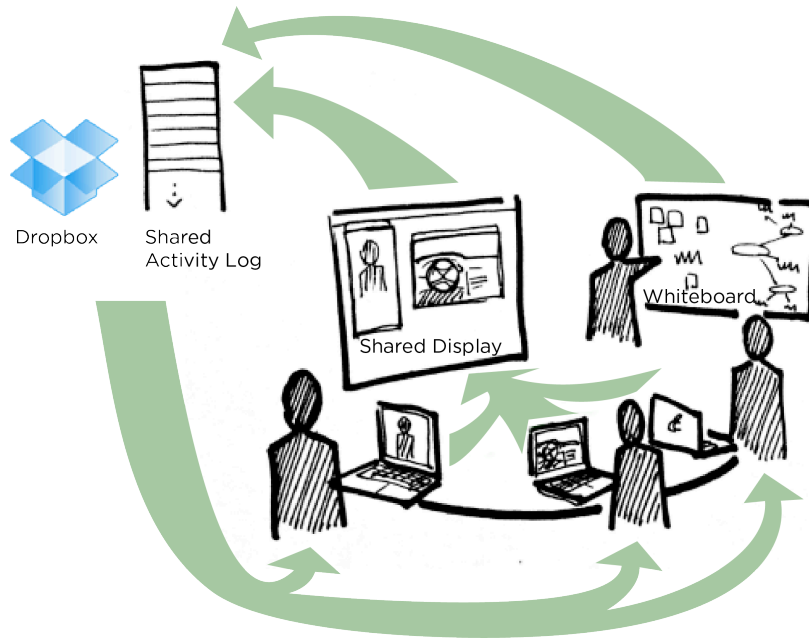


Figure 26: Concept sketch of Dazzle in use. At face-to-face meetings, designers show information from their laptops on the shared display. Dazzle automatically updates its activity log and makes the information accessible to collaborators.

This chapter describes the details of Dazzle’s design and implementation and discusses its evaluation. First, it introduces Dazzle, describing its usage scenario, features, and how those features connect to the design guidelines from the previous chapter. Next, it describes an implementation of Dazzle using Adobe Live Cycle Collaboration Services (LCCS) and Dropbox. Finally, it discusses a user study evaluation of Dazzle using consecutive team meetings addressing user research and conceptual design tasks. Five design teams tested Dazzle over two consecutive sessions: the first focused on synthesizing user research, and the second focused on concept generation. Dazzle was very effective at grounding team conversations about user research but was used less for sharing information during concept generation tasks. Items from the shared activity log were used as sources of inspiration and decision criteria during the concept generation task. The chapter concludes with implications for future iterations of Dazzle and other collaborative tools for creative work.

DAZZLE: SYSTEM DESIGN

Dazzle is a public display system that supports design teams during face-to-face meetings on user research and concept generation (see Figure 27). Dazzle’s features are tailored to address the identified design guidelines (see Table 12). Design team members control Dazzle through client applications on laptops. Digital content can be dragged and dropped on to the laptop client to show it on the large-scale shared display. As individual designers bring the team’s attention to specific content, Dazzle associates the action of showing information on the public display with sharing the shown files through synchronized shared file folders: each team member receives a copy of the file. The client also displays all shared files in a chronological list, the Shared Activity Log. Team members can add tags or annotations to items in the log, which can be revisited during subsequent meetings. A camera captures whiteboard images and adds them to the Shared Activity Log, alongside other files.

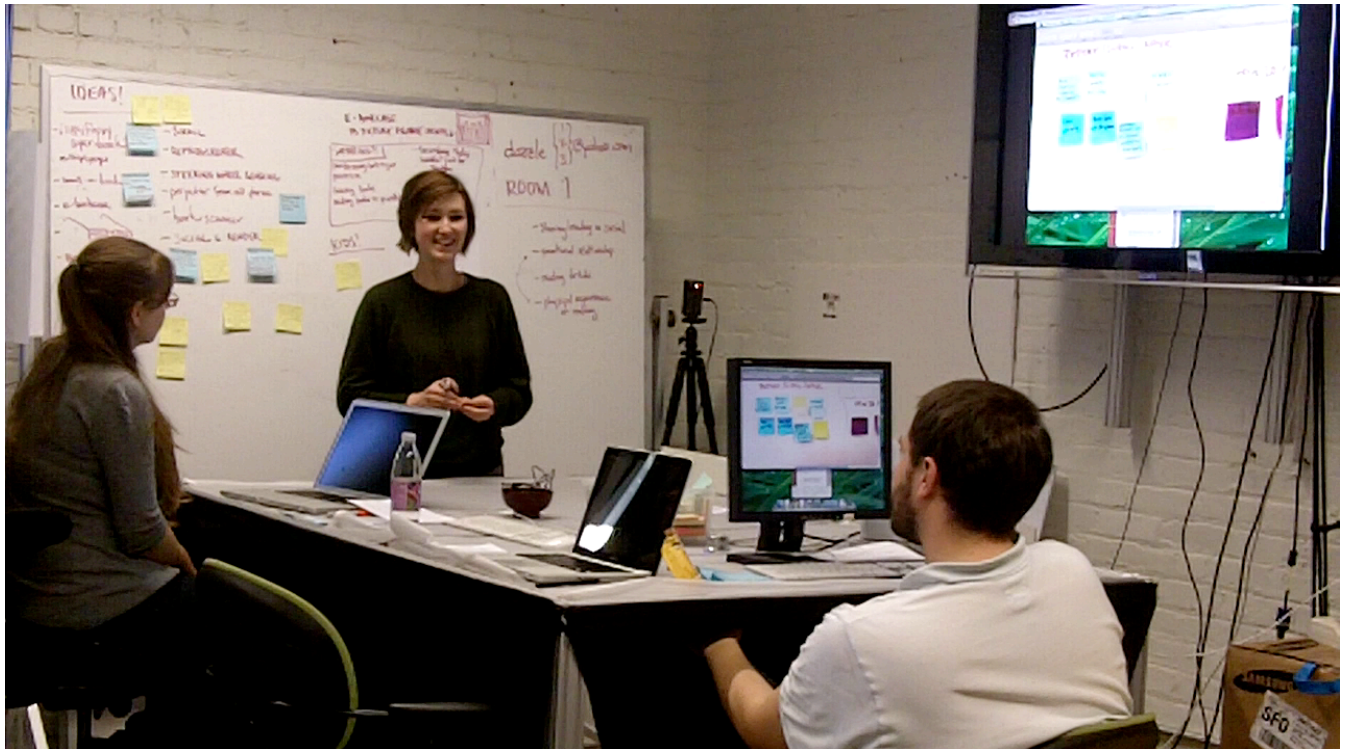


Figure 27: A design team engages in a concept generation task. Dazzle is implemented in the space with a) a large shared display, b) client applications, running on two laptops and a desktop computer, and c) a whiteboard with a capture system to add its content to Dazzle.

The following scenario offers an example of how these features might be used during a design team meeting:

Dan needs to debrief his design team on an in-home interview he conducted last week. At the team meeting, Dan opens a folder of photographs from his interview on his laptop. He drags the first photo onto the drop target on the Dazzle Client (Figure 28A). Once he drops the file, it is opened locally on his laptop (Figure 28B), and Dazzle initiates a screen sharing session to project his desktop on the shared display (Figure 28C). In the background, the file is added to the activity log and copied into a folder. When his collaborator, Julie, wants to return to that photo later in the meeting, she can drag and drop the photo back from her activity log on to the drop target; this opens the file locally and begins screen sharing with the shared display.

Over the course of its discussion, the team has filled a whiteboard with shared notes on their conversations. Dan presses a button on the whiteboard, which triggers an overhead-mounted camera to photograph the board. This photo is uploaded to the shared folder and added to the activity log.

The next section details the system interface (see Figure 29) and design, specifically the shared display, shared activity log, and whiteboard capture.



Figure 28: To bring a file to others' attention, the participant drags that file on to the drop target (A). This opens the file locally on that person's computer (B) as well as initiates screen sharing with a public display (C).

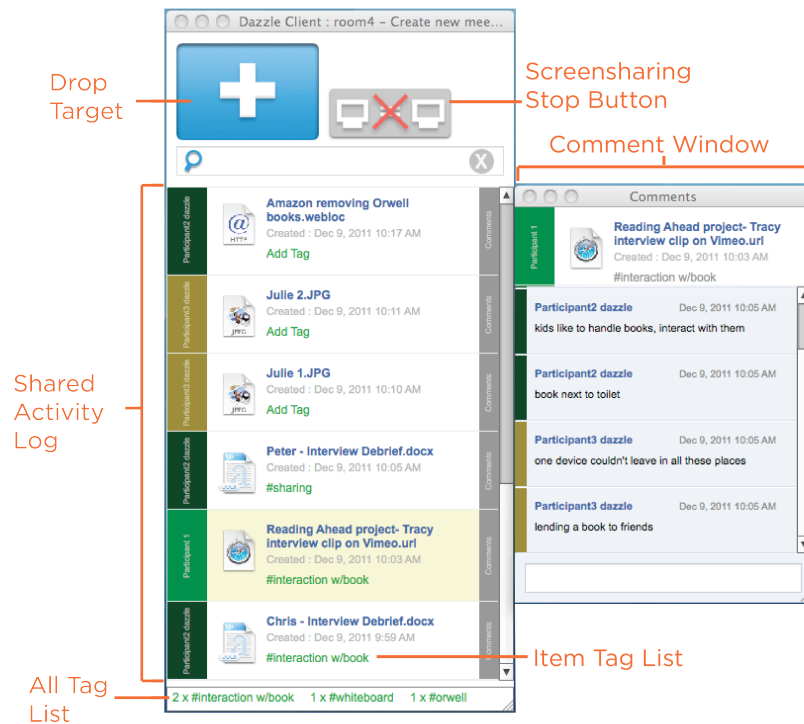


Figure 29: The Dazzle interface shows a drop target, a Shared Activity Log, and a comment window.

SHARED DISPLAY & SCREEN SHARING

Screen sharing was chosen to connect users to the shared display, as different team members may not have the same software installed on their computer (G1). For example, in a multidisciplinary team only one user may have CAD or video editing software. The user initiates screen sharing in his or her client application by dragging a file from his or her desktop or the client's activity log into the screen sharing drop target. Dazzle responds by: 1) opening the file locally on the user's computer, 2) initiating screen sharing with the shared display, and 3) uploading the file to a shared directory for those who have software that can open it. Dazzle also adds this action to the shared activity log. With just one action, the user can bring select items to the team's attention (G2) and allow others access to that file (G6).

SHARED ACTIVITY LOG

When the user logs into Dazzle, they can see a shared activity log that reflects all individual actions that have been taken on Dazzle (G4). Users can *annotate* or *tag* entries in the shared activity log. The annotations and tags allow the team to highlight and prioritize information that is important to the group's decision-making process (G3). The user can view the comments panel (Figure 29) by clicking on the comments button on the right of each menu item. Here, the commenting system has similar affordances to instant messaging—comments are listed in chronological order, and once authored they cannot be edited or deleted.

A list of all tags is at the bottom of the main Dazzle window (Figure 29). The user can click on the tags for each item and edit the tag in a pop-up menu. The default view of the shared activity log is in reverse-chronological order; users can filter its contents by selecting a set of tags or by searching over filenames, comment, and tag text (G5).

WHITEBOARD CAPTURE

A ceiling-mounted SLR camera captures the contents of a nearby whiteboard. To capture the whiteboard, a user presses a large button on the conference table. Dazzle takes a whiteboard photo and adds it to the shared activity log. Individuals can either review the image on their personal laptop computer or bring that image to the team's attention by dropping it on to the screen sharing drop target. This helps refresh the team's memory, particularly when the whiteboard has been erased.

SYSTEM IMPLEMENTATION

Dazzle leverages distributed collaboration technologies for screen sharing and file sharing (Figure 30). Dazzle uses Actionscript and Adobe AIR (Adobe Systems Inc. 2012), a platform-independent application framework that enables users to run Dazzle on a wide range of operating systems. Dazzle was implemented using Adobe LiveCycle Collaboration System (LCCS) (Adobe Systems Inc. 2012), a cross-platform, hosted toolset for screen sharing and messaging, with synchronized data structures. Dazzle uses Dropbox (2012) as a backend for peer-to-peer file sharing. Dropbox is a cloud-based file sharing system that allows files to be easily shared across various users or across multiple devices. Computers that have the Dropbox client application installed have a folder on their filesystem that automatically synchronizes its contents with the Dropbox server. Each Dazzle client has a local copy of files that are synchronized with a shared Dropbox folder for the team. If one Dazzle client copies a file to this folder, others automatically have access to and receive copies of the file. Dazzle uses a file monitor to watch this folder on each local client and updates the shared activity log based on files added to this folder. The whiteboard capture system is a remote-triggered digital SLR camera. The whiteboard photo is color-corrected, copied to the Dropbox folder, and added to the activity log.

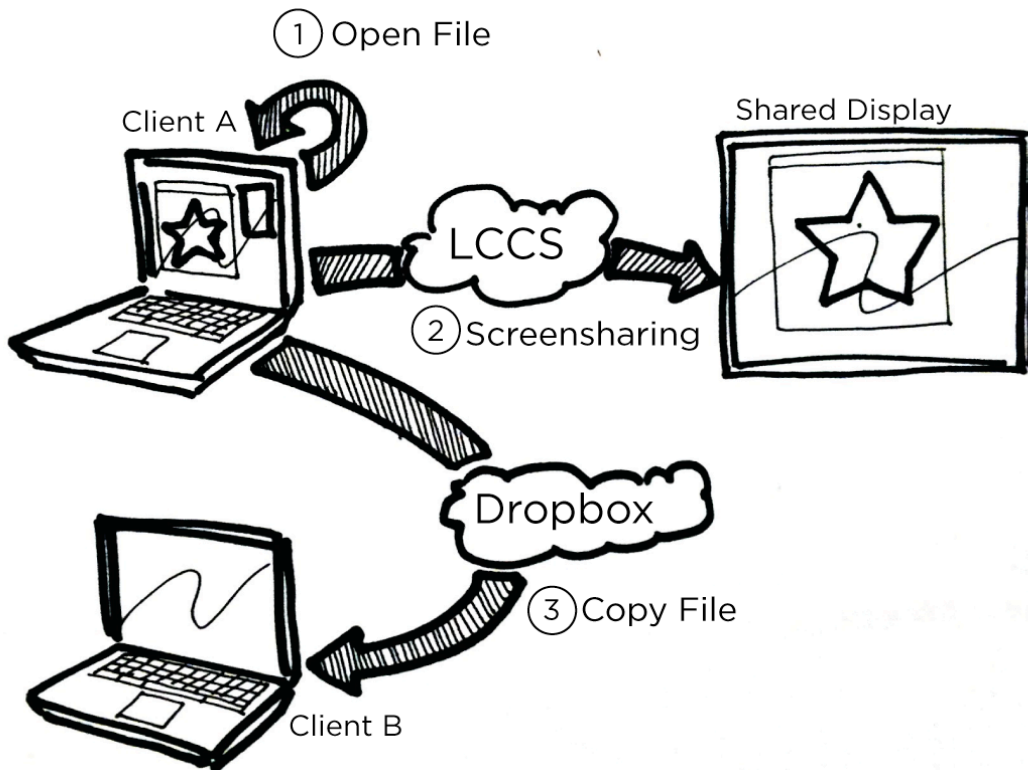


Figure 30: Each time a user drags and drops a file on its drop target, Dazzle responds by 1) opening the file locally, 2) initiating screen sharing with the shared display over LCCS, and 3) making the file available to others over Dropbox.

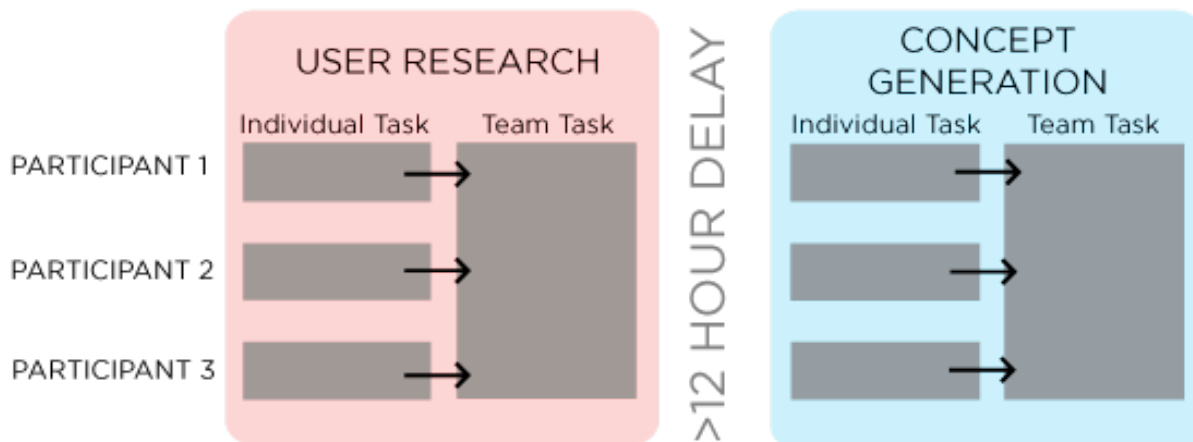


Figure 31: Concept diagram of evaluation. Each team participated in a user research and a concept generation session, separated by at least 12 hours. In each session, the team works individually on a task before working together.

EVALUATION

A user study was conducted to learn more about how Dazzle's features would affect the team's ability to share information, develop a shared memory, and synthesize a shared understanding. The study also evaluated whether or not the design guidelines would have the desired effect in improving the quality of people's interactions around sharing design information.

METHODOLOGY

Participants were assigned to teams of three, and each team was brought in for two sessions—one on user research, the other on concept generation (see Figure 31). Each session consists of an individual task followed by a team task. To familiarize participants with Dazzle, Dazzle was first demonstrated and participants performed warm-up tasks at the first session. An example task from the study protocol is included in the Appendix.

SESSION ONE: USER RESEARCH ANALYSIS

In the first session, each designer was provided with a different set of seed user research data. The original user research was conducted by a professional design research consultancy for an open-source project on the future of reading (Portigal Consulting 2009). This included an interview protocol, summaries of interview participants, video excerpts from interviews, images from diary studies, and outside articles and videos about reading practices.

In the individual task, each designer was given 30 minutes to review and become familiar with the unique set of user research data on his or her local computer. For the team task, the team was asked to share its research with each other, address a set of questions about the nature of reading (similar to those addressed in the final findings of the professional designers (Portigal Consulting 2009)), and arrive at an agreed-upon list of prioritized needs, personas, or themes. The team was instructed to use Dazzle to document its process, as this documentation would be available to them in the following session on concept generation.

SESSION TWO: CONCEPT GENERATION

In the second session, the teams were asked to leverage its user needs analysis from the previous session and brainstorm concepts what the "Future of Reading" could look like. In the individual task, participants were asked to generate 15 ideas and were allowed to use Dazzle to refer back to previous information. As a team they were tasked with sharing ideas and generating 10 more ideas as a group before deciding on three to five ideas that they would want to prototype in the future. The teams were asked to document anything that they would want in future team meetings. During the second session, the teams could additionally use Post-it notes and Sharpies to hand sketch their ideas.

By conducting consecutive user research analysis and concept generation sessions, the teams had an opportunity to use the activity log. This also allowed separate tasks where the original sources for the shared information were from external sources (user research analysis) and from the designer's imagination (concept generation).

Dazzle was tested with five teams of three participants (fifteen participants total, see Table 13). The two sessions were at least 12 hours apart to simulate the type of intermittent meetings that are common in real-world new product development teams, as observed in student design teams (Chapter 5) and reported in interviews with professionals (Chapter 4). The session ended with a brief group interview; the team was asked specific follow-up questions on its usage of Dazzle, and general feedback for future iterations of system design. Field notes and video were recorded during each session.

Team	Participant	Discipline	Gender
A	1	Architecture	F
	2	Mechanical Engineering	M
	3	School of Information	M
B	1	Mechanical Engineering	F
	2	Architecture	M
	3	School of Information	F
C	1	Computer Science	M
	2	Electrical Engineering	M
	3	Computer Science	M
D	1	Mechanical Engineering	M
	2	Mechanical Engineering	F
	3	Mechanical Engineering	F
E	1	Chemical Engineering	F
	2	Computer Science	F
	3	Mechanical Engineering	F

Table 13: Summary of evaluation participants. References are made to specific participants during either the first or second session. For example, a comment made during the second session of Team D by Participant 3 would be noted as (P3D2).

RESULTS & DISCUSSION

The findings from the evaluation of Dazzle are structured according to how Dazzle addressed design guidelines G1-G6, to show whether Dazzle effectively realized these guidelines.

G1: SUPPORT HETEROGENEOUS CLIENTS AND MEDIA

Our study did not directly test supporting heterogeneous clients, as computers were provided to all participants. However, teams' uses of physical and digital media were observed during both sessions. For example, most teams chose to use Post-it notes and the whiteboard during the concept generation session. However, Team C elected to not use physical tools for brainstorming or sharing ideas. During the individual concept generation task, one participant (P2C2) first reached for Post-it notes before noticing that his teammates had started typing; this participant switched to typing his ideas in order to match his teammates. For the collaborative task, one participant (P1C2) used Dazzle to compile the team's ideas in a text file in front of the team on the shared display instead of listing ideas on the whiteboard. While it is important to support heterogeneous clients when sharing individual information (G1), the team must also agree on a common technology when building information together.

G2: SUPPORT FOCUSED SHARING OF "RICH" MEDIA

During the user research analysis sessions, Dazzle's approach of making information both visible and accessible to collaborators was effective at allowing individuals to share "rich" media while focusing the team's conversation (G2). All participants richly shared all of their interviews and enhanced their verbal summaries by showing interview debriefs, photographs, and videos on the shared display. Participants drew their team's attention to specific aspects of items on the shared display by highlighting text, gesturing with the mouse over a specific area, or talking over the audio in a video. Participants described why presenting design information directly to the team (G2) was so important:

"Sometimes I wanted to just give an idea, but sometimes I wanted the other people in my group to see what I was seeing, so they could form their own opinion, they could see the source not the secondary source. I'm a secondary source, and I'm reporting on a primary source. So, if I wanted them to get a sense of the primary source, they'd need to see it" (P2B2).

Another participant noted: *“I thought it was easier, the barrier to participation was taken down a little bit by being able to show pictures and, like, ‘Look at this thing that I’m actually talking about,’ instead of all the onus being on me to describe what it was”* (P1D1).

However, being able to directly show rich information also impacts the team’s cognitive efforts to understand the information as group. In the course of its user research discussion on “The Future of Reading,” Team B brought up the impact that moving from verbal descriptions to visual media had on creativity and imaginations: *“Why would you need to imagine something if you could immediately Google it and see it? Describing a dinosaur or describing a landscape is really different from looking it up”* (P2B2).

When asked about how Dazzle may have impacted the team’s creative imaginations, one participant said: *“It serves as a crutch—you wouldn’t have to necessarily think about it critically and then describe it to us. You could just say, ‘here, watch this.’ So, maybe there’s not that next step in your own thinking about the thing when you bring it to this discussion”* (P1B2).

In contrast to user research, the sharing mechanism was less helpful during concept generation. Perhaps this is because presenting new information does not necessarily support designers’ creative thinking and abilities to generate new ideas. For example, Team A used Dazzle in the concept generation meeting to show each other existing product and services that address “the Future of Reading.” The team’s concept generation conversation stagnated in two ways. First, participants spent time looking up and sharing references rather than making a quick verbal reference in passing. This delay rendered these references irrelevant to the rest of the team and prevented the team from keeping a quick pace of concept generation. Second, these references to competing technologies often included more information than necessary to make the point. Instead of a passing reference that highlights relevant similarities, the team saw the full details of the competing technologies. The richness of the conversation afforded by Dazzle’s ease of sharing left too little to the imagination. While this guideline is beneficial while sharing descriptions of observed user behaviors (*assimilating*, in experiential learning), it is less helpful when generating possible solution paths (*converging*, in experiential learning) (Beckman and Barry 2007).

G3: OFFER COLLABORATIVE WAYS TO ORGANIZE INFORMATION FROM DISPARATE SOURCES

Several teams annotated items in the shared activity log to take meeting notes (Team D, Team E), switching note takers as each individual took turns sharing. However, they had difficulty keeping up with the latest file shown on the public display. Our participants requested that annotations be automatically and continuously added to new items as they are shared with the team so that the annotator does not have to switch to a new item each time to restart their annotations. Users also requested that annotations be collaboratively editable by the team (similar to an online collaborative editing system such as Google Docs).

None of the teams used tagging extensively. Dazzle assumes that team members would tag items as they were shared using an emerging coding scheme. However, most teams generated key terms, which could be used as tags, at the end of their user research analysis exercise:

“I didn’t like having to assign a tag. It seems like it’s forcing you to converge too quickly. Instead of holistically thinking about all the stuff people said and then coming up with words, you have to go through each thing and see if you have similar tags. It seems like it’s going backwards; you have to categorize specific things too quickly

instead of coming up with general ideas. I had trouble with that since the tagging feature forces you to do it per post” (P2D1).

This particular implementation did not support shared meta-analysis of information (G3) as intended. Suggestions to address this shortcoming included allowing tags to be created without assigning them to any items or spatially clustering similar items before applying an appropriate tag to that clustered set. Participants also wanted to annotate the tags themselves with notes on a set of themes, as the team often looked for patterns across sets of information:

“I thought it’d be helpful to sort the shared things into folders, so that there’s a [interviewee] folder. I was putting in a couple tags and comments, but they applied more to the overall person than a specific document, so I didn’t know if I should be repeating them or if they’d get lost” (P2D1).

Tagging and annotation are critical to synthesizing individuals’ contributions into a larger framework. Future work should include tools to construct these frameworks using shared individual information, such as the items in the shared activity log, as input.

G4: RECORD ALL ACTIVITY IN THE BACKGROUND, BUT ALSO LET INDIVIDUALS RECORD ITEMS EXPLICITLY

As each of the teams worked throughout the sessions, Dazzle automatically recorded their individual contributions to the shared display. In addition, team members also explicitly used Dazzle’s automatic features to ensure that items were recorded in the shared activity log. For example, some teams used a text file to keep notes for the team, either instead of, or in addition to, the commenting system. This file was then dragged into the drop target and shared with the rest of the team at the end of the meeting, recorded along with the supporting individual contributions to the conversation. In Team D, two individuals kept meeting notes, and both sets of notes were added to Dazzle. The whiteboard was also used as a shared note-taking surface to summarize the user research or concept generation conversation. All teams captured the whiteboard at the end of both meetings for future reference, filed alongside the individual activity from the meeting.

G5: MAKE THE RECORD OF THE TEAM’S ACTIVITY NAVIGABLE BY INDIVIDUALS G6: MAKE THE TEAM’S PAST ACTIVITY VISIBLE AND ACTIONABLE BY THE TEAM

Participants had access to the shared activity log from the user research session during the concept generation session. Much of how they navigated this archive was through the reverse-chronological record, and using the search bar. During the individual concept generation exercise, most participants found inspiration by referring back to their personal notes, images from others’ interviews (PIC2), secondary references and articles (P2D2, P3D2), or the whiteboard image from the last session. In this way, Dazzle acted as a shared record for the team:

“I opened up the whiteboard [photo], I also opened up my notes that I had taken so I could remember that one more time, be reminded of the personalities. I feel like yesterday [Dazzle] was more of collaborative tool and today was more of a... you know, more of just a reminder, like a notebook” (P1D2).

During the team meeting itself, the teams primarily referred back to the whiteboard image from the user research meeting (Figure 27). Having access to the whiteboard’s history allowed the team to root its discussion and decisions in its previous shared frame. Some previously shared individual resources were also brought up during the team meeting. Team B reviewed secondary research—a video of interviews with teachers about the use of iPads in classrooms—to generate new ideas specifically around how reading might be taught in differently in the future.

Unlike sharing new information during a concept generation session, re-sharing information from the shared activity log supported specific ends: re-introducing a shared source of inspiration to generate more ideas, or reminding the team of the user-centered basis for its decision-making.

CONCLUSION

This chapter illustrates how information technology might be designed to support the human-centered design team's process of sharing information and reaching a shared understanding of a design problem. This includes exploring features to help individuals communicate to teams, recording and augmenting the team's shared memory, and helping the team apply its shared knowledge to design decisions. This chapter presented the results of a formative study of design teams at work, which informed a series of design guidelines for tools that support information sharing, and shared documentation, reuse, and synthesis. To evaluate the guidelines presented in the previous chapter, they were embodied in a collaboration system, Dazzle. This chapter describes Dazzle's system design in detail, connecting features to the guidelines offered in the previous chapter. Dazzle was evaluated by bringing in teams of human-centered design students to use Dazzle for user research analysis and concept generation meetings around the topic of "The Future of Reading." These studies found that participants shared their user research using direct sources and rich media, such as photos and videos. In the concept generation meeting, the team was able to refer back to shared conclusions from the previous user research meeting and use that to both inspire new ideas and inform which to select for prototyping.

Ultimately users actively used Dazzle for assimilating divergent information, and only referred to this information as designers generated divergent concepts. While Dazzle does not singlehandedly take care of all of design team's information needs continuing on through conceptual design, it does integrate well with existing practices, continuing to offer a way to capture and archive shared materials as the design task changes.

CHAPTER 8

CONCLUSIONS & FUTURE RESEARCH

SUMMARY

This dissertation examines how designers interact with information tools to share information in collaborative teams. In sum, it analyzes designers' self-reported and observed behavior; generates new conceptual models; develops insights into design team challenges; proposes design guidelines for new technology; and introduces and evaluates a new system design. This chapter summarizes the research contributions offered in this thesis. It also identifies some methodological limitations and broader implications of this work. Finally, new research directions that stem from this work are proposed.

NEW CONCEPTUAL FRAMEWORK: THE SHARING CYCLE

The sharing cycle (see Figure 5 in Chapter 4), a new conceptual framework that describes information sharing behavior in early stage collaborative design, was introduced. In contrast to sharing semantics or the formality spectrum, this framework describes how information is processed over time—both individually and collaboratively during user research and conceptual design stages of new product development. Examples of each stage of the sharing cycle are described using excerpts from interviews with professional and student designers.

NEW INSIGHTS: TEAMS' INFORMATION SHARING CHALLENGES

Nine challenges that design teams have when enacting the sharing cycle during face-to-face team meetings were identified. These challenges are:

- C1. Translate from individuals' preferences into a common format.
- C2. Identify relevant information for the team.
- C3. Efficiently share richly with collaborators.
- C4. Control how information is interpreted by the team.
- C5. Ensure that shared decisions reflect individual contributions.
- C6. Negotiate how information is recorded, and by whom.
- C7. Decide what to record in the present moment.
- C8. Find relevant information from previous sessions.
- C9. Present past information in a format that is useful to the team's current activity.

We also offer specific examples from observations of student design team meeting during user research and conceptual design that develop these challenges, illustrating the nuances of how each of these challenges impact the team's ability to progress.

NEW DESIGN GUIDELINES FOR COLLABORATIVE TECHNOLOGY

Seven design guidelines for new technology that supports face-to-face design teams were identified. These guidelines are:

- G0. Maintain a personal space where materials can be prepared for public view.
- G1. Support heterogeneous clients and media.
- G2. Support focused sharing of "rich" media.
- G3. Offer collaborative ways to organize and structure information from disparate sources.
- G4. Automatically and explicitly capture shared information about design activity.
- G5. Make the record of the team's activity navigable.
- G6. Make the team's past activity visible and actionable.

A review of other guidelines for collaboration and collaborative design tools was also presented, and illustrated how the themes of these guidelines connect to and build upon previously proposed design guidelines for collaborative systems. A comparison of how proposed systems from research and industry compare to these guidelines was also offered, identifying specific technological approaches that are effective at addressing designers' information sharing needs.

NEW SYSTEM DESIGN: DAZZLE

Dazzle (see Figure 29 in Chapter 7 for a screenshot of the Dazzle client interface), a collaboration tool developed according to the design guidelines, was introduced. Users can drag and drop items into Dazzle's Drop Target—this action initiates screen sharing on a shared display, copies the item into a shared folder on Dropbox, and records that action in a shared activity log. Items in the log can then be tagged or annotated, searched over, or re-shared into the Drop Target. A whiteboard camera also captures a physical whiteboard in the room and adds this documentation of a shared resource to the shared activity log.

The design guidelines are evaluated through a user study of Dazzle (see Figure 27 in Chapter 7) with five three-person design teams over two consecutive design sessions. Teams used Dazzle extensively in the first meeting to share user research information with each other; in the second meeting, Dazzle was used more as a reference, referring back to the prioritized user needs from the previous meeting in order to inspire new ideas.

FUTURE RESEARCH

This research highlighted many insights on the information tools that designers and design teams use to share information, as well as the interactions that design teams have with those tools. There are opportunities to add more depth to this work through additional research.

Extend longitudinal observations of design teams. The observations of student design teams focused specifically on meetings that were directly focused on user research and concept generation. Across an entire design project, however, designers iterate on user research and will return to user

research findings in later meetings after the initial user research phase has been completed. This research relies on interviews with designers and design teams to identify longer-term patterns in how they engage with information.

Extend longitudinal deployment of a revised Dazzle into the real world. While the user study tasks were designed to simulate design activity, they do not have the same realism as a deployment with a professional or student design team. Established relationships between designers and a longer-term engagement with a months-long design project would undoubtedly effect how participants use Dazzle and the extent to which they are able to employ Dazzle. Such a deployment would involve a design iteration of Dazzle, incorporating feedback from user studies and revising Dazzle’s design with current technologies.

Include professional designers in observations and user studies. While professional designers were interviewed, it was difficult to find any professional designers who were willing to allow observation of their design work, or participate in user studies of Dazzle. This difficulty to access professional designers is primarily due to professional time constraints disclosure concerns. However, including observations of professional designers would reinforce observations of student teams, and allow a more direct comparison between expert and novice designers as well as between educational and professional practices. Running user studies with professionals may help test how Dazzle can be adapted to fit with established, expert design practices.

RESEARCH IMPLICATIONS

This research has implications on engineering education, engineering design practice, and the design of new technologies for creative collaboration.

This dissertation’s findings on collaborative practices and tools will help engineering educators coach the next generation of engineers on how to use technology to become more effective designers and collaborators. Engineering educators agree that future engineers need the skills to confront socio-technical problems. ABET mandates that all engineers graduate with the ability to “function on multidisciplinary teams,” “communicate effectively,” “design a system, component or process to meet desired needs,” and “understand the impact of engineering solutions in a global context” (ABET 2012). This research helps engineering educators fulfill that mandate; educators can offer better advice to students on how to communicate within a multifunctional team, and how technology might help students better understand users’ needs and the broader impact of their work.

This research also offers professional designers a conceptual model that can ground communication on how the team is capturing, reflecting, and sharing information. It also can help professional designers identify which tools are most appropriate throughout the sharing cycle.

This research also has direct implications for the design of new technologies that support creative, collaborative behavior. Research insights from the conceptual frameworks and descriptions of design behavior from Chapters 4 and 5, as well as the resulting design guidelines offered in Chapter 6, can help technology designers develop new technologies that are more tailored to the reality of design work.

BROADER STRATEGIC RESEARCH DIRECTIONS

There are several future research directions that are opened up by this research. These include extending this work into distributed design teams, tracing how values such as sustainability are

propagated through the design team over time, and extending this work into later stages of the design process such as prototyping.

SUSTAINABLE DESIGN TOOLS & METHODS

In addition to technical information and user research, designers also share information about their professional values that guide their design decisions. For example, a designer who values sustainable design not only considers the end users' needs and the available technology, but also the sustainability impact of the design decisions that she makes. By tracing how a value such as sustainability is brought up and discussed throughout the sharing cycle, researchers can learn how individuals' design values are transferred and acted upon in collaborative design teams.

DIGITAL AND PHYSICAL PROTOTYPING TOOLS

As the team moves into later stages of design, the team begins to deal less with abstract information from user research and concept sketches, and increasingly turns their conversations to the designed artifact itself. The object of design is often prototyped both digitally (through CAD software) and through physical models in order to explore, test and refine their design solution. A natural extension of this thesis would be to look at later stages of design, evaluating how digital and physical prototyping tools impact the team's conversations during exploratory and verification prototypes.

INFORMATION SHARING IN DISTRIBUTED DESIGN TEAMS

While many designers work in a shared design studio, distributed teams are increasingly common; these teams can address global issues of gathering regional sources of expertise, conducting international user research, or coordinating overseas manufacturing. While the design studio may have more space, support, and computing power, it's critical that the contextual information from the field be effectively communicated back to the team. One way to do this is to not wait for the team members to return from the field, but to report back from the field. This might allow the team to quickly adjust the information that's being gathered from the field, and dig deeper into contextual issues.

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APPENDIX

**APPENDIX A:
RANGE OF TOOLS**

	Subcategory	Tool Name	Design Phase	Affordances	Practicing	Student	
Tangible Tools	<i>Small Scale</i>	Post-It Notes	All	User Needs Analysis, Conceptual Design Capture & Analysis	8	6	
		Paper "Scraps"	All	Communication	0	4	
		Index Cards	User Needs	Analysis	7	2	
	<i>Medium Scale</i>	Paper Notebook	All	Design Journal	10	1	
		Bound Notebook (e.g., Moleskine)	All	Design Journal	0	4	
		Spiral Notebook	All	Design Journal	0	3	
	<i>Loose-leaf Paper</i>	Loose-leaf Paper	All	Conceptual Design	6	4	
		Folder with Loose-leaf Paper	All	Design Journal	1	2	
		Binder with Papers	All	Design Journal	0	1	
	<i>Large Scale</i>	Whiteboard	All	Collaborative Work	9	3	
		Large-format Paper (e.g., Butcher Paper)	User Needs	Collaborative Analysis	3	0	
	<i>Other</i>	Magazines & Design Books	All	References	5	0	
		Physical Prototype	All	Prototyping	5	0	
Digital Hardware	<i>Mobile</i>	Smartphone (e.g., iPhone, Android)	User Needs	Data Capture	11	2	
		Digital Pens & Notebook (e.g., Livescribe)	User Needs	Data Capture	2	0	
	<i>Portable</i>	Tablet (e.g., iPad)	Conceptual Design	Capture	0	1	
		Laptop (non-Tablet)	All	User Needs Analysis, Prototyping	3	4	
	<i>Digital Capture Devices</i>	Photo Camera	User Needs	Data Capture	7	1	
		Video Camera/Recorder	User Needs	Data Capture	13	0	
		Audio Recorder	User Needs	Data Capture	4	0	
		Tablet Input (e.g., Wacom Tablet)	Conceptual Design	Conceptual Design, Prototyping	1	0	
	Software	<i>Prototyping</i>	Solid Modeling CAD (e.g., Inventor, SolidWorks)	Conceptual Design	Prototyping	3	2
			Surface Modeling CAD (e.g., Rhino, SketchUp)	Conceptual Design	Prototyping	0	3
			Wireframing Software (e.g., Omnigraffle)	Conceptual Design	Prototyping	3	0
Image Editor (e.g., Photoshop)			Conceptual Design	Prototyping	3	3	
Desktop Publishing Software (e.g., InDesign)			All	Data Sharing	4	1	
<i>Notetaking</i>		Notetaking Software (e.g., One Note)	User Needs	Data Capture	1	1	
		Augmented Notetaking Software (e.g., Pear Note)	User Needs	Data Capture	1	0	
		Digital Post-It Notes	Conceptual Design	Capture	0	1	
<i>User Needs Capture & Editing</i>		Video Editing Software (e.g., QuickTime, iMovie)	User Needs	Analysis	3	0	
		Custom-built Software	User Needs	Analysis	3	0	
		Audio Recording Software	User Needs	Data Capture	5	0	
		Usability Testing Software (e.g., Morae)	User Needs	Data Capture	2	0	
		Screen Capture Software	User Needs	Data Capture	2	0	
<i>Other</i>		Word Processing (e.g., Word)	User Needs	Data Capture	11	3	
		Spreadsheet Software (e.g., Excel)	User Needs	Analysis	13	0	
		Presentation Software (e.g., PowerPoint, Keynote)	All	Data Sharing	14	2	
Web Services	<i>Online User Needs Tools</i>	Online Surveys	User Needs	Data Capture	2	0	
		Online Card Sorting Tool	User Needs	Data Capture	3	0	
		Online Design Games	User Needs	Data Capture	1	0	
		Twitter	All	Communication	2	0	
		Mailing Lists/User Forums	User Needs	Communication	2	0	
		Mechanical Turk	User Needs	Data Capture	1	0	
	<i>Online File Management</i>	Online Whiteboard (e.g., Dabbleboard)	Conceptual Design	Collaborative Capture	1	0	
		Online Applications (e.g., Google Docs)	User Needs	Data Capture, Analysis	6	3	
		Online File Sharing & Project Management (e.g., Dropbox, Basecamp)	All	Collaborative Development	0	3	
	<i>Communication</i>	Email (e.g., Gmail)	All	Communication	10	3	
		Instant Messaging	All	Communication	1	0	
		Web Conferencing (e.g., Skype, GoTo Meeting)	All	Communication; Collaborative Work	6	1	
	<i>Notetaking</i>	Blogging (e.g., Tumblr)	All	Design Journal	1	1	
		Online Notetaking (e.g., Evernote)	All	Design Journal	0	2	
		Wiki	All	Design Journal	0	2	

APPENDIX B: INTERVIEW GUIDE—PROFESSIONAL DESIGNERS

This portion of the study involves interviews with professional product designers with one or two researchers present. Due to location, time and budget constraints some interviews we expect to perform either over the phone or via computer.

It is expected that the interviews will follow more or less the themes outlined below but allow room for exploration of additional topics that seem relevant to both the interviewee and the interviewer. This guide is not intended to provide a comprehensive list of questions; instead, it highlights the main themes and key questions of this portion of the study.

Questions will revolve around the following topics:

- How would you describe design?
- Please tell me what your company does and your particular role within it.
- Would you walk me through the development process for the last, or a current, project that you worked on?
- Tell me about who you collaborate with on this project.
- How involved are different collaborators at different steps of the project?
- Describe your last group meeting. Other meetings?
- How did you use your design journal before the meeting? During the meeting? After the meeting?
- Tell me about a time you had difficulty using your journal.
- When did you first start keeping a design journal?
- To what extent did you or do you reference pages after they've been made?
- What information do you share with collaborators? How do you share it?
- Tell me how your understanding of your project developed as a story.
- How do you prepare to share information with people outside your team?
- What kinds of formal communications have you developed for this project? How did you decide on the format?
- How do you convey insights and tacit understanding of your users to collaborators?

APPENDIX C: DESIGN TOOL USE SURVEY

University of California at Berkeley Consent to Participate in Research Framing in Design and Innovation

Introduction and Purpose

Our names are Lora Oehlberg and Celeste Roschuni. We are graduate students at the University of California, Berkeley working with our faculty advisor, Professor Sara Beckman in the Haas School of Business. We would like to invite you to take part in our research study, which concerns how people in various roles use different information tools throughout the design process.

Procedures

If you agree to participate in our research, we will ask you to complete the attached online survey/questionnaire. The survey will involve questions about your role, which tools you use, and what contexts you use them in, and should take about 15-20 minutes to complete.

Benefits

There is no direct benefit to you from taking part in this. The results of this study will be applied in developing tools and methods for supporting interdisciplinary design projects.

Risks/Discomforts

As with all research, there is a chance that confidentiality could be compromised; however, we are taking precautions to minimize this risk. In particular, we will not be asking for your name or other identifying information.

Confidentiality

To minimize the risks to confidentiality, we will collect your study data in an anonymous manner. When the research is completed, we may save the data for use in future research done by others or ourselves. We will retain these records for up to 2 years after the study is over.

Compensation

You will not be paid for taking part in this study.

Rights

Participation in research is completely voluntary. You are free to decline to take part in the project.

You can decline to answer any questions and are free to stop taking part in the project at any time.

There will be no penalty to you or loss of benefits to which you are otherwise entitled whether or not you choose to participate, to answer any particular question, or continue participating in the project.

Questions

If you have any questions about this research, please feel free to contact us. We can be reached at: Lora Oehlberg, 650-823-7722, lora@berkeley.edu; Celeste Roschuni, 415-830-1499, celery@berkeley.edu

If you have any questions about your rights or treatment as a research participant in this study, please contact the University of California at Berkeley's Committee for Protection of Human Subjects at 510-642-7461, or e-mail subjects@berkeley.edu.

If you agree to take part in the research, please print a copy of this page to keep for future reference, then click on the button below to accept and continue.

- I accept
- No, Thanks

For the following series of questions, please respond based on your experiences in your most design-relevant job role.

What is your job title?

How much work-related experience do you have?

- Less than one year
- 1-4 years
- 5-8 years
- 9-12 years
- 13+ years

What type of designs do you work on? Please check all that apply.

- Buildings & Environments
- Business & Services
- Physical Products
- Software
- Websites
- Public sector products/services
- Other (please specify): _____

Which of the following job function(s) do you do? Please check all that apply.

- Planning design/user research studies
- Conduct generative/exploratory research
- Competitive analysis
- Compile and present generative research results
- Develop product or brand strategy
- Ideation/generate design concepts
- Generate design requirements
- Build prototypes or mockups
- Validate or test concepts/prototypes with customers
- Validate or test concepts/prototypes with stakeholders
- Aesthetic refinement of designs
- Functional development of designs
- Develop designs for manufacturing or release
- Quality assurance testing/technical validation
- Product or Project management
- Client management
- Other (please specify): _____

What is the zip code of the city/metropolitan area of your primary work location? _____

What type of company/organization do you work for? If you are freelance or a consultant, please do not include the types of client companies that you consult for.

- Corporation or Enterprise
- Design Consulting Firm
- Freelance/independent
- Academia
- Startup
- Other (please specify): _____

How many people are in your company/organization, at ALL locations?

- 1-9
- 10-49
- 50-99
- 100-249
- 250-499
- 500-999
- 1,000-9,999
- 10,000+

Approximately how many people work on a typical project team? Please include clients or consultants that are involved on a day-to-day basis.

- 1-2
- 3-5
- 6-9
- 10-15
- 16+

Are you in a group that is organized by function (e.g., Engineering, User Experience, Manufacturing), or a group that's organized by product line (e.g., Printers, Digital Cameras), or do you have a hybrid structure where you report to both?

- Predominantly by Function (e.g., "Design Division")
- Predominantly by Product Line (e.g., "Printer Division")
- Predominantly by Hybrid Structure (e.g., reports to both "Design Division" and "Printer Division")
- Other (please specify): _____

DEALING WITH DATA

The following questions will ask you about which design tools you use when Capturing Information About the Design Problem, or during Information Analysis and Synthesis.

FIRST, we will ask you to identify design tools that you use regularly or occasionally in these design activities.

THEN, we will ask you to identify which of those design tools you use in different collaboration contexts.

Of the following tools, which do you use regularly or occasionally in your design practice for:

ANALOG TOOLS

	Capturing Information about the design problem			Information Analysis and Synthesis		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
Small Scale Analog (e.g., Post-its, index cards, paper scraps)						
Medium Scale Analog, Bound (e.g., bound notebooks)						
Medium Scale Analog, Unbound (e.g., looseleaf paper)						
Large Scale Analog (e.g., whiteboards, butcher paper)						
Physical Prototypes/Artifacts (e.g., existing products, concept mock-ups)						
Analog Capture Devices (e.g., film photography)						

DIGITAL HARDWARE TOOLS

	Capturing Information about the design problem			Information Analysis and Synthesis		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
Digital Mobile Devices (e.g., smartphones)						
Digital Tablet Devices (e.g., iPad, Tablet PC)						
Digital Capture Devices (e.g., digital audio recorder, digital camera)						
Digital Hardware Prototype (e.g., existing)						

	Capturing Information about the design problem			Information Analysis and Synthesis		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
products, concept mock-ups)						

SOFTWARE TOOLS

	Capturing Information about the design problem			Information Analysis and Synthesis		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
Prototyping Software (e.g., 2D Graphics, Solid/Surface Modeling)						
Software Prototype (e.g., existing products, concept mock-ups)						
Notetaking Software (e.g., Microsoft OneNote)						
Media Capture Software (e.g., Camstudio, Camtasia)						
Media Editing Software (e.g., Video Editing)						
Word Processing Software (e.g., Microsoft Word, Open Office)						
Spreadsheet Software (e.g., Microsoft Excel)						
Presentation Software (e.g., PowerPoint, Keynote)						

ONLINE TOOLS

	Capturing Information about the design problem			Information Analysis and Synthesis		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
Online Data Capture (e.g., Online Surveys)						
Online Collaborative Sharing (e.g., Dropbox, wikis)						
Web Conferencing (e.g., WebEx, Skype)						
Personal Information Collection (e.g., Blog, Tumblr, Del.icio.us)						

Are there any additional tools that you use **regularly to Capture Information about the design problem?**

Are there any additional tools that you use **regularly during Information Analysis and Synthesis?**

COLLABORATORS AND CLIENTS

We are interested in how people communicate the raw data (unedited video, non-curated photo collections, full transcripts, etc.) they gather with others that they work with, particularly:

Direct Collaborators: those you work with closely on a project (including client representatives or contractors),

Clients or Management: those you are doing the work for, to whom you report back your progress or findings.

If you share raw data with others, **please check all tools that you use to communicate raw data with direct collaborators and/or clients or management.**

ANALOG TOOLS

	Direct Collaborators	Clients or Management
» Small Scale Analog (e.g., Post-its, index cards, paper scraps)		
» Medium Scale Analog, Bound (e.g., bound notebooks)		
» Medium Scale Analog, Unbound (e.g., looseleaf paper)		
» Large Scale Analog (e.g., whiteboards, butcher paper)		
» Physical Prototypes/Artifacts (e.g., existing products, concept mock-ups)		
» Analog Capture Devices (e.g., film photography)		

DIGITAL HARDWARE TOOLS

	Direct Collaborators	Clients or Management
» Digital Mobile Devices (e.g., smartphones)		
» Digital Tablet Devices (e.g., iPad, Tablet PC)		
» Digital Capture Devices (e.g., digital audio recorder, digital camera)		
» Digital Hardware Prototype (e.g., existing products, concept mock-ups)		

SOFTWARE TOOLS

	Direct Collaborators	Clients or Management
» Prototyping Software (e.g., 2D Graphics, Solid/Surface Modeling)		
» Notetaking Software (e.g., Microsoft OneNote)		
» Media Capture Software (e.g., Camstudio, Camtasia)		
» Media Editing Software (e.g., Video Editing)		
» Word Processing Software (e.g., Microsoft Word, Open Office)		
» Spreadsheet Software (e.g., Microsoft Excel)		
» Presentation Software (e.g., PowerPoint, Keynote)		
» Software Prototype (e.g., existing products, concept mock-ups)		

ONLINE TOOLS

	Direct Collaborators	Clients or Management
» Online Data Capture (e.g., Online Surveys)		
» Online Collaborative Sharing (e.g., Dropbox, wikis)		
» Web Conferencing (e.g., WebEx, Skype)		
» Personal Information Collection (e.g., Blog, Tumblr, Del.ici.ous)		

Any additional comments on tools you use to **communicate raw data with others?**

INFORMATION ANALYSIS AND SYNTHESIS

We're interested in how people communicate their research findings with others they work with during Information Analysis and Synthesis activities, specifically:

Interim Findings, including initial impressions, emerging themes, or progress (e.g., research memos or highlights, works in progress)

Final Findings, including concrete opportunities, synthesized information, and/or items that may be considered a formal "deliverable" (e.g., reports, presentations, personas, journey maps, etc.)

Of the tools you use for Information Analysis and Synthesis, **which do you use to communicate interim or final research findings with direct collaborators and/or clients and management?**

ANALOG TOOLS

	Interim Findings		Final Findings	
	Direct Collaborators	Clients or Management	Direct Collaborators	Clients or Management
» Small Scale Analog (e.g., Post-its, index cards, paper scraps)				
» Medium Scale Analog, Bound (e.g., bound notebooks)				
» Medium Scale Analog, Unbound (e.g., looseleaf paper)				
» Large Scale Analog (e.g., whiteboards, butcher paper)				
» Physical Prototypes/Artifacts (e.g., existing products, concept mock-ups)				
» Analog Capture Devices (e.g., film photography)				

DIGITAL TOOLS

	Interim Findings		Final Findings	
	Direct Collaborators	Clients or Management	Direct Collaborators	Clients or Management
» Digital Mobile Devices (e.g., smartphones)				
» Digital Tablet Devices (e.g., iPad, Tablet PC)				
» Digital Capture Devices (e.g., digital audio recorder, digital camera)				
» Digital Hardware Prototype (e.g., existing products, concept mock-ups)				

SOFTWARE TOOLS

	Interim Findings		Final Findings	
	Direct Collaborators	Clients or Management	Direct Collaborators	Clients or Management
» Prototyping Software (e.g., 2D Graphics, Solid/Surface Modeling)				
» Notetaking Software (e.g., Microsoft OneNote)				
» Media Capture Software (e.g., Camstudio, Camtasia)				
» Media Editing Software (e.g., Video Editing)				
» Word Processing Software (e.g., Microsoft Word, Open Office)				
» Spreadsheet Software (e.g., Microsoft Excel)				
» Presentation Software (e.g., PowerPoint, Keynote)				
» Software Prototype (e.g., existing products, concept mock-ups)				

ONLINE TOOLS

	Interim Findings		Final Findings	
	Direct Collaborators	Clients or Management	Direct Collaborators	Clients or Management
» Online Data Capture (e.g., Online Surveys)				
» Online Collaborative Sharing (e.g., Dropbox, wikis)				
» Web Conferencing (e.g., WebEx, Skype)				
» Personal Information Collection (e.g., Blog, Tumblr, Del.ici.ous)				

What artifacts/documents/deliverables do you create **specifically to communicate final findings with clients or management?**

Any additional comments on tools or deliverables you use to **communicate interim and final findings with others?**

CONCEPT GENERATION AND PROTOTYPING

The following questions will ask you about which design tools you use during Idea Generation, or for Prototyping & Implementation.

FIRST, we will ask you to identify design tools that you use regularly or occasionally in these design activities.

THEN, we will ask you to identify which of those design tools you use in different collaboration contexts.

Of the following tools, which do you use regularly or occasionally in your design practice?

ANALOG TOOLS

	Idea Generation			Prototyping & Implementation		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
Small Scale Analog (e.g., Post-its, index cards, paper scraps)						
Medium Scale Analog, Bound (e.g., bound notebooks)						
Medium Scale Analog, Unbound (e.g., looseleaf paper)						
Large Scale Analog (e.g., whiteboards, butcher paper)						
Physical Prototypes/Artifacts (e.g., existing products, concept mock-ups)						
Analog Capture Devices (e.g., film photography)						

DIGITAL HARDWARE TOOLS

	Idea Generation			Prototyping & Implementation		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
Digital Mobile Devices (e.g., smartphones)						
Digital Tablet Devices (e.g., iPad, Tablet PC)						
Digital Capture Devices (e.g., digital audio recorder, digital camera)						
Digital Hardware Prototype (e.g., existing products, concept mock-ups)						

SOFTWARE TOOLS

	Idea Generation			Prototyping & Implementation		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
Prototyping Software (e.g., 2D Graphics, Solid/Surface Modeling)						
Software Prototype (e.g., existing products, concept mock-ups)						
Notetaking Software (e.g., Microsoft OneNote)						
Media Capture Software (e.g., Camstudio, Camtasia)						
Media Editing Software (e.g., Video Editing)						
Word Processing Software (e.g., Microsoft Word, Open Office)						
Spreadsheet Software (e.g., Microsoft Excel)						
Presentation Software (e.g., PowerPoint, Keynote)						

ONLINE TOOLS

	Idea Generation			Prototyping & Implementation		
	Regularly	Occasionally	Never	Regularly	Occasionally	Never
Online Data Capture (e.g., Online Surveys)						
Online Collaborative Sharing (e.g., Dropbox, wikis)						
Web Conferencing (e.g., WebEx, Skype)						
Personal Information Collection (e.g., Blog, Tumblr, Del.ici.ous)						

Are there any additional tools that you use **regularly during Idea Generation**?

Are there any additional tools that you use **regularly for Prototyping & Implementation**?

DIRECT COLLABORATORS & CLIENTS/MANAGEMENT

We're interested in how people articulate their design ideas to themselves, to Direct Collaborators, and to Clients or Management. We define:

Direct Collaborators as those you work with closely on a project (including client representatives or contractors),

Clients or Management as those you are doing the work for, to whom you report back your progress and ideas.

Please check all tools that you use to articulate design ideas:

ANALOG TOOLS

	Solo/to yourself	to Direct Collaborators	to Clients or Management
» Small Scale Analog (e.g., Post-its, index cards, paper scraps)			
» Medium Scale Analog, Bound (e.g., bound notebooks)			
» Medium Scale Analog, Unbound (e.g., looseleaf paper)			
» Large Scale Analog (e.g., whiteboards, butcher paper)			
» Physical Prototypes/Artifacts (e.g., existing products, concept mock-ups)			
» Analog Capture Devices (e.g., film photography)			

DIGITAL HARDWARE TOOLS

	Solo/to yourself	to Direct Collaborators	to Clients or Management
» Digital Mobile Devices (e.g., smartphones)			
» Digital Tablet Devices (e.g., iPad, Tablet PC)			
» Digital Capture Devices (e.g., digital audio recorder, digital camera)			
» Digital Hardware Prototype (e.g., existing products, concept mock-ups)			

SOFTWARE TOOLS

	Solo/to yourself	to Direct Collaborators	to Clients or Management
» Prototyping Software (e.g., 2D Graphics, Solid/Surface Modeling)			
» Notetaking Software (e.g., Microsoft OneNote)			
» Media Capture Software (e.g., Camstudio, Camtasia)			
» Media Editing Software (e.g., Video Editing)			
» Word Processing Software (e.g., Microsoft Word, Open Office)			
» Spreadsheet Software (e.g., Microsoft Excel)			
» Presentation Software (e.g., PowerPoint, Keynote)			
» Software Prototype (e.g., existing products, concept mock-ups)			

ONLINE TOOLS

	Solo/to yourself	to Direct Collaborators	to Clients or Management
» Online Data Capture (e.g., Online Surveys)			
» Online Collaborative Sharing (e.g., Dropbox, wikis)			
» Web Conferencing (e.g., WebEx, Skype)			
» Personal Information Collection (e.g., Blog, Tumblr, Del.ici.ous)			

What artifacts/documents/deliverables do you create **specifically to communicate concepts with clients or management?**

Do you have any additional comments about the tools or deliverables you use **to communicate design ideas?**

TASK MANAGEMENT

Of the following tools, which do you use regularly or occasionally in your design practice for Task or Process Management?

ANALOG TOOLS

	Task or Process Management		
	Regularly	Occasionally	Never
Small Scale Analog (e.g., Post-its, index cards, paper scraps)			
Medium Scale Analog, Bound (e.g., bound notebooks)			
Medium Scale Analog, Unbound (e.g., looseleaf paper)			
Large Scale Analog (e.g., whiteboards, butcher paper)			
Physical Prototypes/Artifacts (e.g., existing products, concept mock-ups)			
Analog Capture Devices (e.g., film photography)			

DIGITAL HARDWARE TOOLS

	Task or Process Management		
	Regularly	Occasionally	Never
Digital Mobile Devices (e.g., smartphones)			
Digital Tablet Devices (e.g., iPad, Tablet PC)			
Digital Capture Devices (e.g., digital audio recorder, digital camera)			
Digital Hardware Prototype (e.g.,			

	Task or Process Management		
	Regularly	Occasionally	Never
existing products, concept mock-ups)			

SOFTWARE TOOLS

	Task or Process Management		
	Regularly	Occasionally	Never
Prototyping Software (e.g., 2D Graphics, Solid/Surface Modeling)			
Software Prototype (e.g., existing products, concept mock-ups)			
Notetaking Software (e.g., Microsoft OneNote)			
Media Capture Software (e.g., Camstudio, Camtasia)			
Media Editing Software (e.g., Video Editing)			
Word Processing Software (e.g., Microsoft Word, Open Office)			
Spreadsheet Software (e.g., Microsoft Excel)			
Presentation Software (e.g., PowerPoint, Keynote)			

ONLINE TOOLS

	Task or Process Management		
	Regularly	Occasionally	Never
Online Data Capture (e.g., Online Surveys)			
Online Collaborative Sharing (e.g., Dropbox, wikis)			
Web Conferencing (e.g., WebEx, Skype)			
Personal Information Collection (e.g., Blog, Tumblr, Del.ici.ous)			

Are there any additional tools that you use **regularly for Task or Process Management?**

FACE TO FACE AND REMOTE COLLABORATION

We are interested in which tools are used in face-to-face or remote communication with Direct Collaborators (those you work with closely on a project, including clients or contractors) during meetings.

Face-to-Face: Communication with a Direct Collaborator who is co-located in the same physical space.

Remote: Communication with a Direct Collaborator who is not in the same physical space.

Of the tools you use, **which do you use in meetings with Direct Collaborators for:**

ANALOG TOOLS

	Face-to-face Communication	Remote Communication
» Small Scale Analog (e.g., Post-its, index cards, paper scraps)		
» Medium Scale Analog, Bound (e.g., bound notebooks)		
» Medium Scale Analog, Unbound (e.g., looseleaf paper)		
» Large Scale Analog (e.g., whiteboards, butcher paper)		
» Physical Prototypes/Artifacts (e.g., existing products, concept mock-ups)		
» Analog Capture Devices (e.g., film photography)		

DIGITAL HARDWARE TOOLS

	Face-to-face Communication	Remote Communication
» Digital Mobile Devices (e.g., smartphones)		
» Digital Tablet Devices (e.g., iPad, Tablet PC)		
» Digital Capture Devices (e.g., digital audio recorder, digital camera)		
» Digital Hardware Prototype (e.g., existing products, concept mock-ups)		

SOFTWARE TOOLS

	Face-to-face Communication	Remote Communication
» Prototyping Software (e.g., 2D Graphics, Solid/Surface Modeling)		
» Notetaking Software (e.g., Microsoft OneNote)		
» Media Capture Software (e.g., Camstudio, Camtasia)		
» Media Editing Software (e.g., Video Editing)		
» Word Processing Software (e.g., Microsoft Word, Open Office)		
» Spreadsheet Software (e.g., Microsoft Excel)		
» Presentation Software (e.g., PowerPoint, Keynote)		
» Software Prototype (e.g., existing products, concept mock-ups)		

ONLINE TOOLS

	Face-to-face Communication	Remote Communication
» Online Data Capture (e.g., Online Surveys)		
» Online Collaborative Sharing (e.g., Dropbox, wikis)		
» Web Conferencing (e.g., WebEx, Skype)		
» Personal Information Collection (e.g., Blog, Tumblr, Del.ici.ous)		

Are there any additional tools you use in **face-to-face meetings with Direct Collaborators?**

Are there any additional tools you use in **remote communication with Direct Collaborators?**

Do you have any additional comments about the tools you use with Direct Collaborators?

Is there anything else you would like to tell us about how you use design tools in your design practice?

APPENDIX D: DETAILED ANALYSIS OF STUDENT DESIGN TEAM OBSERVATION

GOAL: TRANSFER INDIVIDUALS' INFORMATION TO THE TEAM

As individuals share information with the team, and the team captures that information into their shared consciousness, the goal of any individual on the team is to include individuals' information into the team's shared knowledge.

However, several challenges arise from this:

1. Individuals need to *translate information from their preferred communication mode* to one that is standardized within the team.
2. Individuals also need to *identify personal information that is relevant to the team*.
3. While teams primarily communicate verbally, individuals on the team struggle to find ways to *"share richly"* (Hey 2008) *and be more expressive in how they communicate*.
4. Finally, individuals try to *control how information is transferred to the team*, primarily in prioritizing certain highlights from their information and directing the team's attention to what is important.

Translating from individual preferences

One of the research findings from Chapter 4 was that professional and student designers and design researchers adopt a broad range of information technologies to support their design practice. However, when it comes to sharing this information with the team, individuals must convert their information from their personal preference into a mode that the entire team can adopt and work with. Students were most commonly observed communicating verbally—focusing on verbal descriptions of interviews or solution concepts, or summaries of entire interview participants or possible user needs themes.

Some teams prepared visual communication materials in advance. In the case of the Accessible Public Transportation team, each team member had prepared PowerPoint slides and posted them on Dropbox. These prepared materials help structure and pre-define what each person will present at the meeting. Screensharing over Skype and file sharing over Dropbox allows KIL to view these materials from afar.

However, translation quickly became an issue for unprepared individuals. For the Household Water Conservation team's concept generation meeting, everyone on the team had submitted a course assignment earlier in the week involving paper concept half-sheets, which were then scanned and posted on Dropbox. The shared task for the meeting—arranging and clustering concepts and identifying patterns—relies on the physical paper copy. However, ECH forgot to bring his with him.

HOT Do you have your ideas printed out?
IND Yeah.
ECH I don't have them printed out, but let me see if I have them—
HOT Well we have...
IND We can— if you want to write them up real—
HOT I tried printing yours, and it was super slow to print, so I didn't get very far. Like, the original ones you sketched are—

IND Yeah, dude, the original papers?
 ECH That's what I'm looking for.
 IND Oh.
 ECH I don't have them, but I know what they are if that helps.
 HOT That helps.
 IND We need to have physical things.
 HOT We need to reorganize and stuff.
 IND Do you have extra blanks, so we can write them out real quick?
 JUL I do.
 HOT Did you sketch yours out? And so color it.
 IND You can't use color.

While the others continue the meeting, ECH looks up the concepts he submitted on Dropbox and copies each one to a paper sheet. As a result, he spends the bulk of the concept generation meeting disengaged with the group activity, instead focusing on re-translating his concepts back into a physical format. Trying to speed along the task of translation, JUL offers suggestions to ECH on how to copy his concepts back from the computer to paper.

JUL *[JUL is standing in the middle, but looks over to ECH]* So ECH, don't worry about drawing, because mine are not drawn. *[JUL looks down at some Stickies on the table, in front of where he was sitting. He then looks back at ECH]* Just worry about getting them on there so we can categorize them.
 ECH Do you want descriptions, or can I just explain it as we go?
 JUL Yeah. Just the title.
 ECH Just the title.

When ECH does not have his ideas in the team's common format, he must take time out to perform this translation. This becomes an issue not only for ECH, but also for the rest of the team—the team cannot proceed with the exercise without full participation, and ECH is unable to participate in the larger group discussion about how to cluster the concepts.

Another approach to ad-hoc sharing is to directly display personal sources of information to the rest of the team. For the Working Women's Wardrobe team, CHA immediately shows his teammates a framework from his notes by flashing his notebook to the team:

CHA We could also use this other framework but we will ask whether it actually means in the first place this "use" "usability" and "meaning" thing *[shows page in notebook to the group]* that they introduced.

This team used this approach both to show personal information, and to show the team where new shared files are being created and stored. ALF turns her laptop to the team for a moment to show them what she is doing on her laptop.

ALF *[turns laptop towards group and shows them the word doc]* I'm actually just making it a Word Document, Dropbox, is that cool? And I actually named it *[points to laptop]* "work in process", "customer needs and insights" and then I've dated it for uh...
 CHA For Wednesday.
 ALF For today, cause that's what we did and then we can add to it.

While these two approaches to ad-hoc sharing work well enough for these teams, they are awkward and take some effort— not everyone can see the details or context from a quick glance at a single notebook page or laptop screen.

Another approach to translation is to use asynchronous, distributed modes of communication (e.g., Google Docs and Dropbox).

CHA And can we also set up an Excel Google document where we just jot down all the insights?
 ALF Yeah.
 DEL We can just do it on the Dropbox.
 ALF Or Dropbox?
 CHA [*starts using laptop*] Yeah, okay. Why don't I do it on the Dropbox right now. I wonder if I can uh...

While this ensures that everyone has the ability to translate their insights, it is also a very 'shallow' way of sharing user insights.

Translating from individual preferences is a major challenge for face-to-face team communication. The observed teams generally took two approaches to address this challenge: a) prepare materials in advance so that the face-to-face meeting can smoothly transition from person to person; b) quickly translate on-the-fly. Unprepared or ad-hoc contributions to the team suffer from removing a team member from full participation in the team activity in order to perform translation, or not sharing information as fully with the entire team.

“Share Richly”, Efficiently

In their recommendation for good information sharing practices for teams, Hey (2008) recommends that teams use rich media to share information with each other in order to convey contextual information. The teams we observed did this by offering detailed verbal descriptions, visual imagery, or embodied reenactments of their users. However, is that there is always a tradeoff between providing rich detail and summarizing information to peers.

Many teams spent their meetings verbally describing specific anecdotes with the users that they interacted with. For example, ALF describes her interaction with someone at a retail store:

ALF The nice thing too, like the guy at the Saks store knew all the Theory and all of, like, the clothes there and like he was able to be my Container Store person, 'cause they were out of pants, so he's like "they'll go with this brand instead", so I actually have one suit that's actually, the pants from Ellis De Heart and the jacket from Theory because he knew. [*points with fingers*] But he was able to piece together my whole...

The Accessible Public Transportation team was the only one with access to a large shared display, which they used extensively to show images from their user research. As the other teams did not have the ability to show as much imagery, embodied reenactments and gestures were used to “share richly”.

For example, the Household Water Consumption team physically re-enacted situations from their user research.

GOL And when we live together, you know how when you have roommates, so when you turn on the water [*lifts hand up to pretend to flick open a faucet*] and it's turning warm you're supposed to catch it. So when she takes a shower, she just puts like a bucket [*uses both hands as if holding a bucket and putting it under something*] under and turns it on, does her whole shower, then the bucket's like full [*uses one hand as if it were the base and the other as if it were the top*] with half soapy water,
 JUL How do you use the bucket?
 GOL So you just put it under. [*gestures under*]
 HOT Just leave it in the front of the tub.
 JUL Oh, so if water splashes off.
 GOL You just put it there, as the water is the faucet's going... [*points index finger down as if it were dripping water*]
 HOT ...my personal one is collecting before, like while it's heating up.
 GOL She does both. I only do the collecting. Anyway, so after she's done, then she'll go and put it in the toilet, or if there's no need to flush the toilet she'll put it beside the toilet. And then the next time she goes to flush takes the top off. [*gestures dumping*]

In another example from the Working Women’s Wardrobe team, as ALF demonstrates the limitations of current clothing designs as identified by her user interview:

ALF Just to put their hands, because what Jessica said, [*ALF stands up and models her hands in her pants pockets*] she said like, when you’re talking to someone you can feel really awkward if you don’t have a place, and you’re like this [*puts two hands by her side*], or you’re like this [*crosses arms*], sometimes it’s just nice to just be all relaxed [*puts two hands in pockets and sits down*].

By demonstrating their observations through reenactment, the re-enactor is able to specifically highlight observed actions, and the team is able to ask follow-up questions of the simulated user. This helps the rest of the team associate the experience of witnessing the reenactment with the individuals’ user research, building the team’s empathy for the user.

However, “sharing richly” and communicating detail to the team takes time—often more time than the team is able or willing to spend at a single meeting. For example, the Accessible Public Transportation spends most their meeting stepping through a few interviews in verbal detail but they begin to run low on time. One team member proposes summarizing their interviews instead of going through them in more detail. KIL voices a concern:

KIL Maybe we should... it’s tough. I was going to say maybe we should summarize, but in some ways you might lose some interesting points if we self-edit right now. Um, I don’t know.

While Hey (2008) recommends to “share richly,” it’s important to also recognize the limitations of rich sharing—availability of resources that allow rich sharing, as well as the time that it takes to go into detail. Teams then need to identify ways to share richly, efficiently so that they can gather more detail from each other’s insights despite limited time and technology.

Identify relevant information for the team

Individuals also need to identify what information is relevant for the team and therefore worth sharing. Identifying relevant information occurs both before information is shared—navigating to find the information itself, or glancing over a peer’s shoulder to request information— or as information is being presented—responding to follow-up questions.

When sharing information with a team, most individuals spend time looking through their personal information, and time their contributions to the conversation with the point at which they are able to contribute. While this is a challenge for individuals, it is not always an observable challenge unless a barrier is in the way. For the Accessible Public Transportation team, only one person (MIK) was able to control the shared display. As a result, the rest of the team needed to explicitly ask MIK to do what ordinarily is a silent task on personal machines—navigate to the items that they want to show to the team. This occurred repeatedly:

KIL You know what, I just realized that the PDFs I put on Dropbox I think only contained one image. So—
MIK Let me open it.

MIK Do I have to pull anything up from the Dropbox or—
KIL Um, no. I did not know how it was best to share our stuff.
MIK Okay. Should we kind of—well, I guess we can
NOV We could do it under [*NOV gestures to large display*] you—under user survey, right?

MIK Where is that?
NOV It’s under interview—and then, interview. Anne and Sandy, there. I imagine that everybody could just put it in there.

LIM So can you go to Dropbox again?
MIK Okay.
LIM Go up one. Walking. Can you go to Walking from this? And Shorter Person Questionnaire... that one.

Another way that individuals identify what is interesting is by responding to others' requests for information. Ordinarily, others are unable to view individuals' information. However, personal information is often in the peripheral view of others in their personal space. At the Household Water Conservation team's user research meeting, all six members are squeezed around a small table. As a result, they are able to glance at each other's laptop screens and notebooks and ask about what they see. For example, JUL glances over at GOL's notebook, asking about what he is drawing; this is effectively a request to make that information known to the rest of the team.

JUL Is that your solution? [*Looks at GOL's notebook. HOT and FOX lean over to try and read GOL's notebook, too.*]
GOL I'm trying to draw pictures. [*HOT flips the pages in his notebook. IND picks up notebook from the table. He opens it up horizontally, leans back in his chair, and begins to draw lines and write.*] It's like I haven't thought any of these the last time we talked, but something on like a meter that would give you feedback on consumption could be in a bunch of places so one could be like in the shower. Like a picture of some kind of...you can stick on, it has some kind of control system that links to your water, and there's like how much you've used so far, or a green or red light that flashes [*GOL has palm facing out like a stop sign*], or all three, like a number that counts up as you're running it [*GOL winds his index finger*], and then it's green until you hit the same as your aggregate [*GOL has his palm out like a stop sign*]. Just for your information, nothing else.

As this team primarily communicated verbally, they were able to control how their ideas were presented through careful word choice. However, we did see instances of follow-up questions where other teammates asked for additional information—or question the validity of the information itself. For example, in the Working Women's Wardrobe team meeting BRA makes a general statement about women more generally:

BRA So I get one of the reasons women don't buy pricy pants or whatever, it's because they want more, right? They want like 20 different shirts, 20 different pants.
CHA And this is guessing or did you hear that in an interview or was it...
BRA Yeah, because she, they, my wife said, right.
CHA Oh, okay
BRA [*CHA writing on the board*] She wants to buy a lot, right, because she wants like, like what you said, right, they want to wear different outfit everyday, so they tend to buy a lot, that's why. [*CHA turns away from board and faces group again*]

CHA questions the source and the basis for BRA's statement. BRA is able to respond to the request for more information about his sources and adjust his statement.

CONTROLLING HOW INFORMATION IS TRANSFERRED TO THE TEAM

Often designers want to ensure that whatever they communicate is properly interpreted by the team. Sometimes they do this by offering a synopsis or synthesis of their user research data instead of the details, such that the rest of the team has interpretations of research data instead of the raw data itself. When reporting data in detail, individuals will use words and gestures to direct others' attention in order to emphasize important points of their data. However, it is important to note the exception to this challenge—when sharing new concepts, misinterpretations actually expand the solution space. Therefore, tight control of describing concepts is not necessary.

Offer synthesis, not just data points

Another way that this team controls how others interpret things is to offer their own interpretation of their interviews without necessarily reporting details from the interview itself. CHA shares his

interviews on a higher level, already synthesizing across his users without necessarily learning what happened with anyone else. It's unclear whether or not this team is actually listening to each others' stories and integrating them together, or if they assume that they all had the same (or similar) experiences.

CHA The norm, that's what I meant. What I got from my interviews here was that the diversity of brands out there is something that people value. They like to shop around. They like there is a Banana Republic, there is a Theory, and other players in the market. So if you come up with a solution that kind of, 4 for 5 or 5 for 4 or whatever, you're limiting their experience to one shop, which might not even be a lot, so they would miss out...

Directing Navigation

Issues of control are particularly evident when technology limits the amount of control each person has in presenting their concepts. Throughout the meeting MIK is not only typing meeting minutes, but also responding to others' requests for what they to have shown on the display. LIM, NOV, and KIL control what is displayed as they are talking through verbal requests, gesturing at the large display, or by physically reaching over and taking control of the laptop. These backseat driving action are often to serve two main ends: navigating to the desired file on Dropbox to be shown to others, and directing the team's attention to specific parts of what is being shown.

DIRECTING ATTENTION

Next, the team directs attention via gesturing—however, they both gesture directly to the large display, as well as using the cursor on the display to do a 'remote' gesture that the remote participant KIL can see.

Verbal Instructions

Individual designers also directed their team's attention by verbally highlighting or specifying what the team should be looking at. This was particularly necessary for the remote participant, who was unable to see in-person gestures; often times KIL was directly addressed to specifically bring her attention towards something.

NOV So KIL, if you look at this bus, the picture on the right, they have a lot of vertical bars.

Gesturing at the large display.

As LIM begins to review some secondary research, MIK asks if he'd like to open up the file with his notes.

MIK Do you want to pull up your...? Let me see, where's the...
LIM Ah, yeah yeah yeah.
[LIM gets up from his chair to lean over and point to a corner of the large display]
LIM If you can open here
MIK This one?
LIM Yeah. That's it.

LIM and NOV also gesture and point at the large display to direct attention towards specific elements of what they are sharing.

NOV I think this bus grip [NOV reaches over to point at display, then retracts her hand] is more like the U.S. one.
LIM [LIM points to large display, on the left side] Can you go up one slide? Is there any— [LIM extends his outstretched arm towards the display, more overtly at the left side of the display] no, no, the... [gesturing at the Table of Contents view on the left side of PowerPoint]

MIK This one?
[MIK brings up a PowerPoint slide with images]
 LIM Yeah. So this assumes in every case, people had grabbed something. Is there any simulation that they don't have anything to grab?

'Remote' Gesturing with the Cursor

The cursor can also be used to gesture over digital content that is publically viewable to the team over the large display. For the Short Transit team, this is particularly effective as KIL can also remotely view these gestures. NOV often gestured with her hands during the meeting—she also instructed MIK to gesture with the cursor so that she could direct KIL's attention.

NOV And also right behind the seat I believe that's where the engine was, because I was standing there and it was hot. They have a horizontal handle bars *[NOV emphasizes the word horizontal by moving her hand horizontally]* that are very low. Can you move the cursor there? Below that... *[NOV points to the large display]* ... This is the bar from the back of the seat, but the one behind it.
 MIK This one. *[MIK moves the cursor]*
 NOV Right there.
 KIL Got it.

Verbal cues can also enhance virtual gesturing with a cursor. In the following example, NOV instructs MIK to go to a specific slide. NOV is trying to point out the image on the right to KIL. MIK uses the fact that they are sharing screens with KIL to chime into the conversation by gesturing with the cursor to the image on the right.

NOV Actually, *[NOV points to the large display]* can you go up one slide?
[MIK switches to a slide with two images, one on the left and one on the right]
 NOV So, Jenny, if you look at this bus, the picture on the right, they have a lot of vertical bars.
 KIL On the right.
 NOV Yeah. So the picture on the right.
 MIK This one. *[MIK moves the mouse over the image on the right]*
 KIL Yeah, uh-huh.

However, only the person who is controlling the large display is able to gesture with the cursor. When necessary, others can attempt to physically take over the laptop in order to gesture with the cursor. In one instance, LIM reaches over to the touchpad in order to directly gesture with the cursor.

LIM So here you can see some, you know—
[LIM reaches over to use the touchpad on the laptop in front of MIK]
 NOV Oh, the back of the seat.

While the large display is dominated by whatever images or files are under discussion, MIK also reserves a corner of the display for the agenda document, where she adds her notes and keeps the team on task. When the discussion turns towards what the team should do next in the meeting, this agenda returns to the main focus of the large display.

LACK OF CONTROL: BRAINSTORMING

During the first section of the meeting, the authors of the concepts had little to no control over how things were presented. The order is switched: offering access and visibility before the discussion. Clustering initially and then going through to discuss each idea.

ECH Alright, here. This is the idea of like taking the *[inaudible]*.
 JUL Okay.
[ECH hands the paper to JUL. JUL hands the paper over to FOX]

It's important to note the differences between user research and brainstorming tasks. User research information tries to be an accurate and honest account of the user's experience. Individual designers are reporting on their perceived 'truth' of the users. Brainstorming, however, is entirely up to the designer's imagination—there is no one correct interpretation, as it's still a very flexible idea. If anything, multiple interpretations continue to expand the space of possibilities. Ideas iterate over time to further levels of detail, refinement, and specificity; a concept may intentionally start out fuzzy and eventually develop more detail.

Comparisons in Brainstorming

Sometimes these conversations lead to the introduction of alternate interpretations.

JUL Alright—using a soap that you can then water the plants with?
ECH Ohh, as a nutrients in it or something like that?
JUL No, it just doesn't have bad stuff in it; it's biodegradable.
ECH Okay.

The team spends most of its brainstorming meeting identifying patterns and making sense of each person's ideas. This is done by comparing each idea to existing concepts or products, previously mentioned ideas, or non-sequiturs. The process of identifying patterns also reveals multiple interpretations of a concept—while this would ordinarily be problematic (and why an individual might want to have more control over presentation), in the context of a brainstorming meeting this activity is welcomed as it expands the way concepts might be interpreted or implemented. Ultimately the concepts begin to coalesce and form clusters and stacks of ideas; these stacks are then discussed as blocks of ideas, instead of having to refer to each interpretive variant in that stack. This allows the team to handle high-level patterns, while acknowledging each of the individual contributions to those patterns.

GOAL: SYNTHESIZE INDIVIDUAL INFORMATION INTO THE TEAM'S SHARED FRAME

As the team reflects on its collective data, it must then reflect on that individual information and incorporate it into a shared frame for the team. However, while individuals can share information with the team, this does not guarantee that the team will be able to include that information into the team's cognition.

The challenge of *ensuring that shared decisions connect with individuals' contributions* occurs as the team is visualizing information together, comparing between diverse data points, and as the team creating a shared abstraction of that data.

ENSURING THAT SHARED DECISIONS CONNECT WITH INDIVIDUALS' CONTRIBUTIONS

This team made extensive use of the whiteboards available to them in order to visualize the team's thought process and list identified patterns. This whiteboard is the focal point for the conversation and re-edited to reflect how concepts have evolved. Individuals on the team also verbally connect information by taking two anecdotes, identifying commonalities and synthesizing a higher-level idea. Ultimately, the purpose of pattern identification is to synthesize individual findings well enough that the team can make a shared decision and select a shared path for the team to follow going forward.

Visualizing information together

The teams that had access to a whiteboard (Working Women's Wardrobe, Household Water Conservation) also had the ability to visualize the entire team's contributions and information on a single canvas. Creating the whiteboard visualization itself elicits conversation. For example, CHA opens up to the Working Women's Wardrobe team to ask what should be written, eliciting discussion or a counter-proposal.

CHA I mean, just as an insight, I can put on the list "diversity of brands is great".
[CHA walks towards the left side of the whiteboard and writes something down.]

While in the Household Water Conservation team's user research meeting, JUL's writing on the whiteboard creates a team activity of identifying a category and fleshing out relationships.

JUL Feel-good factor. So let's break it up, first is people like to, people need to, hmm. To enjoy your shower, right. People, just enjoyment of taking the shower. And then people... [JUL writing on the board]
HOT Time to think would be also part of that right.
??? Right.
HOT Is that the same thing or is that a separate point. Like this is my thinking, my space kind of.
IND Yeah, yeah. That extra part of the shower that's not cleaning.

This visual locus is also a place where the team can physically gesture to highlight important information.

CHA The confidence part. This is probably pretty important.
[CHA points to the left part of the board]

This visual instantiation of the information allows the team to view the product of its conversation. From this visualization, the team can begin to synthesize diverse information through comparison.

Comparing ideas to each other

As the teams work through their user research and concepts, they begin to compare one data point to the next.

The Household Water Conservation team's concept generation meeting offers examples of several types of comparisons. Once ECH is done writing out his ideas, he presents them to the team. Each time he describes his concept, and hands it to someone else who adds it to the other ideas. As each idea is presented, the group discussion immediately turns to finding connections across concepts. These comparisons may be with related products/services/businesses, previously introduced concepts, or with complete non-sequiturs that make the concept more sticky. For example, one concept brought up a comparison with a related existing product comes up (Verda Fero):

ECH Solution database—it just gives you all the, like the options on how to save water. It's like just a bunch of solutions that already exist and this would provide a better interface—
IND So this would be an extra resource.
ECH Yeah.
JUL Is it a website?
ECH It's a website, yeah. It links to—it's like that um, Vero Federo thing—it's like a resource for solutions
IND Verda Fero?
[HOT is holding out a piece of paper, and talking with FOX]
HOT Kinda looks like...
[hands FOX the paper, who puts it in another pile]
JUL Do you know them?
IND They came to talk to us at class.

Other presented concept was compared to previous concepts that had already been proposed (e.g., Human Carwash, fish tank shower):

ECH The human dry clean—so like we use a lot of water to wash ourselves, why not use something else? Yeah. I dunno, it's kinda out there.
[FOX steps back towards the team. The group talks in a tighter circle.]
HOT Yeah, it's kind of like his—
JUL You mean like chemicals?
IND You mean like a human carwash?
ECH Yeah. Something that's not water. *[ECH gestures out with his right hand]*
JUL No, but actually it's different. He's saying not to use water, just use chemicals.
IND It's still a completely different washing system *[IND stretches his arms out]*
ECH I mean, I dunno. It's kinda out there? It's an idea.
HOT It'd be in your out there ideas category
IND Put it with my Human Washing System
[FOX says something to ECH]
ECH It's something that's not water though.

ECH The fish tank shower—*[ECH reads the title from the paper, passes the paper to JUL who immediately passes it to HOT]* hang on, I'd like
IND We have that a couple more times.
HOT Everybody has some version of that, I had the digital version.

Or, the team may make a comparison to a non-sequitor that helps make a concept more 'sticky' (e.g. "The Jetsons").

ECH And then there's another one that says shower navigation. It like tells you when to shampoo, when to rinse, tells you when to do whenever.
[HOT bends down and puts the paper on the floor, then turns back to the group]
HOT It's like the Jetsons?
ECH If that helps, yeah.
HOT Okay.
[ECH hands HOT a sheet of yellow paper. HOT looks at it]
JUL If that helps. Hahahaha.

Examples of these categories were also found in the other teams' meetings. For example, members of the Working Women's Wardrobe team chimed in as others presented information, to indicate where similarities were found in their own data.

ALF And then also on to, so I had an interview with a woman who is my age and she was very, like and we stayed specifically on pants and that may have been my fault because I didn't really let the interview... run but highlighted things like wool, women's pants lack really good pockets, place to put hands, and...
CHA Yeah, I got the same feedback.
ALF You did?
CHA Yeah.

One way that team compare ideas is by verbally hopping from story to story. For example, during the Household Water Consumption team's user research meeting, JUL begins to build connections between ideas.

JUL You know that's the other thing one of my users said you can't move the meter... (?) Even if he saves 50 percent of his water, it's not doing anything... (?) But then, going back to, I thought your point the other day was one of the best. Maybe we're not going to save a ton of water *[puts one palm face down on top of another]* but if we can take that save and *[moves hands to side of body]* make a bigger impact somewhere else, I thought that was huge. So maybe you're not really... (?) by yourself, *[lifts palm]* but in aggregate, it's going to really help. Do you guys remember?

Constructing a Shared Abstraction

As the team compares ideas, abstract patterns emerge that synthesize the team's perspective. However, the team must still be able to agree on these shared patterns, and make sure that they still resonate with the individual information that was presented.

Having the earlier visualization allows the team to point to concepts, build relationships, and the relationships between them.

- JUL But let's say before you have this thing set up, when it's warm enough, [?] so you're not really sacrificing. It's behind the scenes, so there's no... sacrifice, there's no you can still feel good and relax. Um, okay, so they kind of tie in together. So the second place that you can reduce guilt, which also can be tied into... It's about feel good about the water use. Feel good but it's different. Well, if there's two different ones. Here you put shower and pleasure.
[Everyone is looking at the board. JUL points to board while talking to GOL.]
- GOL Yeah that's why I was...
- GOL So in my mind, the feel good factor point is almost (erasable?)... (?) *[points towards board with pen]*. It's like shower pleasure, and the next point was reduce guilt.
- JUL So they're two, they're different. Feeling good about saving water and then reducing guilt.
- GOL *[nods and opens hands out to agree]* It's like the flipside of... (?)
- JUL Yeah let's say you are helping a nonprofit make money then you're feeling good about that. It has nothing to do with guilt, you're just doing good to feel good. And, if you waste this water and you're like, ahhhh I took five minutes, shoot. I shouldn't have done that, so yes. It's kind of the same point, but there's a nuance.

JUL's last story is an example of an abstract narrative that synthesizes the team's point of view. These stories are not user stories, but ones that generalize to a higher-level narrative that applies broadly to their users more generally. In the Household Water Conservation team's user research meeting, JUL tells the story of a hypothetical user as a way of reflecting his interpretation of the team's current shared understanding.

- JUL So they found these energy savings programs. Say you can save five cents does not change anything. But if you make it into like a competition? Where you're in the good zone [uses hands to denote two sides], and you're in the bad zone, then that gets people really mad. Shit my neighbor's saving more, I gotta get on. Or man, I'm not doing very well, I gotta do better *[punches one fist into one palm]*. Unfortunately the flip side of that is that the people who are accomplishing that(?)... (?) *[pretends to turn a knob]*, they're like, aw. I'm doing great, I can. But maybe they're not going to. So yes there's this competitive nature or there is this keeping up with the Joneses. If the Joneses only use this much water *[shows level with one hand]* and I live right next to them, and I'm using that much *[uses other hand to denote another level]*, then I need to pick it up. It's definitely... (?) I don't know for water since we don't think about it as much. It's certainly for energy.

These stories are effectively prototypes—provisional new narratives that the team can continue to test, craft, and refine until it resonates with the team's perspective, and potentially its users.

One way that teams build abstractions is to physically cluster similar ideas together, and labels those clusters with category names. The team even goes so far as to identify concepts that are not only similar, but also close enough that they can be assumed the same to reduce redundancy and complexity.

- JUL No, no, no. So for instance, FOX, explain this one is—you set a temperature and it doesn't let the water come out until it reaches that temperature. Is that right?
- FOX Yes. So it just, you use, that's right—you set temperature here until you have the temperature that you need over here, and then you—the pump is off, until that time—
- JUL But it won't come out of the faucet until it hits that temperature?
- FOX I agree.
- JUL So that's the same thing as mine. So you can now combine this, right?
- ECH Then this is pretty much a very similar.
- IND I think all of the, uh... all of the same ideas can be combined, right?

JUL Yeah, there were a few of those. So these two—FOX, you came up with this one that talks about the mother-father-daughter. You [*JUL gestures with paper towards HOT*] came up with showering ideas, can these be combined? [*JUL overlaps the two papers in his hands*]

HOT Yeah, yeah. It's in-shower adapter.

JUL It's an in-shower adapter.

HOT That's maybe connected by wifi... or something else.

JUL That's gotta be connected by something—the problem is water isn't connected to WiFi, right?

FOX But, he has another part to take the water. [*FOX points to HOT*]

HOT Well, yeah, I mean, yeah. So, you could—

JUL Where are these—where is the sticker and the stamp?

HOT That was in here.

JUL Did you combine those?

HOT Yeah.

This allows the team to reduce the complexity of their decision going forward. However, this abstraction has its consequences on the team's process going forward, which the team discusses.

IND I think when you combine ideas though, we should not do it so much where it becomes generic though, because when we talk about, if we go through this and try to generate more ideas, then maybe there's still variation, but that might spark something.

JUL When we talk about the ideas, we talk about everything that's in that stack.

These abstractions help the team gain a new perspective on where their design process has taken them, and where the team needs to proceed next. In the Accessible Public Transportation team meeting, LIM breaks from the flow of the team's conversation to discuss the big picture with the team, looking at high-level patterns or trends in the information that has already been discussed in order to synthesize and identify the team's findings and inform their collective next steps in the design process.

LIM First of all, no innovative ideas, right?

MIK Yeah. Or ideas that really like, I think, cater to shorter people. [*MIK looks at LIM*] It seems like all the solutions they have tend to be, like, [*MIK looks at NOV*] the same things that you find here, wouldn't you say?

[*MIK returns her gaze to the laptop in front of her.*]

KIL Right, but it seems like they prioritize high volume a little bit more.

[*MIK starts typing on the laptop again*]

[*NOV nods and laughs*]

KIL They certainly have the room to put in more hanging straps, but, I mean, I guess they were—it remains to be seen why it [*indistinguishable*] like, why you go on the MUNI bus, it's like there's one strap every 10 feet or something if you're lucky

MIK [*mmhm*]

KIL and they slide around, you know, in each section of the bar they're on. It's like they could be even more than that.

LIM In terms of safety or comfort for a shorter person—do we have anything? Totally new, or... I don't see any significant learning from this. What I mean is—do we need to dig into [*LIM gestures towards MIK, with a "diving" finger*] this Asian thing? Or my idea is that we don't need to do that.

[30.59]

[*MIK looks up to LIM, over to large display, over to NOV, then back to the laptop*]

NOV I think the buses in Asia are just really trying to increase the number of seats and that's all they think, right? But, I don't know exactly the best solution for us, 'cause...

LIM Not the best solution for us, I think. [*LIM and NOV look at each other. MIK looks at laptop and types*] Yeah, the reason why we did this research was maybe, we thought that we could find some new idea or new solution for our issues, right? [*NOV drinks from her water bottle, LIM rotates back and forth in his chair*] But we couldn't find any new ideas that we can learn from them, so—I think this was a good exercise to start from, but, you know. We don't need to spend any more time.

HOT also steps back from the problem to identify the Household Water Conservation team's high-level user research patterns, and its implications on how the team will continue to go forward.

HOT But there's two approaches. One is you deal with all this waste water, and the other is you deal with it before. You have some storage or you have some device that allows water to heat up till sufficient temperature before it comes out or something like that. One's post and one is pre. Yeah, yeah, I'm just

saying there's like [*using both hands to denote two sides*] two sides to this issue, and one is handling it after the fact(?). So you don't even have a problem if you handle the plumbing side.

During the Household Water Conservation team's concept generation meeting, it's unclear if the newfound abstraction will lead to convergent or divergent activity. The clusters create fewer objects to decide between and have helped identify some patterns, but it's still unclear what (if any) decision they should make. *Should they expand to even more ideas, or decide among the ones they have? At what level do they narrow things down —narrow down to categories, or narrow down to individual ideas?*

JUL I think that's a good idea, I think it'll take way too long to do that here. But if we can get them down to 10, then that's a really good idea. So do we want to continue going through each of these and then say how we can improve that? Yes, no, maybe? What's the most efficient way to diverge and converge?
FOX So from here we vote first?
HOT I actually feel like we need to diverge a little bit
FOX From now? I thought we'd already diverged, so now we just vote to converge. And then after that we can diverge to add more ideas to like the 10 things left
HOT Okay, I mean, we can do that too.
JUL I don't think there's one right way, I think both of them could be good.

Towards the end of their team meeting, the Household Water Conservation team make some motions towards deciding how they would converge on their ideas —unsure if, now that they've identified patterns, if they should go back and generate more ideas or begin deciding upon a design direction.

Proximity to clusters: who interacts with them how

However, while the team multitasks and evaluates the clusters, they puts ECH's ideas with the clusters of everyone else's ideas. FOX and HOT become the managers of the clusters: FOX identifies similar concepts while IND provides names for each category.

Similarly to how proximity affects the use of whiteboards (Ju et al. 2008), the proximity of the team from the ideas on the floor affects their engagement with those ideas. "Sharing" and concept-by-concept discussion and manipulation happens up-close, stepping back is where pattern finding/decisions happen.

This was very similar to how the Working Women's Wardrobe works with data—CHA is closest to the whiteboard, and has the ability to edit it. However, the people who are further away make more big-picture comments.

GOAL: BUILD ON PAST TEAM ACTIVITY IN THE PRESENT MOMENT

As the team shares information, discusses its important points and nuances, and synthesizes their ideas, they are also trying to keep their current discussion in line with their previous work. In order to keep continuity, the team needs to both record information in the present moment that will be useful in the future, and refer to previously recorded information to inform current decisions.

This section identifies four challenges that emerge from these two sides of design rationale and recall:

- *Deciding what to record*
- *Negotiating who will record, and how*
- *Finding information from previous sessions*
- *Accessing information in a way that's useful for the team's present activity.*

Deciding what to record in the present to communicate with the future

While the team cannot entirely anticipate their future information needs, they do collectively try to predict what will be relevant and capture that information for the team.

The designers who are taking notes alert others of what is being written, so that they are aware of what is being recorded and can offer alternate suggestions on what to record. For example, ALF takes notes throughout the Working Women's Wardrobe meeting on her laptop, based on both what is said during the meeting as well as what is written on the whiteboard. As she does so, she often reiterates and reads what she has recorded for the team, keeping them up to date on what is being recorded.

ALF Yeah, okay. So uh... I'll just put pant pockets. [*typing on laptop in MS word*] Pockets pant design. Alright.

ALF So terms like, yeah, ok, alright, I'm going to put accessories down here... [*typing on laptop in Microsoft Word*]
What were you going to say CHA?

This same thing happens when CHA records things on the whiteboard—even though it's visible, he brings it to the team's attention by repeating verbally what he is writing.

CHA Fabrics... licensing... [*talks over DEL, writing on the white board*]

The team also makes sure to record the present visualization when it's clear that the team has concluded its thoughts and is changing directions. Individuals on the Household Water Conservation team (ECH, FOX, HOT, IND) take pictures of the whiteboard throughout the user research meeting with their smart phones. They take pictures of the whiteboard when the team appears to be changing direction and focus, and are therefore done with the current whiteboard:

JUL Should we just jump right into solutions?
GOL Um its ten after three, we need concepts by Monday. [*ECH takes a picture of the board with his iPhone. JUL yawns*] You guys think we should do it, just brainstorm?

However, it can also be overwhelming trying to capture everything that occurs as a team is rapidly sharing rich information. Some teams give up entirely; others shift to alternate ways of sharing information. After the Accessible Public Transportation team reviews their secondary research, they begin to recount their user interviews. KIL goes first, and recounts her interviews verbally to the rest of the team. MIK types continuous notes, while LIM and NOV watch her notes appear on the large display. KIL stops periodically to allow MIK to catch up with her notes. At one point during KIL's description, MIK finally stops typing.

KIL And then, in terms of the TransStrap, she said, "I wouldn't use it, it's tying yourself to another place where you can't move. I already have a pole I can grab on to." So she is really looking for a [*muffled*] solution, which was reflected in her following comment...
[*MIK stops typing and buries head in her hands*]
MIK I can't do this... [*aside*]
KIL "I'm annoyed but not so much that I'll go buy something extra. It's harder when it's not built into the metro system." She also says that, "if this is something I bought, I always forget what purse it's in, always have to be remembering where it is."
MIK Could you, um, I'm losing it with typing this...
KIL No worries, I can just—I'll just upload these. I just didn't know how we were gonna share these...
LIM Do you have it typed out?
KIL It's all typed up.
MIK Oh, alright, cool. [*laughs*] That's so much easier.

While MIK is trying to record the conversation as it occurs, she is unable to singlehandedly keep up with the pace of KIL's commentary. However, with a combination of KIL's raw data and MIK's discussion notes, the team has a much better chance of having a rich, documented discussion without being weighed down by the burden of capturing everything.

Negotiating WHO will record present information, HOW, and WHERE.

Even if it's clear what should be recorded, the team still needs to agree upon who will record that information, how it will be recorded, and where that information will be stored.

The role of the recorder may be a regular, established role (e.g. ALF's typing notes for Working Women's Wardrobe, MIK's role as the team recorder due to her typing speed). However, these roles are also up to re-negotiation. In the user research meeting for Household Water Conservation, JUL opens up the role of recording information on the whiteboard to the team.

JUL Anyone else wanna write as well?

The recorder is often burdened with writing others' ideas instead of being able to contribute ideas freely themselves. In the Working Women's Wardrobe team, ALF is burdened with writing down others' ideas for connecting with users further:

CHA We should definably do that. We should for example try to contact all the people who are working here and not going to school. The people at the career center and there are a bunch of women who are
ALF That's an interesting idea, yeah. *[ALF using Microsoft Word.]*
CHA And I literally want to go with my secret camera and take pictures of people who come out of the BART in San Francisco. *[ALF using Microsoft Word.]*

The team also verbally negotiates who on the meeting is taking notes and recording meeting activity. JUL and GOL, who facilitate the meeting, do not record the whiteboard but do check to ensure that someone is recording the meeting notes.

JUL Did you write them down? Did you get these two?
[JUL is at the whiteboard with pen and erases the whole board.]

FOX What time's the meeting? Like eleven? *[FOX takes a picture of the board using his iPhone.]*
?? Think it was eleven.
GOL Sure so you'll take, you'll kind of copy it down.

These personal notes are often distributed across the entire team, and it's unclear who has the meeting notes written down, and where. Ultimately, multiple people (ECH, HOT, IND, FOX) simultaneously take pictures with their phones of the same final whiteboard (see Figure 1).



Figure 1: Four Household Water Conservation team members take pictures of the same whiteboard using personal smart phones. Whiteboard contents include the meeting's agenda, prioritized needs, criteria for evaluation, and frameworks for understanding needs.

The team communicates verbally with each other in order to verify that the whiteboard has been captured by at least one of them.

- HOT You get a picture of it?
[HOT stands up and pulls out phone.]
- FOX Yeah we got a picture of it.
[ECH pulls out phone. ECH and HOT take pictures of the board on the right. IND scoots back, away from the table, as people take pictures]
- LORA Can I take a picture if you guys are taking pictures?
[LORA runs over to behind the group and takes a picture of the team.]
- JUL She's making fun of you.
- LORA No, I told Alice that multiple people take pictures.
- HOT Really? As opposed to what?
- IND We do this like every single time.

In the follow-up interview with the team, they mentioned that these notes were then emailed out to the team members, for their reference.

The Household Water Consumption team used smartphones in a similar fashion during the concept generation meeting to document an ephemeral shared representation. In order to physically cluster concepts, the team borrowed paper copies of the concepts from the individual designers in order to work on the shared pattern identification task. This shared representation is very fragile—an ephemeral visualization of clusters, created out of information scraps that are not shared team assets and are returned to the designers at the end of the meeting. IND and FOX take out their smart phones to document the clusters.

- HOT I just want to make sure we get all these major categories
- IND *[IND takes his smartphone out of his pocket]* Oh, I guess I'm going to take some pictures.
- JUL On the shower experience—what's that—could you explain that? Active...
- IND Well...
- HOT Well, also maybe we should divide it up *[IND leans over with his smartphone to take pictures]*
- IND Camera.
- FOX My camera is out.
- IND Yeah, you and the rest of us. We all have iPhones except for JUL.
- HOT Maybe we can each take one section.
[IND walks to the right of the cluster. FOX is on the opposite (left) side of the cluster with another phone]

It's unclear if IND and FOX's smart phone pictures of the stacks of paper are for their individual use or captured in a shared location for the team. It is possible that they were shared via email, or simply kept with IND or FOX's personal electronic files; in this case, the team must rely on remembering that IND or FOX took these pictures, and that IND or FOX is able to find them again. After the meeting, HOT sent an email to the team letting them know where he had put a .zip file with photos that he had also taken during the meeting.

The team does have explicit conversations to discuss where information should end up once it's recorded. The Household Water Conservation team discusses what to do with the results from their concept generation meeting—how record their shared work online and perhaps integrate with a voting schema.

JUL So there is another thing, just so we can vote on our own. Maybe we can somehow throw this into a Google spreadsheet—all the ideas, and then you each go and place your 10 votes
HOT Ideally, we'd just have this online, and then you could just—with a paired picture or something.

Part of what colors this decision of what to do with their design information is to help their absent participant, GOL, feel included in the decision and have the ability to still contribute. Their consideration of what technologies to use is driven by how the entire team will be able to access and participate in the process in the future.

FOX Yeah, so now we need to separate them. I mean after you give me the name of these, I can go back into the list, the thing that we already uploaded, and then put them into categories. It should be very easy, right? Because I just look at the name. If you give me the name here, and just—
JUL Okay.
FOX And then I can—we can like number them like 1, 2, 3, 4, 5, and then you go through—1, 2, 3, 4, 5 to vote.
JUL Okay. That's a good idea. So after we talk about this, before we move all of this, let's just number them.
FOX Yeah.
JUL That's what we'll do, okay. Does that help? So GOL will have a harder time, a little bit. Because he wouldn't have gone through the explanation, but- Let's stand chart here and describe these in ideate for each one of them.

Confirming that information is properly recorded takes time too—if technology fails to record what is intended, then the team's conversation is derailed from the topic at hand. In the following exchange at the Working Women's Wardrobe meeting, CHA is interrupted by ALF and DEL who are confirming that DEL is able to see files that ALF has posted on Dropbox.

CHA Yeah. And then... and then we can apply this... [CHA fades away as he sees that ALF and DEL are focusing on DEL's laptop screen]
ALF I'm sorry CHA, just one second. Go back to... I think this should do... [ALF cuts off CHA to focus on DEL's laptop screen. ALF checks her screen afterwards and finds what she is looking for] Did it not save that? Oh yeah, here it is. Is it not updated in your Dropbox.
DEL Well, it's just, is this, do you want me to print the meeting agenda or do...
ALF Yeah, but that's an old one. Final deliverables.
CHA Did you save it? Did you save it then it should be there.
DEL There... there we go. (mumbles) Dropbox...
ALF There it is. Okay, cool. Alright, so, okay, so, I'm really sorry because I got that, but I didn't get how it translated it over to the insights.
CHA So we have to translate the insights [looks at the board], which we already did, from this kind of customer feedback, into outcomes, so um... I think we did with the stuff, and, but, individually [looks at laptop.], so the framework that we using which was in the book was you have a customer statement, and then you interpret the statement and come up with a need. And I say this need is pretty close an outcome, but significantly different from what the consumer might have told you.

At the beginning of the Accessible Public Transportation meeting, the team negotiates their roles.

LIM Yeah, but it's different for yours. Maybe you feel more comfortable using yours.
 MIK Oh, Yeah, it's either way—but yeah. If it's good, we'll just use yours today. I can just install. Unless, do you want to type? 'cause I don't, like...
 LIM My typing is—[LIM shakes his head] super slow.
 MIK Okay, sorry. I don't mind doing it...

As she is the faster typist, MIK is the primary use of the laptop throughout the meeting.

Finding information from the past

Recalling information from individual or shared stashes is generally a seamless, unnoticeable operation—individuals find information from the previous meeting in their personal notes. In the following examples from the Household Water Conservation team's user research meeting, verbal recall of previous team activity occurs in passing, brings that information back into the team's current conversations.

GOL You also brought up a good thing last time we met [GOL points towards IND] when you talked about like being able to come up to your friends what you're doing, which I guess that fits in with membership [points to board] or unity. But that might be a different... Do you think, well okay so. Turning that into a question, do people care how others, if others, know their water consumption? I didn't ask about that. But it's a pretty private thing. Like you guys don't know if I left the tap on all day.

FOX I think last time somebody talked about a label...
 GOL I'm trying to draw pictures. [HOT flips the pages in his notebook. IND picks up notebook from the table. He opens it up horizontally, leans back in his chair, and begins to draw lines and write.] It's like I haven't thought any of these the last time we talked, but something on like a meter that would give you feedback on consumption could be in a bunch of places so one could be like in the shower. Like a picture of some kind of... (?) you can stick on, it has some kind of control system that links to your water, and there's like how much you've used so far, or a green or red light that flashes [GOL has palm facing out like a stop sign], or all three, like a number that counts up as you're running it [GOL winds his index finger], and then it's green until you hit the same as your aggregate [GOL has his palm out like a stop sign]. Just for your information, nothing else.

However, breakdowns in the team's ability to find information from the past can halt a meeting's progress and entirely derail their conversation.

The Accessible Public Transportation team began to discuss their interviews, including how some participants responded to the team's benchmarked concept (the TransStrap). However, the team's conversation is halted for 2 minutes as the team recalls and finds further information about their previously-agreed upon benchmark.

LIM Does this product mean what you mentioned at the previous class? So, some—
 MIK Yeah, it's... [MIK bends over to get something in her backpack]
 NOV I'll look it up... [NOV focuses on her laptop]
 MIK [MIK sits upright at the table again to look at her laptop] No, oh, I can look it up; it's in the Dropbox.
 KIL It looks like something that is out of business now, and after talking to a bunch of people, I guess I can see why.
 [MIK laughs]
 [laughter]
 MIK Did you put the picture in this—oh, no, no, no, I looked it up, I remember. Yeah, [MIKMIK flips over her notebook] Let's see if I have it.
 [MIK flips through notebook and leans over again to look in her bag. NOV is still typing in her laptop]
 [silence]
 NOV I'm assuming this is what it is [NOV rotates her laptop to show others what she found]
 MIK What is it called, a Trans... Strap? [MIK looks at NOV's laptop while typing] It's in Japanese... this is not it? [new webpage flashes on large display] Is that back? I hope so.
 NOV Go back
 [LIM and KIL laugh]
 KIL I think every time I actually try to save the image, [LIM reaches over and rotates the laptop towards him] it's like—it's, the site doesn't exist any more, so, the image is only half—

NOV Is this like, a... [NOV leans in and gestures towards the large display] I can read that, kind of ...
 MIK Can you, really?
[a matrix of images pops up on the large display]
 KIL Yeah, there it is.
[LIM turns the laptop back towards MIK. NOV rotates her laptop back towards herself]
 LIM Oh, [laughter]
 KIL It's pretty funny. *[Large display now shows product page for the particular product]* And supposedly this company came up with another product in the blind, that was like a swing that allowed you to wrap yourself around the pole and move yourself at the same time when you touched it. Hopefully we'll find pictures of it.
 LIM Is there any company which is still doing this kind of business? Or?
[MIK navigates away from the product webpage]
 KIL I mean, not that I'm aware of. I haven't looked into it too too much, but—

The shared display commands the attention of the entire team as they try to recall the TransStrap—while this is a distraction for everyone, it also allows the team to collectively remember and navigate to a previously understood concept.

The Household Water Consumption team also struggles to find information from their user research meeting at their concept generation meeting. When the team finally reaches the point of making a decision, ECH remembers that they already came up with solution criteria at the previous meeting, and that they can use that to do a first pass through selecting ideas.

[34:00]

ECH On our business model, we have certain criteria for our solution, right, our product?
 JUL I'll take this.
 ECH Sort of like it has to be cheap, it has to—it has to be affordable.
 HOT How about we write this on the board right now
 ECH Yeah, yeah, and then we can take out some of this by just like—
 JUL Do you have that? Can you pull that out?
 ECH Some here that we can toss out right away and maybe take good aspects of those and like filter.
 JUL That's a good idea. Let's keep in mind what we've already, that's a good idea.

HOT Well before we start that, let's put up the-mission statement—I mean the needs
 JUL Well I'm sorry, I can do it here and I'll put mission statement up there. So go ahead. Greywater.

The team tries to multitask (have ECH look up the information) while the rest of the team continues with their conversation. However, the team reaches a point where it can't continue without their mission statement. Four out of the five people in attendance start to look for the information, each finding a different piece of the puzzle.

HOT Yeah, I think, but I think putting up—Let's put up the needs and maybe mission statement, and then
 ECH I'm looking for them. They weren't on here, were they? The mission statement.
 [35:43]
 ECH Because I'm not finding actual like, adjectives.
 JUL Uh.
[JUL begins flipping through his notebook]
 ECH That's the impression I was under, but they might be somewhere else?
[ECH looks at his laptop]
 FOX Oh, you're looking in the Dropbox?
 ECH Uh-huh.
 FOX Uhh, it's under—
 ECH We did have like a bunch of adjectives, right, for our solution that we settled on.
 HOT You mean from today?
 ECH No, just like from before.
 HOT Umm.
 ECH Remember we had all those stickies? Oh—JUL put them up.
 HOT Oh, you mean the cluster chart?
 ECH Yeah.

HOT It's in the Dropbox.
 ECH It's in the Dropbox.
 FOX Final?
 JUL The cluster chart mean like—the cluster chart said, like, price, and—
 IND Is it not here?
 FOX Oh, you mean-
 HOT Guys, isn't it in the final-
 JUL *[JUL is looking at his notebook]* Oh, yeah, needs, I have that together. You mean: feel-good, reasonable price?
 ECH Yeah, let's just write those on the board
 HOT But we broke it down into our 3 needs, though, right?
 JUL Today we did.
 HOT No, no, no. We already have that though, I don't have my stuff with— but the—

The downside of having the team distribute roles and where information is recorded is that it's not always clear who recorded information, what information exactly was recorded, and where that information now exists.

ACCESSING INFORMATION FROM THE PAST IN A WAY THAT IS USEFUL TO THE TEAM'S PRESENT ACTIVITY

Once information from the team's archive has been found, the team then needs to access that information in a form that is useful to the team's present activity.

Sometimes, all that is needed is a cursory description of what happened, in order to jog the rest of the team's memory. For example, JUL helps the Household Water Conservation team recalls what happened at the previous meeting in order to set the agenda and tone for their user research meeting.

JUL So, yes we keep going trying to find something else, but I feel like a shower, there's reason why people stay in there. And they're gonna continue because they don't see the need, so I agree with your need to identify the need. I think when we were talking in the last meeting—guilt seemed to be a recurring theme? And so I don't know if that is a need that we want to possibly look at. Should we talk about the needs then? Or either the created needs that we're gonna talk a bit about, or the needs that they have.

However, this also leaves it up to the individuals to be responsible for staying connected with the team's process. Individuals on the team also refer to documents that were shared asynchronously and are then assumed to be included in the team's shared memory. In another example from the Household Water Conservation user research meeting,

JUL So we have a couple we haven't talked about. I don't know if you guys saw the second page of the PowerPoint, there's the feel-good, the save-time...

Verbal reference to the past

In addition to recalling the events of the previous meeting off the top of his head, JUL individually refers to the tag plot—a previously created document that sums up the group's previous shared state.

JUL You know I think we can clean it up a little bit. I'm not averse to anyone doing that, if anyone needs a PowerPoint.
 GOL I think at this stage in the game I don't know if it's as helpful to clean it up or maybe for some later stage
 JUL For a later stage.
 JUL Um I thought it was interesting because I tried to pull in as many as, the ideas that we all had? using thirty interviews, there's a lot. (?)
[FOX looks over to JUL's laptop]
 HOT Yeah using a tag plot was pretty interesting. Somebody had one of those group..(?) I think it's a way of quickly pointing out common themes.
 ECH The one where the larger it is on the thumb side or whatever, that one.

While HOT notes that, “the tag plot was pretty interesting”, the team is unable to view this important document all at once—only the people who are able to look over to JUL’s laptop are able to see what HOT is referring to.

5 minute search + whiteboard

JUL Tell me what they are on there. I'll write the ones we have.
[JUL waits at the whiteboard, pen in hand, ready to write.]
HOT Um...
ECH Oh. Is it just reducing water use, changing usage behavior and reusing less water. Those were like essential ones, right?
HOT Nope, remember we had—last week we categorized them into-
ECH Oh, that, yeah.
FOX Oh, so that is imperatives actually? Today when we spoke with Alice, right—
HOT Yeah. So do we have it written down?
FOX Yeah. So it's feel-good factor, no sacrifice, feedback on consumption
HOT Yeah, those 3, those 3.
FOX Oh you can—
ECH There it is. Alright.
JUL Alright. Good. We only spent 10 minutes on that. So. We are set! Read it again, Han.
FOX Feel good factor...
JUL 'kay.
FOX two, no sacrifice...
JUL 'kay.
FOX three, feedback on consumption.
JUL 'kay. That's it?
ECH Oh, and some criteria were easy to control and reasonable price.
JUL Okay. I think it's a good idea for us to keep these 5 things in mind, always. Um, here's the question, does our solution have to have all 3 of those?
[38:52]

Even though the entire team has access to the same Dropbox folder and shared emails, their distributed approach to recording information makes it still unclear where activity from the last meeting ended up. This ultimately puts a swift halt to the team’s conversation and diverts everyone for 5 minutes while they search for last week’s decision point. Once this information is recalled, it is immediately written back on a whiteboard and made visible to the team—the team can “keep these 5 things in mind, always” very well when those items are in the team’s peripheral vision as they’re deciding which stacks of ideas to keep.

Is this from the individual or the team?

CHA brings up the use-usability-meaning framework brought in class, and is able to show it to the team by turning and showing a page in his notebook, and comparing it with the alternate way of viewing their data that he wrote on the board.

CHA We could also use this other framework but we will ask whether it actually means in the first place this “use” “usability” and “meaning” thing [shows page in notebook to the group] that they introduced.
ALF Yeah.
CHA But I like this one better. [points to the board in back of him with his thumb]

The team, however, never gets an opportunity to fully consider the information from the previous session, as it’s represented in a way that’s much smaller and more informal than what is on the whiteboard.

Finding information from the past

In addition to personally recalling what occurred to the rest of the team (and verbally recounting it to others), the team also re-represented information to itself. In the following example, GOL re-wrote the list of needs from the previous meeting on the whiteboard.

- GOL So we need like a simple output...(?) could be, er, prioritization. It'll be like a bulleted list. And it'll be no longer than four. *[Gesticulates]* Another thing would be, to pick one of those two by twos frameworks, kind of take the next step from the cloud of info of process to what's our prioritized stuff. I think prioritization is important.
- GOL *[Rolls towards board, stands up, sits back down, begins writing on board.]* So some of the framework we've looked at—saving water, high cost no cost...
- IND Are you looking at the bird-eye at a couple that are not good, but they're a couple of like ... (?) it's just not common.
- ??? Dropbox?
- JUL I'm not able to get in.
- FOX Do you have a, saving water, and cost? Saving a lot of water?
- IND Yeah ... (?) that was something I thought of.
- GOL No I'm just writing out the six like points, so the other is, easy to implement, *[GOL writes on the white board]* and time to implement, um, the next one is cost, and convenience. I guess the convenience here is the convenience in using or,
- FOX What's the convenience?
- JUL The convenience is, does it impact me. Is it something behind the scenes that doesn't impact me? Or do I have to *[JUL pretends to have a bucket with both hands and dumps it by making a cross-body motion]* take the bucket of water and put it in the toilet.
- FOX So the convenience in using that device.
- JUL Yes.
- FOX And the next one is, about environment and anti-environment or eco-crazy, and the convenience. The other, low/high convenience. And the next one is reducing a lot of water, less water, and convenience. *[GOL flips page in notebook and begins to write]* And the last one I'm thinking of is the feeling of like feeling guilty. And saving more water would mean less water. So what I'm thinking is that actually you don't need to save a lot of water, but you still feel very good. But you save a lot of water, but you feel very bad.
- JUL That's a really good one.
- FOX If we want to emphasize on the guilt, we try to...
- JUL So when they're the metric it's not necessarily saving water, but it's creating new positive feeling.
- FOX Yeah.
- JUL It's interesting. *[GOL picks up whiteboard marker, turns to whiteboard, writes.]*
- GOL ... Just so we don't forget *[GOL rolls towards whiteboard]*

Previously shared information is recalled to refresh the team's memory for where they were last time or to add additional information on where the team. However, bringing up previously shared information is most effective when it is made visible to the team again—translating information from the past into a form that the team can manipulate and work with.

APPENDIX E: EXAMPLE TASK FROM DAZZLE USER STUDY

Task 1B – Brainstorming

You are a design team in Amazon’s R&D department, exploring the “Future of Reading.” Your team will have two meetings.

In the last meeting, you focused on user research.

In this meeting, you will come up with design concepts.

Last time, your team reviewed user interviews for your project on the “Future of Reading”. At the end of your meeting, you created personas and discussed themes that would help you generate concepts.

In this session, you will be brainstorming ideas. Feel free to use Dazzle to refer back to any of the user research that you shared with each other from last session.

Take 15 minutes to individually, generate at least 15 concepts. Refer back to your own user research notes or use Dazzle to look up what your team shared in the last meeting.
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Take 30 minutes to share your ideas with each other, and generate 30 more ideas as a team.
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Please feel free to use Dazzle to refer back to last meeting, or to share more research material or references from the internet. Be sure to use Dazzle to document your work for a (theoretical) next time.
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In the last 5-10 minutes, I will ask your team which ideas you would like to prototype for a (theoretical) next time.
