Understanding University Students' Use of Tools and Artifacts in Support of Collaborative Project Work

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Abstract

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When designers collaborate on projects, they use an assortment of tools to generate a variety of artifacts that help them complete their work. However, it remains unclear how *university students* use tools and create artifacts as they collaborate on design projects. More importantly, it is unclear how these students make tool-related decisions throughout their design projects, as well as how the different types of work they perform influence their overall collaborative

process. Developing a greater understanding of these phenomena will help members of the computer-supported cooperative work (CSCW) community better understand the complex structure of collaborative project work, as well as the role of tools and artifacts in both structuring and being structured by students' coordination practices. The current research project explores university students' use of tools and artifacts for collaborative project work by observing the work practices and decision-making processes of the students in an advanced interaction design class throughout an entire academic quarter. These students performed task work, articulation work, and metawork as they consulted their personal toolbelts, decided which tools to use, and then developed artifacts using those tools, all in order to create the necessary deliverables and final design products for the course they were taking. Students' decisions about how to structure their task work influence their choice of tools, and those choices in turn influence their processes of artifact creation as well as their performance of articulation work and metawork. This dissertation documents the reflexive nature of that relationship among students' tool-related decisions, artifact-related creative processes, and collaborative practice.

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DEDICATION

To my friend, Professor Tom Williams, who helped me disambiguate my academic life;

to my wife, Dr. Thérèse E. Dugan, who is always there for me;

to my daughter, Mary Jane Annelies Thayer, who can take any path she chooses;

to my family, who are awesome in every way;

and to Jimi Hendrix and all the other musicians who provided the soundtrack for this work.

"Everybody loves progress and hates change"

– Dr. Dan Odell

"I am a scientist, I seek to understand me / I am an incurable and nothing else behaves like me"

– Robert Pollard

Chapter 1. Introduction

When designers (whether students or professionals) collaborate on projects, they use a wide assortment of tools to complete their work (cf., Oehlberg, Roschuni, & Agogino, 2011). As they perform tasks using different tools, they also generate a variety of artifacts such as sketches, handwritten notes, interface design ideas, and so on (cf., Bucciarelli, 1994; Henderson, 1991; Henderson, 1999). However, it remains unclear how *university students* use tools and create artifacts as they collaborate on design projects. More importantly, it is unclear how students make tool-related decisions throughout their design projects, as well as how the different types of work they perform influence their overall collaborative process. Developing a deeper understanding of these phenomena will help members of the computer-supported cooperative work (CSCW) community better understand the complex structure of collaborative project work, as well as the role of tools and artifacts in both structuring and being structured by students' collaborative practice.

The current research project begins to fill these gaps in the discourse by exploring university students' use of tools and artifacts for collaborative project work. This research project involves observing the work practices and decision-making processes of students in an advanced interaction design class at a large university in order to describe how they make tool-related decisions in the context of their performance of different types of work.

The overarching research question for this study is as follows: **How do university students use different tools and artifacts for their collaborative design project work?** Answers to the following research sub-questions will help address the overarching question:

- What is the constellation of tools and artifacts that university students use and create to support their collaborative work?
- How do they decide which tools to use to support their collaborative work?
- How does their performance of task work, articulation work, and metawork organize, facilitate, and constrain their collaborative project work?

The findings and data analysis from this research project yield theoretical and practical results relevant to the CSCW research community. Specifically, the theoretical concept of “metawork” is a distinct type of work separate from task work and articulation work; given that this concept is presently undertheorized, this dissertation further specifies what it means for students to perform metawork. Finally, students’ performance of the combination of task work, articulation work, and metawork are analyzed in the context of their tool-related decisions and artifact creation processes in order to better understand the sociotechnical nature of collaborative design project work.

Study Overview

The setting for this study was an advanced interaction design (IxD) course at a large university in the Pacific Northwest region of the United States. This university operates on a quarter system, meaning that all courses span 10 to 11 weeks for classroom-based sessions plus an additional week for final exams and presentations. This course took place during Winter Quarter 2012 and lasted from January 3 to March 8; final presentations occurred on March 13. The course officially met twice a week for 170 minutes per session, for a total of about 63 hours of scheduled course time.

The 28 students in the course formed six teams, with four or five students per team, within the first two weeks of the quarter. Each team was required to have three IxD students and one or two students from other departments and disciplines. The course was organized around a central theme: developing design concepts for the Microsoft Design Expo 2012, which is an annual competition among a select group of student teams. This event occurs during the annual Microsoft Research Faculty Summit. As the quarter progressed, students were asked to complete one assignment independently and 10 assignments collaboratively. As a course requirement, students formed their teams around the IxD students, all of whom had taken the junior-level version of the same course during the prior academic year.

This study used a combination of research methods to gather data about the student participants. A survey with closed- and open-ended questions was conducted to collect students' demographic information, their uses of software and hardware in the context of their academic work, and their thoughts on how they selected the teams in which they would work throughout the academic quarter. Participant observations were conducted in order to develop a clear picture of students' facilitation of their collaborative project work. The results of these observations yielded interpretive insights into students' decisions about how to facilitate their collaborative efforts, as well as their processes for their performance of task work, articulation work, and metawork. Within a month after the end of the academic quarter, 16 of the 28 students were interviewed about how they planned, analyzed, and evaluated the tasks and activities they completed for their project.

Chapter 2. Research Motivation and Literature Review

Given the broader question of how university students use tools and artifacts in the service of their collaborative work, the review that follows drawn upon literature from the CSCW, human-computer interaction (HCI), and design studies communities. As the name suggests, the CSCW literature base includes a number of sources that discuss how cooperative and collaborative work are performed in the context of technology use. CSCW scholars have spent a great deal of time documenting work as a phenomenon, and the sources included here provide the necessary background in this regard. The CSCW literature base is complementary to that of the HCI literature, and provides a host of relevant studies and theories about the different types of interactions that take place between humans and technology, and how to improve those interactions. Finally, research in the design studies community attempts to tie together concepts of work and how projects proceed with the specific types of tasks, activities, and practices in which designers engage.

This literature review is divided into six parts. The first part describes the definitions of essential terminology related to collaborative project work. Specifically, coordination, cooperation, and collaboration are defined in the context of students' team work practices. The second part of the literature review distinguishes the types of work that occur on collaborative projects, with a focus on describing the concepts of articulation work and metawork.

The third part of the literature review draws upon research from the design studies community to define important terms that relate to the use of tools and artifacts on collaborative design projects. The fourth part discusses how the CSCW concepts of ordering systems and brackets situate the concepts of tools and artifacts in the context of collaborative work in general, and takes a design studies approach to revealing how tools and artifacts are used during the collaborative design process in particular.

The fifth part of the literature review presents the concept of project-based learning, the current thinking around this pedagogical approach, and the most important questions that are currently related to university students' collaborative work. Finally, the sixth part provides an overview of the terminology and application of actor-network theory (ANT). Elements of ANT form the conceptual framework for this dissertation research.

Coordination, Cooperation, and Collaboration in the Context of Students' Team Work

Within and across academic disciplines, the words "coordinate," "cooperate," and "collaborate" intermingle so much that it becomes challenging to differentiate among them without a field guide. In this section each of these terms is defined in turn before the interconnections among them are described in the specific context of this research project.

Coordination defined. Bannon and Schmidt (1989) describe "coordinative" work as distinct from "collaborative" or "cooperative" work, but do not elaborate on what exactly constitutes coordinative work. Malone and Crowston (1994) are among the first CSCW scholars to provide this clarification. After reviewing a number of different definitions for coordination, they define it as "managing dependencies between activities" (p. 90), where "dependencies" can refer to the requirement that a task is completed successfully before the next task can begin, or to the availability of a team member to work on a task. The next section characterizes the definition and alignment of these dependencies in the context of articulation work.

Additionally, Malone and Crowston are purposefully vague about who, or what, is managing interdependencies; although they distinguish between human and non-human systems, they regard coordination as occurring in either type of system. Further, their definition of coordination enables researchers to explore the types of dependencies present within systems and the processes by which those dependencies are managed (p. 91).

Tellioglu (2010) advances the work of Malone and Crowston by citing coordination work processes, impact factors, and coordination mechanisms as the three elements that comprise a typology of coordination (p. 313). Coordinative work processes describe how the work itself gets done, including decisions about the division of labor, the composition of the teams doing the work, and so on. Impact factors describe the types of interdependencies among resources, tasks, and other aspects of project work. Finally, coordination mechanisms comprise a coordinative protocol and a coordinative artifact, which respectively describe the "rules" for articulating activity and the tangible thing onto which those rules are inscribed. The topic of coordination mechanisms is discussed again later in this literature review in the context of ordering systems (Schmidt & Wagner, 2004).

Coordination is defined here as *the management of interdependencies among actions and activities*. This definition is based on the combination of early and recent CSCW theorizing about coordinative work (cf., Carstensen & Schmidt, 1999; Gerson, 2007; Schmidt, 2011; Schmidt & Wagner, 2004). In this definition, "management" describes the coordinative work processes that occur, "interdependencies" describes the impact factors that influence the work being done, and "actions and activities" describe the work that occurs around the coordination mechanisms that people create and use when they work together. Following Malone and Crowston (1994), this definition of coordination purposefully excludes any mention of systems as a way to avoid overconstraining what is meant by coordination in this dissertation.

Coordination can describe a number of situations that do not necessarily involve multiple actors working together. For example, one actor working independently can be said to coordinate the interdependencies present within the project he or she is managing. Additionally, both human and non-human actors can be assigned to projects and, once assigned, are responsible for managing interdependencies in specific, predictable ways. Note that in this dissertation the term "actors" refers specifically to human actors, whereas non-human actors are described as such to avoid confusion.

Cooperation as a characterization of collaborative work. Bannon and Schmidt (1989) provide one of the earliest distinctions between cooperative work and collaborative work. They claim that cooperative work is a neutral phrase lacking in other signifying elements that might indicate certain emotional, categorical, or other identifying traits of team members working together. Collaborative work, by contrast, is a loaded term that has its roots in obeying orders or "'collaborating' with an enemy" (p. 362). This discussion implies a philosophical orientation toward "cooperative" work as the rightful definition for CSCW, an orientation that has taken root among CSCW scholars in the intervening years.

Other CSCW scholars have defined these concepts differently, however. For example, Malone and Crowston (1994) define cooperation and collaboration as follows: cooperation "usually implies shared goals among different actors," while collaboration "often connotes peers working together on an intellectual endeavor" (p. 90). Further, Schmidt and Wagner (2004) seem to suggest that *cooperative* work occurs when actors *collaborate* on a project. This distinction is important because it implies that other forms of collaborative work exist, and that "cooperative" collaboration is one type of collaborative work. In other words, cooperation can be considered a modifier or description of collaborative work, as in cooperative collaboration.

Cohen, Cash, and Muller (2000) suggest an alternative to cooperation as a characterization of collaborative work. Their research explores the difference between “cooperative” and “adversarial” forms of collaboration. Their definition of cooperative collaboration corresponds with that of Malone and Crowston (1994): actors who are working together on a specific action or project and who have the same shared goals. Adversarial collaboration, by contrast, assumes that actors have different goals but must still complete the same action with one another. Adversarial collaborators simply want to complete the actions at hand; it may not be possible for them to resolve their differences with one another, nor is it important for them to do so. Friendly, ongoing cooperation is not a condition of this type of collaborative work.

However, the concept of adversarial collaboration is not necessarily applicable to collaboration among team members but instead across entire teams. The research of Cohen et al. focuses on a specific professional situation in which adversarial collaboration is the norm (competing legal teams working together to produce a document). Students working together on team projects often share the same general goal (e.g., completion of the assignment), but they might have different academic backgrounds, skill sets, and ways of working toward their goals. They might also have different definitions of success or different goals for working on a specific project. Clearly, another characterization is needed to describe the collaboration that occurs among students working together on team projects.

Contested collaboration defined. Sonnenwald (1995) proposes the concept of contested collaboration as a way to describe the communication among designers, developers, and potential users of a specific design concept (p. 872). According to Sonnenwald, complex design processes involve a variety of actors who rely on their diverse knowledge bases to bring unique qualities and skills to those processes. However, their diversity also makes it challenging for these actors to communicate with one another, let alone collaborate meaningfully and successfully. Sonnenwald (1996) suggests that the process of exploring the different knowledge bases that design process participants bring to the table is characterized by "contested collaboration" (p. 279).

Sonnenwald and Pierce (2000) succinctly describe contested collaboration as follows:

> When contested collaboration occurs team members challenge the contributions of others. They may also maintain an outward stance of cooperation but work to further their own interests, at times sabotaging the collaborative effort. When this occurs, it hinders the achievement of the superordinate team goal (p. 463).

Contested collaboration accounts for the fact that different design team members' personal histories, skills, and outlooks make collaboration challenging and potentially rewarding. The actors in these groups must work through some number of interpersonal differences so they can complete their work together. Compared to adversarial collaboration, actors who are engaged in contested collaboration are more interested in cooperating with one another and are, therefore, more likely to attempt to bring their different world views and perspectives into alignment for the benefit of the project.

This give and take among actors points to the usefulness of contested collaboration as a way to describe how students work together on collaborative design projects. Given that collaboration is an often contested phenomenon within teams, team members must set and agree to abide by certain rules and division of labor. When students challenge one another on their assumptions, expectations, decisions, artifact creation processes, and so on, they are engaging in contested collaboration. Although they are attempting to collaborate, they are also defending their own academic practices and ways of contributing to the team as a whole (Sonnenwald & Pierce, 2000).

Other scholars (cf., Adamczyk & Twidale, 2007) consider contested collaboration as an issue that can arise among students working on HCI design projects together. Contested collaboration is not an issue, however, but an eventuality when students collaborate on design projects. Among proponents of project-based learning, a degree of contested collaboration is desirable because its presence within a team indicates that the team members are trying to sort out their differences and work together as effectively as they can. However, the concept of contested collaboration has yet to be thoroughly explored as a potential superset of additional types of collaboration. Additionally, if contested collaboration could be operationalized somehow, it would be possible to see whether it is more or less prevalent when students use certain tools or attempt to complete deliverables for specific design assignments.

Summary. This dissertation defines **coordination** as *the management of interdependencies among actions and activities*. The concept of coordination can be used to characterize a number of work arrangements and situations; one such arrangement is the performance of **collaborative** work, or *the activity of two or more actors working together on the same project*. As a concept, “collaboration” does not describe the actors’ motivations or goals with regard to the work at hand. Instead, this concept indicates that work is occurring among multiple actors who have agreed to work together on a specific project. These actors might have different motivations for their involvement on a project, or they might have entirely different goals or outcomes in mind. It is entirely up to the actors who collaborate on a project to decide how they want their collaborative efforts to proceed.

Further, **cooperation** is defined as *one possible way to characterize how collaborative work occurs on a project*. Although the CSCW literature on cooperative work does not always take such a behavioral view of cooperation, this research project relies on a definition of cooperation that is not a synonym for collaborative work but is instead a characterization of collaborative work. **Cooperative collaboration** *suggests a consistent level of respect among actors and a shared interest in working together*. In reality, however, actors engaged in collaborative work agree and disagree, form alliances, argue, skip meetings, and generally engage in unpredictable behavior. For this reason, it is more useful to characterize collaborative work as *contested*. **Contested collaboration** is defined as *two or more actors working together on the same project who are attempting to address the interpersonal differences and different work styles that make project work more challenging*. Contested collaboration most effectively characterizes how students work together within a specific team because it successfully encapsulates the simultaneously cooperative and adversarial behaviors that can occur when students collaborate.

This discussion of coordination, cooperation, and collaboration raises new questions, however, with regard to terminology. The next section defines the words “project” and “work,” unpacks what it means to perform work on a project, and discusses how different types of work (e.g., articulation work, task work) occur when actors collaborate on the same project.

Collaborative Project Work, Articulation Work, and Metawork

The effort required to complete collaborative project work comprises much more than the completion of a number of different actions. Other types of work are involved, and these other types of work are not necessarily as visible to actors, stakeholders, and researchers who are observing the work as it proceeds. This section first explores the conceptual landscape of these other forms of work, with an emphasis on the research of Anselm Strauss. Next, the concepts of articulation work and metawork are defined and related to the performance of project work. Finally, the section discusses how scholars have combined these understandings with new concepts to describe actors' collaborative project work.

Defining the language of work. Strauss (1985) introduced a number of ideas related to the intersection of tasks and actors that occurs when collaborative project work is performed. However, Strauss uses "action" and "activity" loosely and often synonymously. Typically, an activity comprises actions (cf., Engeström, 1999); when Strauss (1985) references actions, he is actually referring to activity in the way that activity theorists understand the term. Therefore, when Strauss discusses project-related action as "made up of many tasks done over time" (p. 2), he is actually saying that the arc of work of a project comprises many actions done over time. Some actions may be combined into discrete activities, as with steps in a procedure, but that is not necessarily required.

The following list of terms and definitions clarifies the specific terms that are germane to the current research project and are used throughout this dissertation:

- **Action –** Synonymous with task; describes a discrete unit of work that must be completed
- **Activity –** A routinized set of actions that, when performed, leads to a predictable result

- **Actor –** The human or non-human entity that performs actions on a project; can be defined as specifically as individual people, or as generally as entire organizations or teams within and across organizations
- **Arc of work –** The complete set of actions and activities that comprise the effort required on a project
- **Articulation work –** The effort required to keep actors aligned with actors, actions aligned with actions, and actors aligned with actions
- **Division of labor –** Descriptive of how project work is divided among actors, or among actions, or between actors and actions
- **Project –** The combination of an arc of work and the division of labor (characterized by the assignment of actions to actors) in the service of achieving one or more goals
- **Resource –** Descriptive of the actors and the tools and artifacts they use in order to complete specific actions on a project

This list serves as the key for understanding the discussion in the remainder of this section, in which the most important terms listed above are described in greater detail.

Every project involves the division of labor expressed as an "arc of work" (p. 2), which serves as a "trajectory blueprint" (Strauss, Fagerhaugh, Suczek, & Wiener, 1985, p. 151) for the project. Within the arc of work for a project, actors define and assign one another different actions based on their skills and other resourcing considerations. Their completion of specific actions can also be described as the performance of task work. As stated above, a task is a discrete unit of work that must be completed for an activity to proceed as planned. Tasks are not homogeneous units but are entirely dependent on how the actors on the project decide to define and scope the effort required to complete each activity.

Actors are responsible for performing the tasks assigned to them on a given project, although to whom they are responsible may not always be clear, either to them or to the rest of the organization within which they are situated. Strauss puts the onus on the researcher who is studying project work to determine how the accountability and responsibility are assigned or made known on a project (Strauss, 1985, p. 8).

Differentiating articulation work from other types of work. Embedded within the idea of the arc of work is the notion of task articulation. The effort to articulate the tasks that actors have defined for an arc of work can be separated into three distinct types of “articulation work” (p. 4). The first level of articulation work describes the high-level actions that must take place within an arc of work and that are described in terms of general order of operations and exit criteria. An example of a high-level action is a definition of the success metrics that must be met before a project can proceed from one phase to the next.

The second level describes the administrative work of the actors who must design the arc of work and ensure that it runs properly. These actions do not directly advance the project work, but instead facilitate its continued function. Examples of these actions include finding office space in which actors will do their project work, or ordering enough laptops for everyone to use. The third level of articulation work describes the actions required to complete the project. These are the day-to-day actions that comprise the arc of work for the project. For example, one actor might write a segment of software code that will be integrated with other lines of code being written by other actors. It is worth noting that, in the course of performing third-level articulation work tasks, local circumstances sometimes dictate alterations to the order of task operations that was initially created as a result of first-level articulation work.

In order for a project to be completed successfully, the outputs of all three of these types of articulation work must be aligned and integrated into a comprehensible aggregation of elements that describe the tasks and structure of the project (p. 8). This process is called “meshing.” On any project, actors must be meshed with other actors to ensure their successful collaboration. The disparate actions they perform must be rationalized and combined such that the next set of actions can proceed. Actors and actions must also be meshed such that actors are assigned to complete the actions for which they are best suited, a process described earlier as the division of labor within an arc of work.

Articulation work is a useful concept because it enables researchers to characterize how actors, actions, and the combination of both are brought into alignment such that project work can be completed successfully. Gasser (1984) was among the first to suggest that articulation work occurs in every organized social setting whether people are aware of it or not. This suggestion is significant because it highlights the frequently hidden nature of articulation work, which is problematic because meshing tasks and activities may not succeed if project leaders are unaware of the specialized articulation work that occurs around and in support of this meshing process.

Furthermore, when actors work across multiple projects simultaneously, the articulation work associated with one project is impacted by the articulation work of the other projects. Actors who deal with these “bundles of projects” (p. 14 after Gerson, 1983) must prioritize their actions depending on a number of factors (e.g., which project has the highest priority, which actions must occur first, which resources are available at a given time). Clearly, circumstances arise within and across projects that necessitate the performance of articulation work to determine how best to mesh matrices of actors and actions with different actions and outputs.

Evolving the concept of articulation work. As stated earlier, Strauss (1985) defines the arc of work such that the actions required to complete a project are understood only in retrospect (p. 4). However, as Schmidt (2011) points out, Strauss does not discuss what happens *in the moment* when an action is improperly performed. Gerson and Star (1986) acknowledge that the articulation work associated with any project involves responding to unforeseen circumstances and resolving problems as they arise. They use the term "due process" to describe how actors ensure that the effort to dynamically mesh actors, actions, or both occurs within a project (p. 258). With this observation about how articulation work is actually performed, Gerson and Star add the much-needed sense of "ongoing adjustment of action" (Schmidt, 2011, p. 192) that the definition of articulation work lacks.

Schmidt and Bannon (1992) add another nuance to the definition of articulation work by stating that when actors work as individuals (e.g., not collaboratively), far less articulation work occurs than on collaborative team projects. The reason is simple: Collaborative activities necessitate greater amounts of articulation work because more actors are performing a greater variety of actions. Schmidt and Simone (1996) consider it important to distinguish articulation work from collaborative project work because system users perform a great deal of articulation work just to make collaboration possible. This ongoing stream of articulation work is a collection of "individual and yet interdependent activities [that] must be coordinated, scheduled, aligned, meshed, integrated, etc.–in short: articulated" (p. 158).

As a reminder, coordination is defined as *the management of interdependencies among actions and activities*. With this definition in mind, it seems clear that Schmidt and Simone situate the definition of articulation work as a necessary element of coordinative activity, including collaborative project work. In their discussion of administrative assistants, Erickson, Danis, Kellogg, and Helander (2008) cleverly describe these workers as “articulation workers” (p. 617) because so much of their day-to-day work is coordinative. Those scholars conclude that the phrase “articulation workers” carries with it two implications about the work they do. The first implication is that articulation workers spend their time aligning actors and actions in a variety of ways, which is the essence of articulation work as described thus far.

The second implication, however, points to a split in the definition of articulation work. At a high level, the purpose of all this effort is to create coherence within and across projects. It is this latter type of articulation work that Gerson (2007) describes as “metawork,” and that Schmidt (2011) defines as “second-order” articulation work. To avoid causing confusion, this dissertation relies on Gerson’s terminology (local articulation work and metawork) rather than Schmidt’s.

Establishing a new definition of articulation work. The definition of local articulation work (Gerson & Star, 1986) corresponds with the earliest descriptions of articulation work (cf., Bendifallah & Scacchi, 1987; Fujimura, 1987; Gasser, 1984; Strauss, 1985). In the context of this dissertation, local articulation work is defined as *the work that occurs when actors gather or put into use the resources needed for a specific action in order to keep a specific project activity on track*. Each step in an arc of work requires local articulation work to ensure that the right resources are present at the right time, or else the project stalls while actors scramble to rectify the situation. Gerson (2007) describes this effort as “bringing together everything needed to accomplish a task at a particular time and place” (p. 196).

Similarly, Schmidt (2011) describes this effort in terms of actors and actions: local articulation work is the effort of mobilizing actors and deploying them as needed to work on specific actions. Both Gerson and Schmidt regard local articulation work as continuously occurring throughout the lifecycle of a project because the specific circumstances of every project are dynamic. The project leaders must be responsive to changes in these circumstances, which is why an arc of work is always under construction and can be assessed only at the end of the project (Strauss, 1985).

Whereas local articulation work describes the effort required to ensure the successful completion of project actions, metawork describes the classes of activity that comprise the project itself and the processes associated with ensuring that “different *kinds* of activity function together well” (Gerson, 2007, p. 196, emphasis original). Schmidt (2011) concurs with this definition, claiming that metawork comprises the coordination and integration of these classes of activities within a specific project and potentially across bundles of projects. Stated differently, metawork is the work of deciding how to coordinate and integrate classes of activity.

However, the concept of metawork is a more useful research concept when it is used to describe more than the structure of tasks and task work across activities. Metawork is defined here as *the negotiative effort that occurs on collaborative projects when actors discuss how project resources should be aligned across activities, as well as why those particular resources are appropriately aligned in that way*. In practice, this definition implies that metawork efforts pervade collaborative project work, such as when two actors negotiate whether a third actor should be assigned to a particular type of action throughout the project, or how an action should be carried out with the total arc of work in mind.

This research project looks at the performance of metawork in the context of a particular project and its arc of work, rather than the metawork that extends across bundles of projects. Additionally, because scholars have not yet established a clearly-defined division between local articulation work and metawork, this project is focused on developing an understanding of how students perform metawork in the context of their team discussions about resource alignment and fitness. Analyzing these discussions offers one way to trace the decisions that students make with regard to the arcs of work within their collaborative teams. Thinking about how and why students exert control over team-wide decisions by performing metawork will provide a more sophisticated view of how collaborative project work gets done.

The study of metawork poses a thorny research problem, however, because it does not necessarily manifest in an explicit way during team work sessions. For example, in a lab-based study of team project work, it is challenging to elicit the phenomena associated with metawork, although some scholars have indirectly attempted to do so (cf., Stempfle & Badke-Schaub, 2002). Many studies of design communication, or the processes associated with the design of engineering artifacts, marvel at the amount of metawork that occurs within and around such projects (cf., Sonnenwald, 1996; Stempfle & Badke-Schaub, 2002; Stevens, 1999). However, these studies do not focus on explaining the performance of metawork as a specific, demonstrable phenomenon. Instead, these scholars indicate that metawork takes place in specific proportions to other forms of work, but they stop short of explaining how and why metawork is a critical part of students' collaborative processes.

The obvious question, then, is so what? Why is it important to explicate the articulation work processes that occur within and around collaborative project work? And, what does the idea of metawork “do” for this research study? The reason is simple: There is great promise in this concept as a way to connect students’ tool-related choices to the products of their collaborative project work. Discussions about process and how best to structure their task work dominate university-level students’ project activities (cf., Stempfle & Badke-Schaub, 2002). Articulation work is most visible when process-related communication is taking place.

Furthermore, the concept of metawork describes how resources should be aligned and why those resources are most appropriately aligned in that way. Therefore, by studying students’ collaborative project work in action using the conceptual lens of metawork, it is possible to examine students’ discussions and decisions about which tools to use and how to create the artifacts required to demonstrate their progress. Through such discussions, metawork can be developed into a more usable concept that will help scholars understand these decisions with greater clarity.

Artifacts, Deliverables, Products, and Tools in Use on Collaborative Projects

When students collaborate on team projects, they use a variety of resources in support of their work and they generate a variety of materials as they progress toward completing their work. However, given the number of different ways in which other scholars refer to these resources and materials (cf., Lee, 2004; Lee, 2008; Perry & Sanderson, 1998), it is crucial to establish definitions that are used consistently throughout this dissertation. Therefore, in this section the terms “artifact,” “deliverable,” “product,” and “tool” are defined as they are used in this dissertation. Once defined, these terms are then applied to a discussion of the production and utility of artifacts as part of collaborative work in general, and as part of students' collaborative project work processes in particular.

First, a note on the word "object." Some scholars use the word "object" as a synonym for "artifact." For example, in their article on intermediary objects, Boujut and Blanco (2003) use the word "objects" in an inherently synonymous way with the word "artifacts" (p. 211). Although they situate artifacts as a type of object, their other examples of objects all appear to be artifacts as well, indicating that it seems fair to modify the phrase "intermediary objects" to read as "intermediary artifacts." Therefore, to avoid confusion in this dissertation the word "object" is not used as a synonym for "artifact."

Defining artifacts. The concept of the artifact has been situated at the heart of activity theory with regard to understanding how people "control their own behavior" (Engeström, 1999, p. 29). Artifacts are germane to CSCW scholars who use them as a means of tracing and describing practices of collaborative work (Schmidt, 2011, p. 23). Beyond its high-level conceptual importance, artifacts have also been described in various ways using a number of different classifications. For example, scholars have identified physical and social artifacts (Lee, 2004, p. 7), boundary negotiating artifacts that themselves comprise inclusion, self-explanation, compilation, structuring, and borrowed artifacts (Lee, 2004), shared artifacts (Lahti, Seitamaa-Hakkarainen, & Hakkarainen, 2004, p. 353), design and procedural artifacts (Perry & Sanderson, 1998, p. 275), and intermediary artifacts (Boujut & Blanco, 2003). These classification systems are not mutually exclusive, and some are subsumed under others (as with the high-level boundary negotiating artifact and its five constituent types).

In this dissertation, an artifact is defined as *anything created in support of collaborative project work, including a process or practice that is made tangible*. This definition is intentionally broad so that a typology of artifacts is possible. In the particular context of students' collaborative design work, however, some of these types of artifacts are more conceptually useful than others. Within the context of the present research project, the distinctions between physical and social artifacts, as well as design and procedural artifacts, are the more appropriate concepts to define and use.

The communication that occurs within students' collaborative team projects can be roughly separated into two types: content-related and process-related. Based on their study of student design teams in action, Stempfle and Badke-Schaub (2002) claim that only a third of all project-related communication deals primarily with processual topics and issues, while the remainder deals with content-related topics. The distinction between physical and social artifacts (Lee, 2004) eloquently captures how team members make their ideas about content and their need to coordinate their processes tangible for one another. These artifact types are analogous to the design and procedural artifacts that Perry and Sanderson (1998) suggest.

This dissertation uses the phrase "design artifact" rather than "physical artifact" to avoid confusion (because not all artifacts are materially tangible), and because this research project focuses on students' design projects. Additionally, the phrase "social artifact" is used in place of "procedural artifact" because the concept of the social artifact is less constrained and more descriptive of the variety of procedural, processual, and other forms of communication that occur among team members. Finally, intermediary artifacts (Boujut & Blanco, 2003) are said to mediate the behavior of the team members who work with them, enable collective transformation or translation of ideas from one state to another, and represent the design and process aspects of the collaborative project work as it progresses. However, given that design and social artifacts mediate team members' behavior in potentially different ways, it seems analytically useful to characterize artifacts into two types rather than one.

Design and social artifacts defined. Design artifacts are produced primarily to enable communication of ideas. Design artifacts can express the "mental models" (Kazmierczak, 2003, p. 51) that team members have and must somehow explain to others, or they can be the final deliverables that a team produces after months of hard work. These artifacts are the results of the knowledge work that designers conduct independently and collaboratively: They are the hundreds of drafts of an Adobe Illustrator drawing of an icon, as well as the hand-drawn sketches on a whiteboard around which team members discuss and argue over how to proceed with a specific concept.

Design projects result in massive quantities of design artifacts. All large-scale projects take time to complete, and during that time the team members must orient their collaborative project work around frequent discussions of tangible representations of ideas (Schön, 1983). The design process, in particular, requires working with a variety of representations, such as sketches, storyboards, physical prototypes, and so on (Lahti et al., 2004, p. 353). All of these representations are design artifacts, and they might be materially tangible or intangible depending on how they are created (e.g., a sketch on a piece of paper, a Microsoft PowerPoint presentation). Because of the need to share ideas, team members sometimes make their digitally-created design artifacts tangible, such as when the slides in a PowerPoint presentation are printed on paper (Geyer & Reiterer, 2010). However, not all design artifacts are made tangible or even available to everyone in the team: Individuals might iterate their design artifacts for quite some time before presenting a specific design artifact to others.

Social artifacts enable team members to understand and make visible their procedures for working with one another. Whereas design artifacts enable team members (and others) to see what and how they are thinking about specific ideas, social artifacts enable them to discuss the design process itself. As Perry and Sanderson (1998) put it, social artifacts "convey the anticipated design process and help to orient people to it" (p. 275). Social artifacts include project plans, lists of tasks that need to be completed, agreed-upon parameters for a given design task, or even text messages and emails among team members discussing when to meet next. Phrased in terms of project work, social artifacts describe how a given arc of work should proceed, whereas design artifacts represent the work that actors perform when completing the tasks that comprise an arc of work.

Defining deliverables and products. One of the primary reasons why university students create design and social artifacts is because they have to submit some of these artifacts for assessment. Students make available only a tiny number of the artifacts they create while taking a specific academic course. The vast majority of the artifacts they generate are not intended to be seen outside the friendly confines of their teams, or even by other members of the same team. Students select a few artifacts to represent their personal and team-wide output; they create and polish these particular artifacts with the need for assessment or critique in mind.

Two special types of artifacts bear distinguishing from all other artifacts. A **deliverable** is *a milestone in the design process that leads to further iteration of the design concept*. Deliverables are typically design artifacts (although they are also occasionally social artifacts) that students submit for formal assessment or informal peer critique so they can adjust their design process and practice based on the feedback they receive. Deliverables are made available *during* an arc of work rather than at the end of a project.

In the literature on design studies, a **product** is the result of the design process (Margolin, 2002). When a team works together to create something, that final “something” is the product of their effort. Products reflect their social construction (cf., Bucciarelli, 1994) and are *the outcome or result of a design process that are made available to a broader audience beyond the team*. When students collaborate on a design project, for example, they produce and submit for assessment a final product (e.g., a video prototype, a research paper). Products, then, are the design and social artifacts that result from a design process and that are intended as the final expression of that process. Products represent the *end* of the arc of work that led to their creation.

Deliverables and products are worth distinguishing from other types of artifacts because actors create or select these special types as representative of the progress made in an arc of work. It is fair to suggest that actors such as students imbue deliverables and products with their own agency because they are externalized interfaces to students’ ideas and collaborative practices that they choose to make available for formal assessment or informal critique. Actors intend for deliverables and products to speak for themselves, or stand alone as statements about their design concepts. All other design and social artifacts that students individually or collectively develop in the process of creating a product are not necessarily made available when that product is submitted for assessment. Instead, those other artifacts remain with the students or within the teams that created them and slip into obscurity, unless they are later included in portfolios or some other public or semi-public space.

Defining tools. Schmidt (2011) distinguishes between artifacts and tools (p. 239) and defines tools in a way that is complementary to the definition used in this dissertation (p. 74). A tool is *anything (analog or digital, materially tangible or intangible) that students bring to and use as part of their collaborative work*. Note that under this definition, a tool is something used locally during team project work. It is also noteworthy that, unlike their creation of artifacts, students do not "create" tools but instead bring extant tools to their collaborative projects. They use tools in order to create artifacts, or to gather information in the service of team discussion or artifact creation.

It is possible to classify tools into different types. For example, Oehlberg, Roschuni, and Agogino (2011) suggest categorizing tools used within collaborative design teams into four types: tangible tools, digital hardware, software, and Web services. Using this categorization, examples of tools that a design student would typically use include a sketchpad and pen, an Apple MacBook Pro laptop, a copy of the Adobe Illustrator software application or access to this application in the cloud, and Wikipedia. Given that the line between a "tangible" tool such as a ballpoint pen and a piece of digital hardware is blurring, a slightly different set of terminology is used here to categorize the types of tools that students use: analog and digital hardware, software, and Web services.

This terminology is useful in order to draw an unmistakable distinction between "analog" tools such as whiteboards, sticky notes, and paper and "digital" tools such as laptop and tablet computers, mobile phones, and DSLR cameras. This distinction is important because the students in this study often used words like "sketch" and "draw" in the context of sketch paper, whiteboards, laptops, software applications, Wacom tablets, and so on. Each instance of such words was coded appropriately given the broader context of the interview so that, during analysis, it was possible to know whether a student sketched on paper or with a computer mouse.

Defining the concept of the toolbelt. The categorization of tools proposed here can be integrated with the work of Sumner (1995) and her study of the different tools that design professionals use. Sumner uses the word “toolbelt” to describe the different software applications that a design professional uses as part of his or her design practice (p. 178). She differentiates the “high-tech” toolbelt of software applications from a more traditional designer’s toolbelt comprised of physical sketching tools (e.g., paper and pencil). Lee (2008) tacitly makes this point by including digital hardware such as computers, mobile phones, digital cameras, and portable music players as examples of tools within the toolbelts of modern designers (p. 1).

Furthermore, Sumner (1995) introduced the toolbelt concept as a model that describes how design professionals “create different design representations” (p. 179). However, the toolbelt concept is more usefully defined as *the aggregation of all the tools from which designers select preferred tools to perform task work within and across activities*. This definition limits the tools that are in designers’ toolbelts to those they know how to use in some capacity, and with which they feel comfortable enough to work while collaborating. In the context of this dissertation, the toolbelt concept offers a succinct metaphor that helps differentiate the tools that students already know how to use from the tools they learn during their collaborative project work. Only those tools that students learn and use regularly make it into their toolbelts.

Identifying the differences between artifacts and tools. The students in this study do not develop or create the tools they use, nor are they able to modify tools for all others who use them. Although students using Adobe Illustrator can alter the palettes they see on their computer screens, they cannot change the views that all other Illustrator users see when they use their copies of the same software. This distinction is important because, although local modifications are possible, students who work with tools do not change what it means for all other students to work with the same tools. In sum, students collaborating on a design project *use tools that exist outside of their collaborative project work to create artifacts that are unique to their collaboration*.

The definition of tools provided earlier represents them as malleable things, however. This nuance is intentional: Consider that Web sites such as Facebook and Pinterest are socially constructed and, as a result, are ever-changing. The question becomes whether the information presented on a Wikipedia page about fluid dynamics is a “tool” because students bring it to their collaborative project work, or an “artifact” because certain people can edit the content on that page of Wikipedia. The challenge is to rationalize students’ uses of information with this distinction between tool and artifact.

Tools are interfaces (Schmidt, 2011) to the artifacts that students produce, and artifacts are interfaces to students’ ideas. When students read Wikipedia entries on their laptop computers, the information they review and (hopefully) reference informs their thinking about how to use tools or how to create future artifacts. When team members create and use a Pinterest pinboard as part of their collaborative project work, Pinterest is the Web service tool and also the interface to the artifacts that the students create on their shared pinboard.

Different tools are designed to create different types of artifacts. For example, Microsoft Outlook was designed to facilitate the transmission of information from one to one, or one to many, or many to many. Outlook is a useful tool for one team member to send email to other team members telling them when to meet up and discuss their video prototype storyboard. In this case, the tool mediates the creation of what is most likely a social artifact (an email message). Authoring and sending the email is an example of articulation work, in that the team member who authors and sends the email is trying to ensure the local resources needed to do the specific action (storyboarding) will be in place. The decision to use email as the tool for these kinds of tasks is also an example of metawork because the team member who authors and sends the email believes that by using that specific tool, he or she will ensure the storyboarding process will function as smoothly as possible.

As a tool that mediates the creation of social artifacts, Outlook seems effective given that hundreds of millions of people use it for that purpose. Outlook was not designed as a tool for mediating the creation of design artifacts, and it seems challenging to appropriate this tool for that purpose. Adobe Illustrator is a clear example of a tool that mediates the creation of design artifacts, given its focus on presenting palettes of drawing and graphic design tools overlaid on a blank canvas.

Summary. The goal of clearly defining the terms “artifact,” “deliverable,” “product,” and “tool” is to clarify what these terms mean within this dissertation, as well as orient this research project around a standardized use of these terms. The definitions are summarized in the following list:

- **Artifact –** anything created in support of collaborative project work, including a process or practice that is made tangible
- **Deliverable –** a milestone in the design process that leads to further iteration of the design concept

- **Product –** the outcome or result of a design process that is made available to a broader audience beyond the team
- **Tool –** anything (analog or digital, materially tangible or intangible) that students bring to and use as part of their project work
- **Toolbelt –** the aggregation of all the tools from which designers select preferred tools to perform task work within and across activities

The next section of this literature review explains how other scholars fit these terms together into theoretical frameworks that describe collaborative project work practice.

Coordination Mechanisms, Ordering Systems, and Brackets

This section first discusses how the concepts of ordering systems and brackets meld the use of tools and artifacts with their guidelines for understanding how they should be used. This discussion continues with a design studies approach to understanding how tools and artifacts are used during the collaborative design process in general. The section concludes by describing how actor-network theory can be used to study the uses of tools and artifacts in the performance of metawork on collaborative team projects.

Schmidt and Simone first theorized the concept of the coordination mechanism in 1996. A coordination mechanism comprises a coordinative protocol and a coordinative artifact. The term “coordinative protocol” describes the rules of use of a coordinative artifact, while “coordinative artifact” describes “a stable data structure expressed in a standardized graphical format” (Schmidt, 2011, p. 16). Schmidt and Simone situated their terms in the context of computation rather than extending the coordination mechanism to apply to all types of coordinative work. This caveat explains why the definition of a coordinative artifact sounds so technical compared to the definition of an artifact provided in the previous section.

The coordination mechanism concept represents Schmidt and Simone's attempt to split the concept of the boundary object (Star & Griesemer, 1989) into two discrete elements, as well as integrate an understanding of how these mechanisms support the performance of articulation work. Initially, Schmidt and Simone (1996) regarded the coordinative protocol as something that was "imprinted" (p. 180) on its corresponding coordinative artifact. These "artifactually imprinted protocols" (p. 167) resemble maps of procedures or tasks that serve as a resource for what a part of a system should do (p. 169). However, coordination mechanisms can also serve as explicit scripts for system users' actions, as with checklists (p. 173). Finally, because articulation work is easily concealed in the flow of interpersonal communication and artifact use within organizations, Schmidt and Simone posit that coordination mechanisms make articulation work easier to identify and complete for the users of a system.

Schmidt and Wagner (2004) developed the idea of the ordering system as an evolution of the coordination mechanism. When Schmidt and Simone (1996) suggested the coordination mechanism concept, they saw the coordinative artifact and protocol as a relatively tight-knit unit, with one protocol per artifact and vice versa. Ultimately, Schmidt and Wagner (2004) recognized that coordinative protocols and artifacts cannot be bundled so concretely into these one-to-one relationships; instead, coordinative protocols and artifacts are interconnected with many other coordinative protocols and artifacts.

Researchers can observe these connections and describe them in the service of documenting specific examples of complex cooperative work. Extending the example drawn from the data set of Schmidt and Simone (1996), all of the bug report forms used within the organization they studied were stored in a set of binders, which themselves were coordination mechanisms (e.g., the three rings of the binder objectify part of the protocol for storing bug report forms over time). These binders were stored on bookshelves, which were also coordination mechanisms, and so on. Clearly, the potential interconnections among different coordinative protocols and artifacts are complex, subtle, and challenging to observe.

The ordering system concept is an attempt to make sense of this nuanced set of relationships among coordinative protocols and artifacts, again in the context of the performance of articulation work. Conceptually, ordering systems explain how people who are collaborating with one another create and organize “clusters” of coordinative protocols and artifacts (Schmidt, 2011, p. 23). As the prior example of the bug report indicates, there is a great deal of recursion at play: The bug report form sits in a binder, which sits on a shelf, which sits in an office, which sits in a building, and so on. The usefulness of ordering systems comes not from any ability to catalog these nested levels of recursion, but for the ability to identify (or at least clarify) the reasons why the actors align different coordinative protocols and artifacts in specific ways. Ordering systems offer one way to describe the “coordinative practices required in highly complex cooperative work settings” (p. 23).

Where Schmidt and Wagner (2004) replace the coordination mechanism concept with the ordering system, Gerson (2007) suggests the concept of the “bracket” as a synonym (and seemingly as a replacement) for the coordination mechanism. Brackets are similar to coordination mechanisms and ordering systems in that they connect as well as distinguish between two or more protocols and/or artifacts. In so doing, brackets situate those protocols and artifacts within a “larger system of dependencies” (p. 197). However, the bracket concept represents an evolution of the coordination mechanism and ordering system concepts because it accounts for multiple forms of rationalization.

Part of the purpose of a bracket is to ease the effort required of actors to rationalize the relationships inherent among activities by “removing them, homogenizing them, or refining and specializing them” (p. 198). Gerson refers to these forms of rationalization as segregating, standardizing, and coordinating, respectively. The actual process of rationalizing the relationships among activities is too complex for this brief literature review. However, the crucial point with regard to this research project is that the actors involved with a collaborative project use protocols and artifacts not just to coordinate their articulation work, but to simplify it, whether by standardizing, limiting, or eliminating previously required elements of articulation work.

The broader purpose of this extended discussion is to transition from what tools and artifacts **are** to a description of what students **do** with tools and artifacts in the context of their collaborative project work. This section concludes by positioning project-based learning as a lens through which students’ collaborative work with and around tools and artifacts can be fruitfully studied, followed by an overview of the specific aspects of actor-network theory that are germane to this research project.

Exploring Students’ Collaborative Project Work through Project-Based Learning

Project-based learning is a specific pedagogical approach to learning that reflects a shift from lecture-based, “just-in-case learning” to “just-in-time learning” that more closely mirrors how professional knowledge workers perform their jobs (Kirschner, 2001, p. 2). Writing in the context of project-based learning and design education, Waldron and Waldron (1996) put it most simply: “students learn design by doing it” (p. 301). Importantly, project-based learning is different from problem-based learning, which involves a much more structured learning experience and is not as commonly used for projects in design-focused courses and educational programs.

Project-based learning, hereafter referenced as PBL, is based on constructivist principles whereby students learn in a situated way. Situated learning involves solving real-world problems and developing knowledge through the process of working with others and through the practice of creating a finished product that solves a given problem. Rather than placing the instructor at the heart of the learning process, and from whom the “right” answers and all knowledge are expected to emanate, PBL focuses students’ attentions on working collaboratively with one another in pursuit of a defensible perspective on how to solve an ill-formed problem.

The learning that occurs as a result of PBL is achieved primarily through collaborative project work, and is regarded as a useful method for preparing students to become more effective professionals in the future due in part to its focus on getting students to externalize their thinking and reflect their processes through the artifacts they produce (cf., Biggs & Tang, 2007; Witney & Smallbone, 2011). The use of teamwork as an approach to pedagogy has a track record of comparative success when measured against the value of traditional lecture-based instruction (cf., Biggs & Tang, 2007; Witney & Smallbone, 2011). Additionally, teams that are designed to include members with heterogeneous backgrounds and skills may be more successful than teams that include members with relatively homogeneous skills sets. Davidson (2012) describes this phenomenon as “collaboration by difference,” and has written at length about its pedagogical virtues. As stated earlier, the concept of contested collaboration most effectively characterizes how students work together on their design projects, and is defined as two or more actors working together on the same project who are attempting to address the interpersonal differences and different work styles that make project work more challenging. Part of the value of PBL is the fact that student must address these differences in order to succeed as a team.

Successful implementation of PBL involves overcoming a number of challenges related primarily to assessment, task-based and role-based distribution of labor, and the simple fact that university students cannot always find mutually agreeable times to meet (Biggs & Tang, 2007). With regard to assessment, it is potentially difficult for instructors to assess team members' individual contributions to the products that the teams create. Biggs and Tang (2007) review a variety of possible ways to counterbalance the need to assign grades with the desired learning outcomes that a positive collaborative experience can provide. A combination of peer review and discussion with the instructor is regarded as perhaps the most effective way to assess students' individual performance within teams; however, as Biggs and Tang point out, it becomes an onerous task to quantify team members' value such that a grade can be assigned.

The distribution of labor is a significant issue whenever students collaborate. As stated earlier, each student brings his or her own toolbelt to tasks performed with other students. Because projects have deadlines and deliverables along the way, and because the courses that students take are also brief by nature, the students must strive to achieve their assessment goals as they attempt to learn new skills. The simplest way to complete project work is to align the resources with specific skills to those elements of the project that require those skills. Students are smart: Given the opportunity, they will often avoid distributing tasks equally in favor of simply getting their tasks done as efficiently as possible in as little time as possible (cf., Volet & Mansfield, 2006; Yacci & Rozanski, 2011). However, the goal of PBL is to engender learning among students, not to reinforce the particular skills that students already have. The challenge, then, is how to help students grow their toolbelts while also supporting their progress toward the grades they hope to receive.

Finally, a growing number of technologies are available that support remote and co-located collaboration, including freely available applications such as Skype (cf., Beldarrain, 2006). Many of these tools have become widely available only in the past several years, which means that older sources that discuss PBL were published prior to the availability of such tools that support telepresence as effectively (cf., Knoll, 1997). As a result, the earlier discussions of PBL are not grounded in the tools that are currently available to students. Additionally, newer sources often focus on the K-12 application of PBL (cf., Boss, 2011) rather than PBL at the university level.

Because of its strong focus on process and the generation of artifacts, PBL in practice helps students externalize their thinking and makes visible their decisions about how to use specific tools and create artifacts. The chance to study students' collaborative project work in the moment when critical decisions are made is an exciting research opportunity, especially compared to purely post-hoc assessments of student work or lab-based studies of collaboration. As Yacci and Rozanski (2011) point out, self-reported student data are useful but fieldwork that obtains experimental data is potentially more enlightening with regard to how students address these PBL-related issues in practice.

Actor-Network Theory Applied to Students' Collaborative Project Work

This final section of the literature review overviews the terminology and application of actor-network theory (ANT). ANT scholars and opponents have produced a wealth of commentary and debate about this theory and its merits and flaws. Bruno Latour is the de facto champion of ANT, and his texts on this theory are famously difficult to disambiguate.

However, ANT is usefully applied to the study of university students' uses of tools and artifacts in support of their collaborative project work because, as Latour (2005) points out, it is only through the performance of social actions that teams exist. Specifically, "groupings have constantly to be made, or remade, and during this creation or recreation the [actors] leave behind many traces that can be used as data by the informer" (p. 34). These traces form a fundamental part of the data set for this study, as will be described below.

Recall that the concept of an "actor" is defined as the human or non-human entity that performs actions on a project. This definition is implicitly based on the work of ANT scholars such as Latour (2005), who describes humans and non-humans alike as participants in the actions that comprise social life (p. 71-72). In the context of this study, then, tools and artifacts can be considered actors along with the students who use and create them.

It is no accident that Latour's 2005 book is called *Reassembling the Social*, as he wrote that book partly to clarify for the rest of the world how he thinks about ANT and how "the social" has been misrepresented by other scholars. Latour characterizes the social in many prosaic ways in this book; for example, he claims that "ANT is simply the social theory that has made the decision to follow the natives, no matter which metaphysical imbroglios they lead us into" (p. 62).

A clearer definition for ANT in general and the social in particular is that ANT is all about tracing associations (p. 5) that arise as actors collectively participating in different actions (p. 64-65). ANT researchers can provide only accounts of social activities and practices by studying the traces of actors' performative actions with one another and the associations that describe those performances. The remainder of this section explores some of the terms that ANT theorists use to characterize those actions and associations. Specifically, the notions of allies, inscriptions, and conscription devices are considered in detail as all of these terms can be brought to bear on the work that students perform while collaborating on design projects.

Allies and inscriptions. Latour (1987) describes the act of enlisting allies as a way to enlist support for a specific perspective, which is an elegant way to describe how one team member attempts to convince others that his or her perspective is correct. As Latour (1986) puts it, “the name of the game is to accumulate enough allies in one place to modify the belief and behavior of all the others” (p. 31). Returning to the definition of the social, whenever actors attempt to enlist or mobilize allies, they are performing a social action and the traces of that performance and the resulting associations can be studied.

Those traces are made visible through the process of inscription. For Latour, inscription is a transformative action that has the power to convert rats into paper (p. 3). For Callon (1986), inscription is a translative action that is comprised of the negotiation of actor’s identities, possibilities for interaction, and the boundaries within which those actors can interact (p. 203). Again, these prosaic descriptions of ANT terms require disambiguation.

Given that “all knowledge and knowledge claims are socially constructed” (Henderson, 1991, p. 451), it follows that inscriptions are the means through which this constructive process occurs. In the context of actors collaborating on design projects, the artifacts they create serve as their inscriptions as they attempt to socially construct knowledge and come to consensus about their design ideas.

In the specific context of collaborative engineering design projects (which is relevant to the present study), Henderson (1999) provides more detail about how artifacts serve as inscriptions.

> Engineering sketches and drawings are the building blocks of technological design and production. Moreover, because they are developed and used interactively, these visual representations act as the means for organizing the design to production process and serve as a social glue between individuals and between groups. The cascade of ideas on paper, layered and refined from initial tentative sketch to final product of accumulated knowledge, which Latour (1986) has designated a center of calculation, is necessarily also a center of power—the locus of control and negotiation. Looking at the everyday process of work and the visual practices of design with attention to sketches, drawings, and prototypes not only reveals a power struggle but also clarifies the interests and actions of the actors and the process of the final outcome (p. 133-4).

This lengthy quote is included here because it encapsulates how the design process is more than a series of tasks and activities that actors perform with one another. The inscriptions generated throughout a collaborative design project can be analyzed, and that analysis can characterize the qualities of the collaboration that occurred on that project.

Conscription devices. From an ANT perspective, inscriptions are artifacts that are also actors, and that can enlist allies or be enlisted by other actors (human and non-human alike). Henderson (1999) acknowledges these properties of artifacts by proposing the conscription device as a specific inscription type that actors use to enlist allies (p. 74). When people collaborate on a design project, they express their unique perspectives on how to develop their design concepts using artifacts. If they want to influence the ultimate product of that collaborative design effort, they go beyond enlisting specific artifacts as allies: They create visual representations of their design ideas and attempt to establish them as the focus for the team's overall design concept. They do so by using those representations as conscription devices to build consensus among the other people with whom they are collaborating.

Henderson (1999) explains that conscription devices are important because "to participate at all in the engineering design process, actors must engage one another through visual representations of the conscription device" (p. 53). However, the process of creating these visual representations is more complex than Henderson indicates because of the decisions that actors make regarding the tools they select when creating those artifacts. As the concept of the toolbelt indicates, actors know how to use, and prefer to use, different tools.

Therefore, when actors try to use a specific artifact as part of a conscription device, they must use one or more tools to work with that artifact. To borrow a phrase from Latour (1987), those tools are “black boxes” that are situated at the intersection of the social and the technological aspects of collaborative project work. For this reason, when only some of the actors on a team know how to use the tools that were selected to modify the team’s conscription devices, the other actors are not necessarily able to influence the outcome of the design process as they would like to do. Therefore, as with conscription devices, the tools themselves can become the “locus of control and negotiation” (Henderson, 1999, p. 134) when actors collaborate on design projects.

Summary. By considering tools and artifacts as actors enmeshed in worknets (Latour, 2005) with students who are taking an advanced interaction design course, it becomes possible to trace actors’ enlistment of other actors as allies (be they human or non-human). Additionally, it also becomes possible to describe actors’ processes for working with specific artifacts as conscription devices in their collaborative project work, as well as their decisions to use specific tools when working with those artifacts. These processes and decisions are the traces of the actors’ performative actions that this research project attempts to study.

However, studying actors and their associations is hazardous because of the temptation to bring in a number of external definitions and concepts to characterize the traces of the actions they perform. As Latour frames this concern, “it is crucial that enquirers do not in advance, and *in place* of the actors, define what sorts of building blocks the social world is made of” (p. 41, emphasis original). As an antidote to this potential problem of validity, Latour (2005) says the following in the context of explaining how scholars should write up accounts of their ANT-informed research:

> If I had to provide a checklist for what is a good ANT account—this will be an important indicator of quality—are the concepts of the actors allowed to be stronger than that of the analysts, or is it the analyst who is doing all the talking? (p. 30).

It is this quote that resonates through the analysis chapters of this dissertation, and that serves as the mantra for the research study that is described in this dissertation. The next chapter describes the research design in detail, a design that is reflective of Latour's exhortation to simply "describe the state of affairs at hand" (p. 144) when taking an ANT approach to a research project.

Chapter 3. Research Design

This chapter first restates the research questions, then outlines the research setting and course structure, provides an overview of the design process guidance that students received and the assignments and deliverables they were required to complete, and concludes with a description of the research rationale and methods used during the study.

The overarching research question for this study is as follows: **How do university students use different tools and artifacts for their collaborative design project work?** There are also three sub-questions:

- What is the constellation of tools and artifacts that university students use and create to support their collaborative work?
- How do they decide which tools to use to support their collaborative work?
- How does their performance of task work, articulation work, and metawork organize, facilitate, and constrain their collaborative project work?

Research Setting and Course Structure

The setting for this study was an advanced interaction design (IxD) course at a large university in the Pacific Northwest region of the United States. This university operates on a quarter system, meaning that all courses span 10 to 11 weeks for classroom-based sessions plus an additional week for final exams and presentations. This course took place during Winter Quarter 2012 and lasted from January 3 to March 8; final presentations occurred on March 13.

The course officially met twice a week for 170 minutes per session, for a total of about 63 hours of scheduled course time. The precise end time of each session was less important than a typical lecture-based course since students were free to conduct their collaborative work elsewhere if they desired. The course was convened 20 times rather than 21 times because inclement weather caused the cancellation of one course session (a snowstorm that shut down the university). That cancellation occurred near the middle of the quarter when students were already working in teams and did not necessarily need to meet with the instructor in the classroom.

Every session began with the students gathering together in a large classroom located in one corner of the second floor of the Art building. The instructor gave his only extended lecture with presentation notes on the first day of the course. The students spent the next three sessions individually presenting design concepts and discussing the concepts as a class. The remaining eight weeks of the quarter leading up to the final presentations followed a basic pattern: At around 2:30 PM, the instructor would make a few announcements and then the students would begin working collaboratively within their teams around large tables that could be moved to join together. There were five sessions during those eight weeks dedicated to student presentations of team project ideas, user experience walkthroughs, storyboard reviews prior to video recording, video prototype drafts, and final presentation walkthroughs.

Before the start of the quarter, I obtained human subjects approval to conduct the study, as well as the approval of the instructor. On the first day of the quarter I followed the approved protocol for the study and gave all 28 students the chance to exclude themselves from the study. All 28 students chose to participate in the study, and all students pictured in this dissertation provided explicit written consent to have their photos included. All student and team names provided in this dissertation are pseudonyms; team names were invented to protect the privacy of the students.

I attended all 20 course sessions as well as three informal team discussions conducted at times outside course hours, leading to a total of over 65 hours of field observation time. The informal team discussions were challenging to attend because the students frequently set up these meetings spontaneously, provided highly flexible start and end times, had spotty attendance, and conducted them at various locations around the university.

I recorded field notes on a laptop during every course session and during the informal team discussions I was able to attend. I took 511 digital photos, made 17 video recordings, and created 19 audio recordings during the quarter. One student team also provided me with six digital photos and one audio recording of an informal team meeting when I was unable to attend. Additionally, I had access to the Dropbox folder that the instructor established for the course, which students used for the first few assignments but which they later abandoned due to a lack of space and a breakdown in process.

There were 28 students enrolled in the course and they formed teams of four or five students within the first two weeks of the quarter as this was a project-based learning course. The academic background and standing of the students is summarized in the following list:

- 14 IxD senior undergraduate students
- 4 Human Centered Design & Engineering (HCDE) masters-level graduate students
- 4 Informatics senior undergraduate students
- 1 Industrial Design junior undergraduate student
- 1 Industrial Design senior undergraduate student
- 1 Industrial Design masters-level graduate student
- 1 Interaction Design masters-level graduate student
- 1 Visual Communication Design (VCD) senior undergraduate student
- 1 Electrical Engineering senior undergraduate student

The instructor asked that every team have a core of three IxD students supplemented by one or two additional students from other academic disciplines, although three teams only had two IxD students because there were too few IxD students to go around.

These students are of interest because they are neither novices nor experts at design, but are instead advanced knowledge acquirers who have not yet accumulated the knowledge about design that comes with years of professional practice (Spiro, Coulson, Feltovich, & Anderson, 2004, p. 640-1). They must still learn how to reason with information and understand how to apply the right knowledge to their design problems, as well as understand how to describe design problems such that they are solvable. The students must also learn how to critique their team members' ideas so as to facilitate the smooth function and ongoing processes of their project work.

The students formed six teams; the student and team names are provided in the table below and are further referenced using these names throughout this dissertation.

Table 1. List of student names, academic programs, and team memberships.

Team	*Student #1*	*Student #2*	*Student #3*	*Student #4*	*Student #5*
A	**Anne** IxD Senior	Bae Industrial Design Master	**Khloe** IxD Master	**Kylie** Informatics Senior	**Nancy** HCDE Master
B	**Fiona** Industrial Design Junior	**Logan** HCDE Master	**Molly** HCDE Master	Nathaniel IxD Senior	**Peter** IxD Senior
C	**Abraham** HCDE Master	**Holly** Industrial Design Senior	**Kimberly** IxD Senior	Norbert IxD Senior	Ziggy Electrical Engineering Senior
D	**Baron** Informatics Senior	**Delilah** IxD Senior	**Isole** IxD Senior	Karla IxD Senior	N/A
E	Arlene IxD senior	Carl IxD Senior	Clarissa VCD Senior	**Erica** IxD Senior	Timothy Informatics Senior
F	Adele IxD Senior	Astrid IxD Senior	**Kristal** Informatics Senior	Missy IxD Senior	N/A

The bold names in the table above indicate the students I was able to interview; all interviews took place between April 9 and 25, or four to six weeks after the final student presentations on March 13. This gap in time reflects the break between Winter and Spring Quarters, and also gave the students time to reflect thoughtfully on their experiences without letting too much time pass after the end of the course.

Design Process Guidance and Course Deliverables

The course was organized around a central theme: developing design concepts for the Microsoft Design Expo 2012, which is an annual competition among a select group of student teams and which occurs during the annual Microsoft Research Faculty Summit. The goal of the Design Expo is to serve as "a forum where student teams from top design institutions showcase their prototype interaction-design ideas" (Design Expo 2012, 2012). The theme for Design Expo 2012 was “information in my world.” According to the course syllabus, the students’ challenge was threefold (reprinted verbatim from the syllabus):

- Design for a user team different from them, but one they have access to
- Develop conversations with prospective users – eliciting their perspectives
- Create an open design process – design is a conversation, and good designers involve the people they are designing for

The final assignment was to generate a video prototype, presentation, and process book that detailed each team’s design solution and that showed specific artifacts documenting the design process.

On the first day of the course, the instructor provided all of the students with printed copies of the syllabus. This printed syllabus provided the vast majority of the formal guidance that students received for this course. The instructor drew much of the syllabus content from the Microsoft Design Expo 2012 project brief (Microsoft Design Expo Project Brief, 2012), a document that described at a high level how the design process should work. That brief described a set of recommended project stages, which were not reflective of the design process that the students should follow but were instead descriptive of the Design Expo process itself (p. 3-4):

- Team work
- Investigation & Conceptualization
- Prototypes
- Project Selection
- Presentation & Demo

Within the “Prototypes” section of the brief (and reprinted in the course syllabus), there was a list of design process suggestions that were meant to help guide students’ work practices (p. 4). I have added the summary words in bold to the list below, while the rest (including original punctuation) is reprinted verbatim from the brief:

- **Schedule –** Establish a design process with a schedule and use it to help meet your project goals and to mediate your design decisions. Often too much time is spent reaching consensus and brainstorming up front, then too little is left to be spent on the final design aspects of the final project.
- **Maintain Documentation –** Decide up front who and what will be documented throughout—do not document after the prototype is ‘finished’. This work in progress should be posted often to the Web site for your team’s project.
- **Understand Users –** Describe and meet your “ultimate” real users. Then interview these users to find out their problems, needs and desires.
- **Explore Design Space –** Study existing products, markets and research findings, so you do not re-invent some existing work.
- **Create Prototypes to Test with Users –** Prototype your ideas often and in rough ways and forms. Use these to gain feedback from your users, before you start building or designing anything more complete. Do not forget to keep a log of your prototype for later inclusion in your design story.
- **Establish Flexible Design Solutions –** Consider how your design concepts relate to other situations. We think it is useful to design prototype concepts that can be adapted to suit other people for different purposes and with different life styles. This can help to

lengthen the product cycle and allow users to customize and personalize their own devices.

- **Build User Interface Simulations –** Simulate the look and feel of the user's tasks or sequences of operations with any available prototyping tools such as Flash, Silverlight, etc. Please try to make sure you can show your work/presentations on Windows and/or Internet Explorer. This will make remote feedback and presentation setup much easier. If you need additional Microsoft Software (Visual Studio, C#, SQL, etc.) to build your prototypes please let your liaison know and we will try to get you this software.
- **Iterate –** Repeat your cycle of design with users several times and show how you changed your product and interaction design directions.
- **Create Physical Prototypes –** Make physical mock-ups of the devices, wherever appropriate.
- **Create Documentation –** Document any design evolution stages to include later in your presentations.

Additional guidance from the instructor. The two lists of design process bullet points from the Design Expo project brief do not describe the design "process," but are tips for students to consider while doing design work. For this reason, these lists are not helpful points of reference when trying to determine how students were told to approach their design projects from a processual perspective. However, on the first day of the course the instructor gave a presentation that included slides with more details about how students should approach the design project. This presentation was intended to supplement the printed syllabus, was only given once, and did not necessarily answer all of the students' questions about how each assignment would work in practice. The details of the presentation are provided below and are taken verbatim from the instructor's slides, at which I was present:

- Identify an interesting idea: Research market and tech trends
- Define [design] need through contextual inquiry, identify user group
- Model design space, product and system—and how they are related
- Verify model with users
- Identify design seeds (find the leverage points, or pieces and parts of a product where you can have huge impact and that yield most positive change possible with least amount of effort)
- Build rough prototypes, gather feedback from prospective users
- Refine design, check with users
- Final prototype and presentation production: Showtime! (show design as if it's reality)

These design process bullet points are reflective of a typical design process, in that they are properly sequenced and lead students through the typical stages of a design project. The bullets can be adjusted as follows, with corresponding course deliverables included in parentheses and additional process stages included in italics (all content presented verbatim from syllabus and instructor presentation materials with only minor grammatical adjustments):

- Research and identify promising design ideas (outline up to 5 examples of products/services/systems and present each for 30 seconds at an idea fair)
- *Identify design seeds – part of design process that was seemingly listed out of order*
- *Form teams*

- *Ideation* – Formulate project direction by defining design needs for selected idea and identify user group (create a project brief as a single-slide presentation, describe team design directions, project scope, and design seeds)
- Model design space, product, and system – and how they are related (create conceptual model of the selected design concept, which will be designed and prototyped in detail; show relevant workflows and information requirements developed as insights from initial contextual research)
- Verify model with users (present user experience walkthroughs of design concepts, which were also used to elicit feedback from potential users of the finished product)
- Build rough prototypes, gather feedback from prospective users (create and present digital wireframes of the user experience; create sketched storyboards of video prototypes)
- Refine design, check with users (translate sketched storyboards into video prototype scripts; translate user interface design and visual narratives into design presentation, storyline, and timing; create drafts of video prototype)
- Final prototype and presentation production: Showtime! (show design as if it's reality)

Finally, the instructor provided an even simpler refinement of the design process near the end of the syllabus (reprinted verbatim from syllabus):

- Research
- Ideation
- Prototyping
- Presentation/Assessment

This simplified description of the design process best reflects how all of the student teams were recommended to collaborate throughout the academic quarter, as well as how students worked to produce each individual deliverable. These four stages in the design process do not explicitly mention iteration, which is instead baked into all four stages and is integral to each stage but in different ways depending on the tasks being performed.

Course deliverables. As the quarter progressed, students were asked to complete a number of assignments that reflected their progress on their projects. There was only one deliverable that the students each created independently: They each had to find and present five examples of existing products, services, and systems that interested them. The students were asked to make decisions about who they wanted to form teams with after viewing their peers' presentation. The remaining 10 deliverables for the course were all completed as team assignments, and were described in the syllabus as follows:

1. Design project description (1 presentation slide) – due January 17
2. Conceptual model presentation (2-3 presentation slides) – due January 31
3. Interaction sketches and user experience scenario walkthroughs (several slides) – due February 7
4. Digital wireframes of user experience walkthroughs (source files, several slides) – due February 14
5. Video prototype visual narrative (source files) – due February 21
6. Video prototype demonstrations (edited video recordings about 3-6 minutes long) – due February 28
7. Multimedia presentation of the envisioned design (several slides) – due March 8

8. Final video prototype (edited video recordings about 2-3 minutes long) – due March 13
9. Final multimedia presentation of the design (several slides) – due March 13
10. Comprehensive design documentation (bound, hardcopy book; CD or DVD with all documentation provided as PDFs, video files, Flash wireframes, digital photos and videos taken of the process of working collaboratively) – due March 13

All students and teams submitted materials for all of these required deliverables. I obtained digital copies from each team of deliverables #1 and #2 (the design project description and conceptual model presentation), as well as copies from five teams of deliverable #9 (the final video prototype) and copies from four teams of deliverable #3 (the design scenario presentation). I was able to obtain digital copies of some but not all of the other deliverables based on which files were published to Dropbox folders and other course-specific and intra-team resources. For this reason, I focused my interview questions on the conceptual model presentations and the video prototypes because I had copies of every conceptual model and the students themselves provided copies of the video prototypes during interviews when needed.

Summary. As a course requirement, students formed their teams around the IxD students, all of whom had taken the junior-level version of the same course during the prior academic year. The design brief, the syllabus, and the instructor's presentation provided all of the formal design process guidance to the students who took this course. These students had varying levels of experience and were either upper-class undergraduate students or early-career, masters-level graduate students.

Research Rationale

University students were selected for several reasons. First, the particular students under study worked together in teams of four or five on quarter-long design projects; throughout the quarter, each team was required to produce certain deliverables for assessment. Additionally, their work occurred in a setting that is not yet "real" in the same sense as the work of professional designers, but that did have real visibility within the local, professional community of interaction designers and user experience designers.

Second, the students were aware that one "winning" project would be selected for inclusion at the 2012 Microsoft Design Expo. The motivation to win the design challenge and present at the Design Expo was timely because 21 of the 28 students in this study were senior undergraduates and were close to making the transition from student to employee. For most of these students this course was their last before graduation.

Given their proximity to graduation, these students' work processes and decisions should have been richer and more differentiated (to recast a phrase from Stevens, 1999, p. 225) compared to K-12 students, for example, or even compared to first- and second-year undergraduate students. Because the students in this study were from seven different academic programs, they brought powerfully heterogeneous knowledge bases (Stevens, 1999) to their team projects, lending diversity to their project work practices and feelings about how best to work with other team members. Therefore, it was quite useful to observe and interview these students as they went through the tasks and activities associated with their project work.

Third, the students were treated as professional designers in that they were required to structure and resolve a design problem that would provide a significant challenge to a team of professionals. They also had to contend with complex concepts without necessarily having well-established contexts within which those concepts could be understood. To address these problems, the students used a variety of tools in support of their collaborative project work, tools that not all university students were familiar with or were even expected to use. For example, the students in this study produced video storyboards, interface schematics, high-fidelity mockups and presentations, user experience walkthroughs, and video prototypes of their design projects. These students were, therefore, required to use certain tools that students in other departments might never use for their projects, but that professional designers rely on when they tackle similarly challenging design problems.

Fourth, as the previous paragraph implies, the students in this study produced a great number of artifacts as they created their final designs. As stated earlier, they also produced deliverables that were critiqued along the way by multiple audiences: expert professionals, instructors who also worked as professional designers, and fellow students. These artifacts were externalizations of the students' thoughts about how to solve their design problems, which made it easier to examine how they explicitly facilitated and performed their collaborative project work.

Finally, the students were required to complete their design projects in teams of four or five partly because the course instructor's own pedagogical goals were aligned with the perceived value of project-based learning (PBL). PBL is a useful lens for discussing the performance of metawork in an educational setting. Recall that metawork is defined as *the negotiative effort that occurs on collaborative projects when actors discuss how project resources should be aligned, as well as why those particular resources are appropriately aligned in that way*. In the context of university students working on collaborative projects, metawork is reflected in these students' negotiative efforts when they discuss how to best align their limited resources and specific skills in order to create the required artifacts and products. By framing these efforts using the language of PBL, this dissertation aims to connect the research site (university students in a design class) with the theoretical and practical contributions of this project.

Prior research conducted into how university students integrate e-readers into their academic reading practice (Thayer et al., 2011) suggests that reading for academic purposes is but one among many academic activities and practices. For students, reading is a means to an end. Furthermore, when students work on a project together, they often read in a collaborative way, which means they tend to shift focus between the tools in use and on the content they are reading (cf., Marshall, 2009; Twidale, 2000; Twidale, 2005). They also produce a significant quantity of artifacts as they read, such as annotations, drawings, and notes (cf., Brush, 2002).

These artifacts, as well as the tools that students use to create them, are also means to an end: They assist students as they meet their educational goals. Therefore, the main way in which PBL serves as a lens for describing the articulation work and metawork that students perform is by understanding that they use tools and create artifacts for reasons related to their broader academic goals. In order to understand these goals in more detail, researchers should study which tools students are using, what artifacts they are producing, and why they are going about their work in these ways. PBL affords one perspective on how and why these processes of tool use and artifact creation play out as they do (cf., Waldron & Waldron, 1996).

Research Methods

Sonnenwald (1996) outlines three different types of empirical studies that can be undertaken to study the ways in which team members communicate while collaborating on design-related projects. The following list paraphrases the three types (p. 282-3):

- **Retrospective research –** examines historical accounts of a design process as provided in design participants' retrospective descriptions of communication activities and histories of the process; these studies analyze communication using participants' reconstruction of their realities
- **Component research –** focuses on components, or phases, of the design process, and thus [presents] a 'slice' of communication behavior during the design process
- **Progressive research –** investigates the design process as it unfolds, or evolves, over time

Sonnenwald concludes that the best study design incorporates elements of all three study types.

Although this research project takes a mixed-methods approach, the methods used in this study are primarily qualitative and ethnographic in nature. Qualitative, ethnographic research methods enable the construction of "large conclusions from small, but very densely textured facts…to support broad assertions about the role of culture in the construction of collective life by engaging them exactly with complex specifics" (Geertz, 1973, p. 28). The idea is to explore the culture of university students' collaborative project work such that the researcher can understand that culture well enough to describe it to other interested parties (cf., Geertz, 1973; Emerson, Fretz, & Shaw, 1995).

Furthermore, Ackerman (2000) characterizes the "the divide between what we know we must support socially and what we can support technically" (p. 179) as the "social-technical gap." According to Ackerman, this gap is "fundamental" (p. 187) to the CSCW research community:

> CSCW is at once an engineering discipline attempting to construct suitable systems for groups, organizations, and other collectivities, and at the same time, CSCW is a social science attempting to understand the basis for that construction in the social world (or everyday experience) (p. 194).

The social and the technical are not meant to be separated; rather, as Dourish (2006) says in the context of the social-technical gap, “the domain of technology and the domain of everyday experience cannot be separated from each other; they are mutually constitutive” (p. 546).

Ackerman conceptualized the social-technical gap not just to situate it as core to CSCW research activity, but also because “the challenge of the social–technical gap creates an opportunity to refocus CSCW as a Simonian science of the artificial” (p. 181). In this context, the word “artificial” is a reference to organized social activity (e.g., the construction of a building) as distinct from naturally-occurring phenomena (e.g., the lifecycle of a frog). Given that “CSCW software researchers and designers are indeed aware of the need for nuance, flexibility, and contextualization” (p. 189), researchers should consider social action not as empirically measurable but as a contextual, continuously constructed phenomenon. In order to identify and enumerate the ways in which people exhibit nuanced, flexible, and contextual social behavior, research methods must be used that are sensitive to such behaviors. Qualitative research methods (e.g., semi-structured interviews and diary studies) offer the best chance to develop that understanding because these methods require observing participants’ routine work practices and eliciting their thoughts about their tasks and activities.

Therefore, this research project is designed to probe the social-technical gap that exists when students use tools to create artifacts, and to be complementary to the ideas of Sonnenwald and others who have studied the design process in action. The following list situates the methods employed in the present study within the empirical research framework that Sonnenwald describes.

- **Retrospective –** *semi-structured interviews* were conducted with study participants who reflected on their personal goals for their collaborative project, how their team tracked their design goals and progress toward completion of the project, which tools the team members used to create specific artifacts, and which artifacts the team members created in the process of developing their deliverables and final product
- **Component –** *artifact analysis* was conducted of specific artifacts that study participants created while working on their collaborative project together and individually; additionally, a *survey* was conducted of the tools that participants used in an academic setting and their decisions regarding how to select a team to work with (those data are not reported here, but were instead used to provide baseline knowledge for the development of other study instruments)
- **Progressive –** *participant observation resulting in field notes* were recorded that described first-hand the collaborative project work that occurred during the academic quarter

Ethnographic research literature distinguishes between researchers and members, where the researchers are studying members of an often unfamiliar community or cultural team. As Emerson et al. (1995) point out, it is important for all researchers to understand their own points of view, blind spots, and biases when studying members' lives. Emerson et al. describe the need for reflexivity, which "is central both to how we understand the worlds of others as well as to how we understand the research enterprise" (p. 216). When studying students working together in collaborative teams, it is crucial to have a reflexive attitude that regards the students' tasks, activities, and behaviors not as “variables or structures that stand above or apart from people but rather as meaning systems negotiated and constructed in and through relationships” (p. 216).

As the sole researcher working on this project, I chose to immerse myself as thoroughly as possible in the worlds of the students who I was studying. In the process of conducting my participant observations and recording field notes, I engaged with the same lectures and the same materials as the students themselves. Although I experienced the same pedagogical environment as the students, I brought my own personal experiences and depth of professional knowledge to the topics they studied. It was this unique background that set me apart from the students, but it is also what enabled me to develop my interview protocols and survey questions with an attentive eye toward how the students negotiated and performed their collaborative project work. In the next section I provide more details about each of the research methods I employed during this study, as well as the order in which I used them.

Survey with closed- and open-ended questions. At the beginning of the 2012 Winter Quarter, I conducted a survey to collect students’ demographic information, their uses of software and hardware in the context of their academic work, and their thoughts on how they selected the teams in which they would work throughout the academic quarter. The goal of this survey was to provide baseline knowledge about the tools that students consider most critical to their academic work, and to produce a snapshot of their feelings about their teams at the start of the quarter. This snapshot of a specific element of the design process provided an early glimpse at how the students thought their collaborative project work would go (Sonnenwald, 1996). The survey is included in Appendix A.

Participant observation resulting in field notes. I conducted participant observations in order to develop a clear picture of students' facilitation of their collaborative project work. Specifically, I directly observed and recorded field notes about students' in-class collaborative work and, as much as possible, their participation in team meetings away from class. I also took photos of the different tools and artifacts that students used as they worked together in teams, and recorded audio and video clips whenever possible.

I relied on participant observation as opposed to diary studies and other qualitative methods because I wanted to see the routine discussions that students had with one another. In the process of observing those discussions, I hoped to understand the decisions that resulted and the details about those collaborative work situations that students might not self-report. Such seemingly mundane details illuminate how the work itself gets done (Geertz, 1973).

Additionally, Emerson et al. (1995) advocate for field research in general and the creation of field notes in particular as a way to describe the *processes* of social life, as opposed to the *products* that appear at the end of the process (p. 14). The results of my observations of collaborative project work in progress helped me interpret students' decisions about how to facilitate their collaborative efforts, as well as understand the processes that the students followed as they went about their collaborative project work. This information allowed me to design the final study instrument (described below).

Semi-structured interviews. The observational data and survey responses informed the design of my semi-structured interview protocol, which explored students' planning, analysis, and evaluative efforts related to their collaborative projects (please refer to Appendix B to review the final protocol). Within one month after the end of the quarter during which the observed class concluded, I contacted all of the students and asked to interview them about their recent collaborative project work experience. I interviewed 16 of the 28 students about how they planned, analyzed, and evaluated the tasks and activities they completed for their project. I defined the specific questions after collecting the rest of the project data and conducting a preliminary analysis of those data.

These interviews were qualitative by design because I needed to be able to ask relevant follow-up questions of the different participants when necessary. Qualitative interviews are useful for the richness of description they can provide, the potential to describe processes in great detail, and the chance to understand how study participants interpret specific events that occur (Weiss, 1995). Interviews are also one of the primary methods by which qualitative researchers develop their data sets (cf., Miles & Huberman, 1994).

Chapter 4. Describing Students' Tool Use and Artifact Creation

The goal of this chapter is to describe the constellation of tools and artifacts that university students use and create to support their collaborative work. This chapter first introduces a tripartite typology that categorizes the tools that the students used, as well as an expanded typology of the artifacts that the students created. Next, this chapter tells the story of how the students used tools as they worked with one another on their design projects. This narrative description of students' task work performed with and around tools is constructed based on relevant field observation notes, interview quotes, photos, and descriptive details gathered during the study. Finally, this chapter presents an overview of the deliverables that one team of students (Team A) developed for each of the 10 assignments that were required of each team. That overview also describes how the members of Team A used specific tools and artifacts as they created each deliverable.

Identifying a Typology of Tools

This dissertation defines a tool as *anything (analog or digital, materially tangible or intangible) that students use to create artifacts in support of their collaborative work*. Tools mediate the creation of artifacts by serving as the interface between students and the artifacts they generate. Students do not "create" tools as they create artifacts: They select existing tools to use for specific tasks and activities.

Other scholars have studied the tools that professional designers as well as student designers use for their collaborative work (cf., Oehlberg, Roschuni, & Agogino, 2011). For example, Oehlberg et al. recorded 53 different tools in use among the participants in their study, with some difference between professional designers and students. They suggest classifying those tools into four main categories (i.e., tangible tools, digital hardware, software, and Web services (p. 2-3), and 19 sub-categories based on “media” type and Internet connectivity.

The typology developed for this dissertation differs from that of Oehlberg et al. in that it combines software and Web services into “software and online tools.” Oehlberg et al. based their differentiation between software and online tools on the requirement of Internet connectivity for complete functionality of services, whereas software can be used offline (p. 4). However, these categories are combined here because the students in this study worked in environments with ubiquitous Internet access and data plans on their mobile devices. As a result, the boundaries between online and offline work became invisible.

Second, given the research questions for this study, the typology is not designed to precisely quantify the number of tools used (as with the typology of Oehlberg et al.), but to assist in the process of understanding why and how university students use tools and artifacts in the service of their collaborative project work. Therefore, this typology aggregates over 60 tools that students used into three general types.

- **Analog tools** include whiteboards and markers, paper of various shapes and sizes, drawing and writing implements such as pens and pencils, and sticky notes – *any physically tangible tool that enables continuous creation of information is an analog tool*.
- **Digital hardware tools** include computers in various form factors (e.g., laptop, tablet, desktop), DSLR cameras, smartphones, external hard drives and USB thumb drives, and scanners, as well as certain tools that support the use of digital hardware such as camera stabilizers and tripods – *any physically tangible tool that enables discrete creation of information, or that supports the use of such a tool, is a digital hardware tool*.

- **Software and online tools** include every software application or online service (including Websites used to share artifacts or communicate within and across teams) that students can only access using digital hardware – *any tool that is only accessible using a digital hardware tool is a software or online tool*.

These three types of tools can be meaningfully applied to the analysis and discussion of students' decisions to use specific tools in specific collaborative work contexts. The following list classifies the tools that students used in the context of the typology.

- Analog tools:
  - Chalkboards
  - Collective paper form factors: Easel pads, loose-leaf newsprint, sketch paper (various large-scale dimensions)
  - Individual paper form factors: Legal pads, loose-leaf 8.5"x11" paper, personal notebooks and sketchbooks
  - Sticky notes
  - Whiteboards
  - Writing implements (includes pencils, pens, whiteboard markers)
- Digital hardware tools:
  - Camera lenses, stabilizers, tripods, and other accessories for use only with cameras
  - Computers: Apple laptops and tablets, Dell desktops and laptops
  - Digital cameras (includes DSLR and point-and-shoot form factors)
  - External hard drives
  - Memory sticks

- Mobile phones, including different brands of smartphones: Apple iPhones, Google Android phones by various manufacturers, standard mobile phones without data plans
- Scanners
- Video cameras
- Wacom tablets (various form factors)

- Software and online tools:
    - Adobe Creative Suite, including Acrobat, After Effects, Flash, Illustrator, InDesign, Photoshop, Premiere Pro
    - Apple products, including Final Cut Pro, GarageBand, Keynote, Safari
    - Avid Pro Tools
    - Dropbox
    - Email clients: Google Mail, Microsoft Outlook, and a university-specific online tool
    - Facebook
    - Google products, including Chat, Chrome, Docs, Groups, and Plus
    - Microsoft products, including PowerPoint and Word
    - Pinterest
    - Skype
    - Vimeo
    - WordPress
    - YouTube

As this list makes clear, the students in this study used a wide variety of tools while working collaboratively on their team projects. The discussion and development of this new typology positions a later analysis of students' collaborative work practices and processes. The next section provides a typology of artifacts in order to frame the discussion around the types of tools and artifacts that students used and created as they collaborated on their design projects.

Revisiting the Typology of Artifacts

Artifacts are materialized reflections of conceptual thought (Cole, 1996) that are "integral to communication" (Lee, 2004, p. 28) when collaboration occurs among design team members. Students in this study created design and social artifacts so they could explore and communicate their design ideas with their teammates. However, given that the students used analog, digital hardware, and software and online tools to create their artifacts, an updated artifact typology is required.

Design artifacts externalize design ideas and enable the communication of those ideas within and beyond teams. Henderson (1991) describes the use of design artifacts such as drawings and sketches as the organizing frame for design collaborations. Indeed, the students in this study organized their collaborative effort around iteration of their design artifacts leading to their creation of final deliverables. However, based on the tool typology distinction between analog and digital tools described in the previous chapter, design artifacts can be either **analog design artifacts** (e.g., whiteboard sketches of UI elements, sticky notes with design ideas written on them) or **digital design artifacts** (e.g., Adobe Illustrator representations of interaction ideas, digital photos of paper sketches).

Whereas teammates shared their design ideas *through* the creative and iterative processes associated with design artifacts, they relied on social artifacts to communicate with one another *about* those processes. **Social artifacts** helped the members of design teams understand and make visible their processes and procedures for collaborating with one another. The students in this study created social artifacts when they discussed how to create and modify design artifacts, or when they planned and conducted their task work within and across activities. As with design artifacts, social artifacts can be either **analog social artifacts** (e.g., meeting notes written on paper, project plan details written on a chalkboard) or **digital social artifacts** (e.g., Facebook group pages with team members' comments about design ideas and upcoming meeting times, blog posts discussing design seeds and sources of inspiration).

The remainder of this chapter first discusses examples of how students used analog tools, digital hardware tools, and software and online tools during this study. Next, a detailed description of a specific team's deliverables is presented, along with visual examples of representative artifacts that the members of the team created collaboratively as they proceeded with their project. The chapter concludes with a brief discussion of the design competition that took place among the students' teams, including an overview of what happened when a winning team was selected for the Microsoft Design Expo.

Student Collaboration with Analog Tools

All six teams relied on the following analog tools during the academic quarter:

- **Collective paper form factors**, including easel pads, sketch paper, and loose-leaf newsprint paper
- **Individual paper form factors**, including legal pads, loose-leaf 8.5"x11", and paper notebooks
- **Sticky notes** (considered separately from paper because of how students used sticky notes differently from any other analog tool)
- **Whiteboards**

The teams primarily used these tools in support of their collaborative work during the research and ideation stages of the design process, as they oriented their task work around large pieces of paper, sticky notes, and whiteboards. Individual paper form factors are the exception, as students who carried personal notebooks and pads of paper used them throughout the academic quarter.

As a reminder, the following table lists the students' names, academic programs, and team memberships throughout the study; note that no students switched teams during the study.

Table 2. List of student names, academic programs, and team memberships

Team	***Student #1***	***Student #2***	***Student #3***	***Student #4***	***Student #5***
A	**Anne** IxD Senior	Bae Industrial Design Master	**Khloe** IxD Master	**Kylie** Informatics Senior	**Nancy** HCDE Master
B	**Fiona** Industrial Design Junior	**Logan** HCDE Master	**Molly** HCDE Master	Nathaniel IxD Senior	**Peter** IxD Senior
C	**Abraham** HCDE Master	**Holly** Industrial Design Senior	**Kimberly** IxD Senior	Norbert IxD Senior	Ziggy Electrical Engineering Senior
D	**Baron** Informatics Senior	**Delilah** IxD Senior	**Isole** IxD Senior	Karla IxD Senior	N/A
E	Arlene IxD senior	Carl IxD Senior	Clarissa VCD Senior	**Erica** IxD Senior	Timothy Informatics Senior
F	Adele IxD Senior	Astrid IxD Senior	**Kristal** Informatics Senior	Missy IxD Senior	N/A

The remainder of this section describes how the students in this study used analog tools in support of their collaborative project work.

Collective paper form factors. All six teams worked with collective paper form factors during the academic quarter, although not every team continued using paper throughout the quarter. The teams that could not get access to the few available whiteboards relied instead on large sheets of sketch paper, sheets taken from easel pads, or pieces of newsprint (thinner, off-white paper). As Nancy from Team A points out, these large pieces of paper were readily and freely available.

> *In the design classroom there were two or three whiteboards between a couple of classes, which is not really enough for everybody to use one, and then when we were just working casually on things or meeting outside of class we'd be meeting in rooms that didn't have whiteboards at all. But, there was always lots of [large] pieces of paper around. (Nancy 181)*

The following photo from a team meeting on February 3, 2012, reflects one of the ways in which members of Team A physically collaborated around large pieces of paper during a work session; in this photo, Anne (right) is seated at a desk and writing on a large piece of paper as Khloe (left) and Nancy (middle) look on.

Figure 1. Members of Team A collaborating around collective paper form factor.

In this photo, Anne is sketching out a storyline for a specific design idea related to their overall concept of making commuting easier. Notice that Anne is the only one writing on the paper, but all three students are in close proximity so they can see what she is doing as they talk to one another.

At the conclusion of their meeting on February 3, the members of Team A decided to hand off this piece of paper to Bae. He completed the storyline on his own using the progress that Anne had already made. Regardless of whether the students worked independently or together during a work session, it was typical during this study that one team member at a time performed the physical work of writing and sketching on paper. This work sometimes occurred while the team discussed their design ideas, while at other times a team member would expand upon those ideas independently and return to the team with progress to be discussed.

In either case, the papers on which teams wrote their design ideas served as points of reference during team meetings. For example, the following photo from February 16, 2012, shows Anne (left) and Nancy (right) reviewing one of the pieces of paper on which Team A had outlined an early version of a user experience walkthrough; in this photo, Anne holds the piece of paper around which she and Nancy are collaborating.

Figure 2. Members of Team A using collective paper form factor as a design tool. This photo is indicative of how Team A used large pieces of paper to facilitate their collaborative discussions. Note that the inscriptions on this piece of paper indicate a top-to-bottom, left-to-right reading order and appear to have been written by one team member.

These photos also demonstrate the portability and low-fidelity nature of collective paper form factors. However, although pieces of paper can be kept after collaborative work sessions have ended, saving large pieces of paper presented a unique set of problems for some of the teams. Kimberly from Team C liked to sketch, as did her teammate Holly, but they began having trouble keeping track of the numerous pieces of paper that resulted from their sketching and discussions.

> *Holly has a lot of desk space in her studio, so we were keeping a lot of our papers with her. But they got kind of scattered by the time we really needed them…. I think that I ended up keeping a lot of my papers, but then a lot of other people put theirs with Holly, which I should have done. But I kept wanting to refer back to mine because I was doing a lot of visual design. (Kimberly 149-151)*

Kimberly describes how all of her teammates sketched ideas on paper and then gave those sketches to Holly, who did not systematically track how she stored all of the paper sketches. Kimberly continues by describing how her team regarded one specific piece of paper as vital to their progress.

> *I had one 11" x 17" paper that was just full of crazy ideas for interfaces, and then we kept coming back to that, so I held onto that. And I think we really should have scanned all ideas into the computer so that we kept track of it. We tried to take pictures of them with Holly's iPhone, and then she was uploading them to Dropbox, but I think that we didn't take pictures of the ones we needed to, and then the other ones [we kept] only on paper. (Kimberly 153-155)*

As Kimberly describes the situation, she and her group sometimes relied on large pieces of paper to capture ideas about their design project. However, they struggled to retain and reference those ideas when they needed them simply because it became challenging to recall where they kept all the papers they needed, and which ones were even important.

Individual paper form factors. All students from all six teams used individual paper form factors at some point during the academic quarter, although not every student consistently used these tools or even carried individual paper form factors (e.g., personal notebooks, legal pads) with them. However, nearly all students used personal notebooks and legal pads during the first two weeks of the academic quarter. They relied on these tools during that time because they were forming teams, a process that required a great deal of discussion among students regarding their project interests and potential fitness within specific teams.

As these discussions occurred, students wrote down notes in their individual notebooks and legal pads. The following photo of Team E (taken on January 12, 2012) reflects a typical example of what these discussions looked like in practice.

Figure 3. Example of Team E discussion conducted at beginning of quarter.

This photo illustrates how the students have their paper notebooks and legal pads open on the table around which they are all sitting. They are all poised to write things down, but they are listening to one of the students talk. Additionally, four of the five students have laptop computers sitting on the table, but only one laptop is open and ready to accept input; none of the students are attempting to use the laptops. Instead, two of the laptops are actually serving as surfaces on top of which students have placed their paper so they can write down ideas as the discussion occurs.

After they formed their teams, the students collaborated almost exclusively around laptops, collective paper form factors, and whiteboards for the rest of the quarter. During those several remaining weeks, the students relied on their notebooks and legal pads primarily as personal note-taking tools and occasionally as points of reference to clarify ideas or decisions made during prior team discussions. Returning to the photo of Anne and Nancy from the previous section, note how Nancy is holding her personal notebook as they discuss a draft of their user experience walkthrough deliverable.

Figure 4. Nancy's (Team A) use of her personal notebook during design task.

Students from other teams also reported using individual paper form factors in this way; Abraham from Team C described how his teammates relied on their notebooks and legal pads during the academic quarter.

> *Most of us carried some kind of notebook or journal throughout the [design] process, so almost everybody at a meeting would open up their book and [say], 'Oh, here's my notes on things.' (Abraham 247)*

Erica from Team E also described how her team oriented their task work around the notes she had personally taken, and which she brought with her to team meetings.

> *I know that I personally had a lot of notes in my notebook and we would refer to my notebook a lot of times for things that we had decided during meetings or directions that we were going to take, and I would write a lot of those notes [for the team]. (Erica 180)*

The contents of students' personal notebooks and other individual paper form factors reflect their use of those tools for taking notes and drawing sketches of design ideas. As Khloe explained during her interview, the specific contents of her notebook are useful only to her.

> *When you look at different people's notebooks, everybody's notes are completely different, so what I think is important somebody else might not necessarily see as being important. (Khloe 120)*

Khloe described herself as a "*pretty big sketchbook person*" (Khloe 120), a characterization that observations of Team A strongly support.

However, even for a student like Khloe who took a lot of notes in a personal notebook, the students in this study did not have their notebooks and legal pads out very often. While at least one student on every team used a personal notebook, all of the students used laptop computers and other digital hardware tools far more often for their note-taking tasks.

Sticky notes. Every team in this study used sticky notes at some point during the academic quarter. Specifically, 12 of the 16 students interviewed explicitly (but in an unprompted way) mentioned using sticky notes as part of their collaborative work practice. Sticky notes are discussed separately from other paper form factors because students used sticky notes to jot down very specific ideas or small amounts of text (25 words or less, usually only a few words) to describe a specific topic or idea. The following photo reflects how Team A worked with sticky notes as the team members were in the act of writing down ideas before they organized all of the sticky notes into a coherent overview of their design concept.

Figure 5. Example of Team A use of sticky notes.

The members of Team A found sticky notes useful because they enabled all of the team members to individually and rapidly write down thoughts and ideas during team meetings, discuss those ideas as a team, and then physically organize the sticky notes into categories. The small size of sticky notes necessarily limits the scope and detail of the ideas that can be written on them. Khloe from Team A described sticky notes as valuable for their highly modular and mobile nature compared to whiteboards and large pieces of paper.

> *For instance, when we were trying to find out 'what do people want out of travel?' everybody would grab post-its and write one thing per post-it. Then we would try to categorize what was written on the post-its based on trends that we were seeing. (Khloe 099)*

Finally, members of Team A described sticky notes as useful partly because they can be easily organized around central ideas, which can be written on differently-colored sticky notes or on the whiteboards or pieces of paper to which the sticky notes were usually adhered. The following photo that was taken by Delilah from Team D shows how they arranged their morass of sticky notes around central ideas or higher-level topics, which were usually written on a whiteboard or occasionally on a large piece of paper.

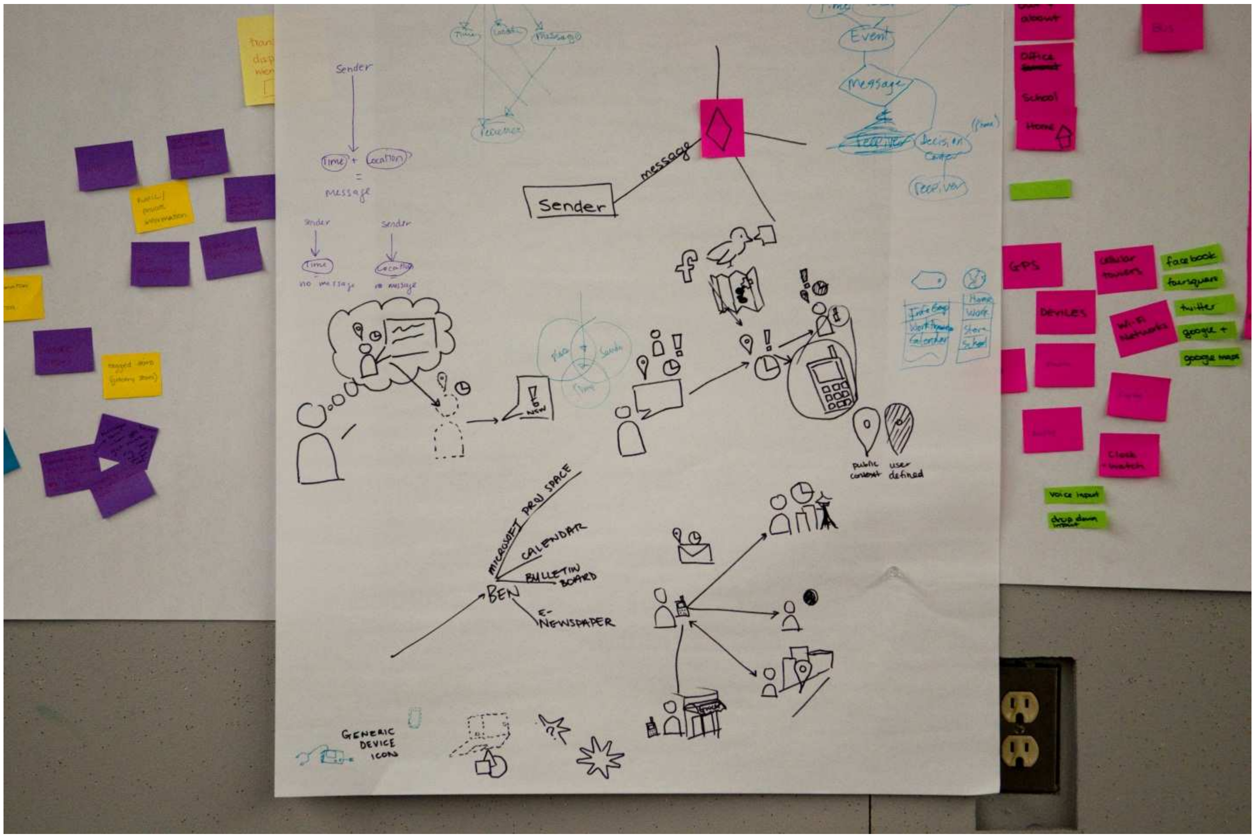

Figure 6. Example of Team D use of sticky notes.

As this image shows, the students in this team attached sticky notes to large form-factor paper or whiteboards and grouped the differently-colored notes based on their connections to the larger ideas being discussed. For example, the yellow sticky notes are higher-level categories of ideas related to their design concept, so those sticky notes have inscriptions such as "*public/private information*" or "*tagged items*." Each purple sticky note represents one thought or example related to the higher-level category, so the notes around "*public/private information*" say "*lab (security)*" or "*none between family members*."

Delilah described why her team used sticky notes as opposed to other tools for some of their task work.

> *We wrote [sticky] notes collectively, and then came back together the next day and reorganized them…we were able to bounce back and forth [design ideas] because that structure and all the key pieces were there [on the sticky notes]. As the person was actually putting the presentation together, they were making some critical decisions about reorganization, but we had established that all those points that were…on these post-it notes...were things that we thought were critical, so they should in some way make [it into the presentation]. (Delilah 115-117)*

In this quote Delilah is describing how her team used sticky notes as they worked on deliverables at various points during the quarter. Her teammate Baron described his thoughts on the value of sticky notes for collaboration.

> *It seems obvious to me why you would use sticky notes because you can organize your thoughts, reorganize your thoughts, and reorganize them again (Baron 133)*

As Baron points out, sticky notes are small and easy to organize and reorganize around higher-level ideas. As Figure 6 indicates, his team used sticky notes in exactly this way: shifting them around and adhering them to different parts of a piece of paper based on connections among ideas. The team members' use of different sticky note colors (as illustrated above) reflects how they wrote different categories of ideas on those different colored notes so they could track and categorize their ideas more efficiently.

Whiteboards. All six teams used whiteboards as much as possible, although the students were not always able to use whiteboards because the classroom had only three movable panels along one wall and two wall-mounted whiteboards behind the projection screen at the front of the room. All of these whiteboards were always in use. Additionally, the other spaces within which the students collaborated (e.g., another room in the same building as the classroom, coffee shops, students' apartments) typically did not have whiteboards.

Team B dominated the three large, free-standing whiteboard panels that were present in the classroom. Members of two other teams explained during interviews that they would have used those whiteboards if Team B had not staked them out throughout the quarter. For example, Holly claimed that Nathaniel from Team B "reserved" the whiteboard panels by writing "do not erase" on them at the end of each course session, as is shown in the following photo.

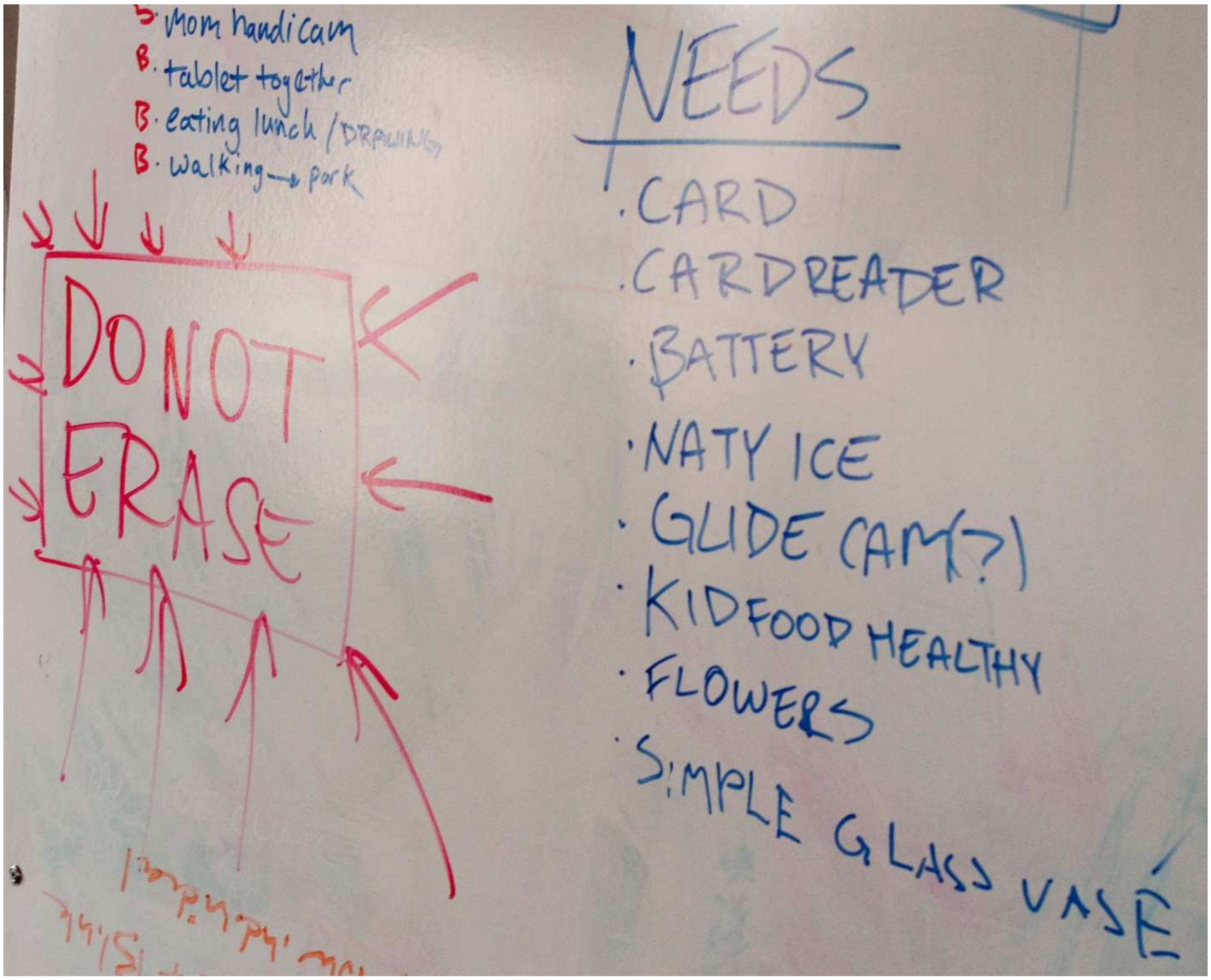

Figure 7. Example of "do not erase" text written on whiteboard by members of Team B.

Members of other teams described during interviews their feelings of resentment toward Team B for dominating the large whiteboard panels, which were often covered with "do not erase" messages written somewhere on them. Holly from Team C was particularly vocal during her interviews about why she thought Team B kept the notes and sketches from their task work visible for everyone else to see.

> *We would have used the whiteboard but we didn't want to deal with [Team B]. And they always said ‘do not erase.’ Always. It was, like, [their] whiteboard. But, that's the awesome part: They just left everything up there just to show everyone how much they did, literally. (Holly 247)*

As Holly indicates, she and the other students respected the “do not erase” messages and did not use the whiteboards whenever they saw that Team B appeared to be using them from one course session to the next.

Peter from Team B told me that he and his team liked using whiteboards partly for all the space they provided for sketching and writing notes.

> *We whiteboarded all the time. It was incredible. And, in fact, I think it’s ruined me forever. Because I can’t sketch or design anymore unless I’ve got a big space to write on. (Peter 103-105)*

The following photo (taken on March 1, 2012) typifies how Team B used the whiteboard panels in the classroom to track their video prototype tasks (Peter’s elbow is visible in the photo).

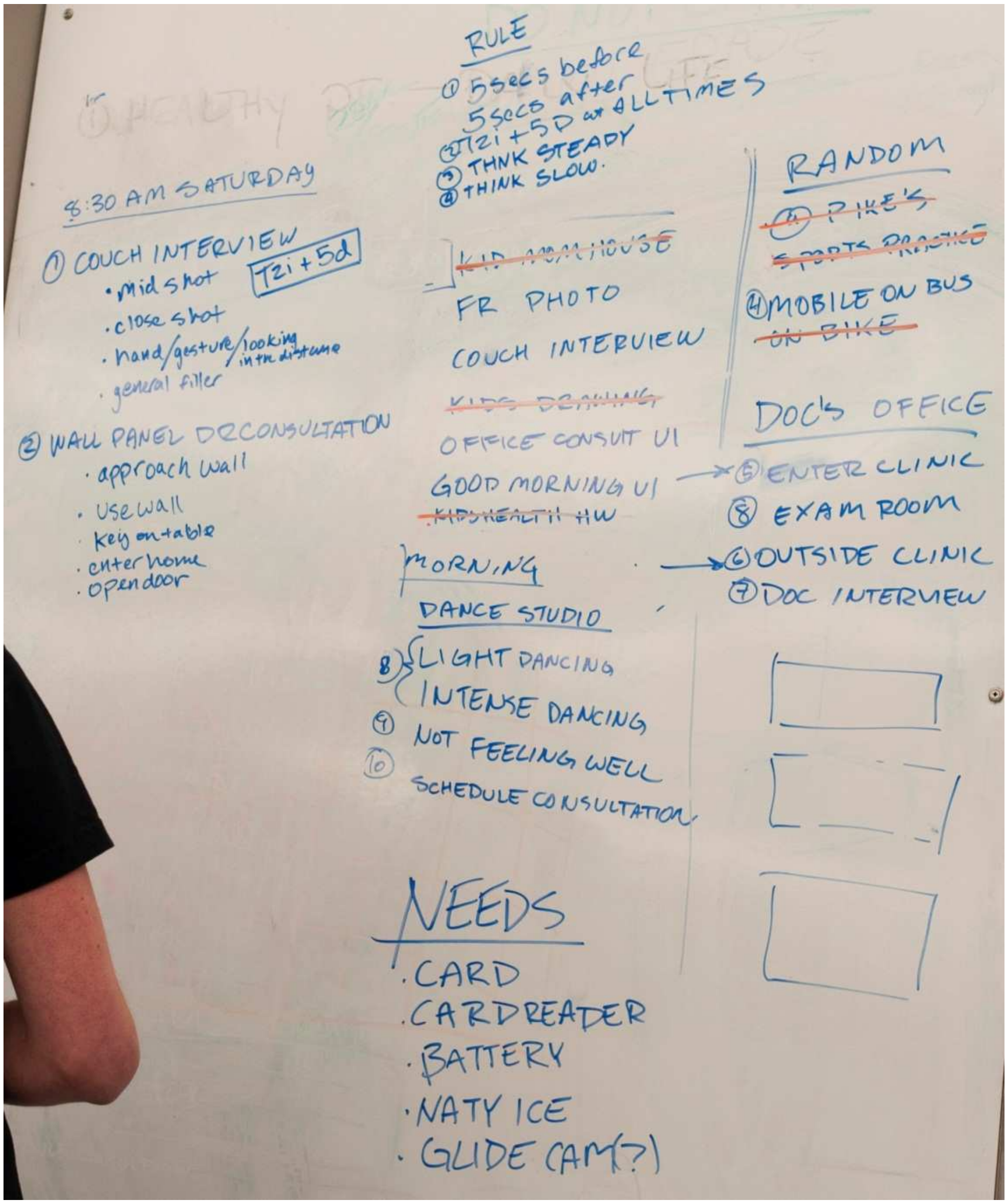

Figure 8. Example of Team B collaborative use of whiteboard panel.

This photo shows multiple contrasting details that are all related to the overall arc of work that Team B had defined, but that are not necessarily related to one another and are not reflective of the same level of information. The left-most list provides the scenes that the team needs to film next, in order of priority (this list would eventually have six scenes). The top-most list describes the four rules that the team needed to follow whenever they recorded video: capture video for at least five seconds before and after every scene, use two DSLR cameras to film every scene, keep yourself steady if you were holding a camera, and speak slowly (and clearly) if you were in a scene.

The lists located in the middle of the whiteboard, as well as along the right side, describe the different scenes that the team planned to include in the video, with numbers that indicate the order of the scenes in the final video. Finally, the bottom-most list describes the tools that the team needed to acquire before they could continue recording their video. That list includes a memory card and reader, a DSLR battery, a joke about the need for cheap beer (“*Naty Ice*”) while filming, and a camera stabilizer. The stabilizer has a question mark in parentheses because Peter, who wrote the list, was unsure whether they would need an additional stabilizer to augment the one that Nathaniel had built. Although the team used two DSLRs for every scene they recorded, they decided against using a second stabilizer and instead left the second DSLR on a tripod when recording scenes.

This photo is also helpful for showing how the members of Team B organized their thoughts in a slightly random way at first. Eventually, they overlaid the numbering scheme as a way to track the final order for all of the scenes in the final video. The red lines through the names of specific scenes indicate that those scenes had already been filmed.

Clearly, Team B liked to use whiteboards. Four out of five members of Team B collectively explained why they preferred to use whiteboards over other tools for their task work. The field notes from that conversation (conducted on February 16, 2012) are presented in the following list, which is reprinted verbatim from the notes taken as the students spoke:

- Whiteboards give **physicality** to ideas:
    - Gesturing is important while writing; gesturing while talking helps Peter come up with ideas more effectively
    - Physically moving around the space in front of the whiteboard while drawing on the board is also helpful for thinking
- Whiteboards lend a **temporary** nature to the ideas being explored:
    - Team members like erasing and editing parts of ideas or sketches based on different team members' feedback (drafting and being able to erase are important)
    - Content is easily modifiable so nobody gets too attached to any ideas
    - Logan noted that he was pulling notes from a notebook and adding them piece by piece onto the whiteboard for broader discussion and revision
    - The whiteboard is an "intermediate" thing, "not something to keep and get precious about" in Molly's words (a reference to temporary, draft nature of content)
- Whiteboards are a **highly visual, easily focused on, and immediately modifiable** tool:
    - Team B likes building things in front of each other's eyes, adding to it as they talk
    - They also like being able to show one piece at a time, having individual elements
- Whiteboards serve as an **orienting device** with regard to team collaboration:
    - Each thing they drew could serve as an "anchoring artifact" (Logan's words) so they could decide to agree on something specific related to their project work

Despite these clearly-elucidated benefits, whiteboards also have a number of flaws with respect to the ways in which task work is supported. One issue that arose during observation of the students' collaborative work is the question of who gets to hold the whiteboard pen. Nearly every time the students used whiteboards, only one student would write on a whiteboard while the other students would stand or sit nearby. Further, because only one person would be writing on the whiteboard at a time during team-wide discussions, that person acted as a filter for those ideas and the act of recording the conversation on the board quickly became a selective record of the discussion. The specific details of this phenomenon are explored in Chapter 6 in the context of the performance of metawork.

Summary of analog tool use. All six teams used collective paper form factors, sticky notes, and whiteboards at some point during the academic quarter. Each of these analog tools had benefits and drawbacks with regard to how students used the different tools.

Collective paper form factors were handy when students decided to engage in brainstorming tasks, as well as other kinds of tasks that required them to physically orient themselves around the tool they were using. They were able to write in a systematic way across the large expanse of the paper, which made it simple for each team member to see what his or her counterparts were doing at the same time. Unfortunately, as Kimberly from Team C pointed out, the large pieces of paper on which she and her teammates wrote their ideas were difficult to keep track of over time. Field notes reveal that members of Team A also misplaced important pieces of poster paper on a couple of occasions, which was due in part to the lack of a systematic way of archiving important analog design artifacts that resulted from their work sessions.

Individual paper form factors appeared to help students as they engaged in discussions with their teammates. They referred to their personal notes as they collaborated around research and ideation tasks as a way to remind themselves of prior discussions or ideas they wanted to bring up with everyone else. However, field notes indicate that students had their personal notebooks sitting out during work sessions, but students typically took notes on their laptop computers. None of the students used any digital pen technologies that automatically convert text written on paper into digital notes.

Students used sticky notes to help them focus their ideas, as the relatively small size of sticky notes meant that students typically wrote only a few words per note. Students also valued the modularity and flexibility of sticky notes: It was simple for each student within a team to grab a handful of sticky notes and begin writing on them. During their work sessions, students wrote design ideas or topics on sticky notes and then organized the resulting collections of notes into high-level categories. They also removed and re-adhered sticky notes at different locations within these categories as needed. This process helped the teams form “mind maps,” or coherent design ideas that they could then begin prototyping. One drawback to students’ use of sticky notes was the need to capture the results of their work sessions. Different teams found different solutions to this problem: Team A photographed their sticky notes at the end of their work sessions, which Team D retained a large piece of paper on which they had adhered all of their sticky notes so they could preserve the order of the notes for later reference.

Finally, whiteboards were the most popular of the analog tools. For this reason, whiteboards were also in demand more than any other analog tool. Students used whiteboards to extend their design thinking from research to ideation. They did so by verbalizing and sketching their design ideas so that all team members could discuss their collective progress, the potential of specific ideas, and their next steps as a team. If a whiteboard was available at the start of a work session, one team member would simply pick up a whiteboard pen and start writing and then the rest of the team would begin discussing ideas or progress on specific tasks. When no whiteboards were available, team members would use large pieces of paper instead.

The students in this study wanted to use whiteboards over comparable analog tools for several consistent reasons described during interviews and made visible during field observation sessions:

- **Simultaneous collaboration:** Multiple students can simultaneously write text or sketch images given that whiteboards are generally large enough to enable at least a few people to gather around them, write in different areas of the board, and read what is being written
- **Flexibility of inscription:** Any kind of language or symbol can be written on a whiteboard, unlike many digital tools that constrain input to specific languages or symbol systems
- **Large "real estate":** Whiteboards offer sizable blank canvases for writing and sketching
- **Ease of erasing and revising inscriptions:** Erasure is simple and usually effective, which makes students feel comfortable using whiteboards for collaborative ideation processes because the ideas are impermanent and easily modified or removed
- **Whiteboards as blank canvases:** Other tools (and projected images) can be overlaid on whiteboards
- **Whiteboards as organizing surfaces:** Students can organize sticky notes on whiteboards, draw connections among notes, or describe categories of information for clusters of notes

- **Differentiation among ideas and categories of ideas:** Students denote different categories of ideas or distinguish among idea spaces using different whiteboard marker colors
- **Support for specific ideation tasks, such as brainstorming:** Whiteboards support ideation and branching out from basic to complex concepts, but do not support nailing down specific topics or ideas as well as other tools (e.g., sticky notes)

Again, as with sticky notes the students had to record the results of their whiteboard use with digital hardware tools in order to save their artifacts for future reference. The next section describes in detail the different types of digital hardware tools that the students in this study used throughout the academic quarter.

Student Collaboration with Digital Hardware Tools

All six teams relied on a combination of the following digital hardware tools:

- Computers in various form factors, although laptops were by far the most commonly used computers (a few students also had tablet or desktop computers)
- DSLR cameras and camera accessories (owned or borrowed)
- External hard drives and USB thumb drives
- Mobile phones, including different brands of smartphones and “dumb” phones
- Scanners

The following sections describe how the students used computers and mobile phones in the service of their collaborative project work. These particular tools receive focus in this section because the DSLR cameras were only used to record video for the video prototype projects, or to take photos of students’ collaborative work in progress (which are discussed elsewhere in this dissertation). Similarly, the scanners were used to digitize copies of notes and sketches made with analog tools, and the external hard drives facilitated storage and transfer of large files (e.g., uncut video files) among team members. Finally, as a reminder the following table lists the students' names and team memberships.

Table 3. List of student names, academic programs, and team memberships.

Team	***Student #1***	***Student #2***	***Student #3***	***Student #4***	***Student #5***
A	**Anne** IxD Senior	Bae Industrial Design Master	**Khloe** IxD Master	**Kylie** Informatics Senior	**Nancy** HCDE Master
B	**Fiona** Industrial Design Junior	**Logan** HCDE Master	**Molly** HCDE Master	Nathaniel IxD Senior	**Peter** IxD Senior
C	**Abraham** HCDE Master	**Holly** Industrial Design Senior	**Kimberly** IxD Senior	Norbert IxD Senior	Ziggy Electrical Engineering Senior
D	**Baron** Informatics Senior	**Delilah** IxD Senior	**Isole** IxD Senior	Karla IxD Senior	N/A
E	Arlene IxD senior	Carl IxD Senior	Clarissa VCD Senior	**Erica** IxD Senior	Timothy Informatics Senior
F	Adele IxD Senior	Astrid IxD Senior	**Kristal** Informatics Senior	Missy IxD Senior	N/A

Desktop computers. Of the 28 students in this study, only one owned a desktop computer; overall, members of three teams used desktop computers. Two students mentioned using desktop computers at the School of Art Computing Center (SoACC) or at a library computing center on campus, but they did not personally own desktop computers. Although students primarily relied on their laptops for their computing needs, a few teams coveted desktop computers because they had specific software tools installed, or because they could perform certain computing tasks (e.g., video rendering) more quickly than other available computers.

The members of Teams C, D, and F used desktop computers for their collaborative project work. Interestingly, unlike Teams C and F, none of the members of Team D owned a desktop computer. Instead, they relied entirely on the computers provided at different labs around the university. Isole from Team D describes why she and her teammates needed to use these university-owned desktop computers to get certain tasks done.

> *We started at the School of Art Computing Center when we were doing Final Cut Pro and then when we had to do After Effects, [but they] don't have After Effects so [we used] Premiere Pro there, which is strange. And no Mac [computers] on campus have it, apparently. I mean, it says they do online, but they don't in the video editing area at [the library] so…that was extremely frustrating because I have After Effects but, you know, it takes like six times as long for my computer to process it so it's like not good. (Isole 99)*

Isole describes two problems in this quote. First, her team tried to use the Apple desktop computers in the SoACC but those computers did not have Adobe After Effects, which is useful for specific types of video modifications (e.g., adding visual effects such as user interface screens). Once they realized the SoACC computers had Adobe Premiere Pro but not After Effects, they tried using the computing center at the main undergraduate library on campus, but those Apple desktop computers did not have After Effects either.

This issue of resource constraints exists only because Isole's laptop, on which she had installed all of the software she wanted to use, lacked the necessary processing power and available memory. Her laptop was very slow when running After Effects, so she tried to find a faster way to complete her tasks when using this particular software tool. Unfortunately for Isole, the only available computers on campus that had After Effects were not running on an Apple OS: They were Microsoft Windows desktop computers. This difference in compatibility posed a problem for Isole and her team.

> *[It] ended up being kind of awful because the only computers they have with After Effects are Windows computers which none of us, well, Baron has [Windows] but he hadn't been doing*

any of this work and…then [the campus computers] wouldn't save things onto the external [hard drives] and so then the thumb drive had to be cleared off. (Isole 093)

This quote from Isole reveals a third problem: For a variety of reasons, her team had to perform a surprisingly large number of tasks each time they wanted to work with their video files. Their collaborative effort to create a video prototype was so complex because they required an increasingly large number of different digital hardware tools to complete their tasks. If Isole's laptop had been able to run After Effects more efficiently, or if the campus computing centers had installed After Effects on their Mac desktop computers, or if their Mac-formatted external hard drives had worked properly with the Windows desktop computers on campus, the task of video editing would have been simpler across activities. Unfortunately for Isole, she had to use a USB thumb drive that could not hold all of the team's video files at one time, all because their external hard drive did not work across multiple operating systems.

Team C encountered a similar situation that shaped their task work at times during the academic quarter, especially the last few weeks when there was a lot of video editing and post-production work to finish. Kimberly from Team C was the only team member who had a computer that could run Adobe After Effects and Premiere Pro quickly enough to enable Norbert, another team member, to perform the specific video-related tasks he considered necessary for their video prototype. Kimberly had her desktop computer in her small bedroom, which was one of several rooms in a shared dwelling; she explained what the task work around her desktop computer looked like.

Towards the end of the project, we started doing all of our meetings at my house, because I have a really fast desktop computer. .... It just saved so much time. So we ended up having, like, everyone was basically living in my room for the last week and a half of our project, which...I guess it was fun. [Laughter] It was kind of better than being in school, especially when it got like really late at night. Or at least for me, because I was like 'I would be here

> *anyway.' But yeah. I had five roommates in my small bedroom for a while. (Kimberly 161; 173-175)*

For Team C, Kimberly's desktop computer became a hub of activity because it could perform video rendering and post-processing tasks more efficiently than any other available tool. Because Kimberly had this computer in her bedroom, she wound up with "*five roommates*" toward the end of the project. Holly, another member of Team C, described the process of trying to schedule time on Kimberly's computer.

> *We were always working together basically. Most of the time toward the end when it came to [video] production we all met at Kimberly's house to work in the basement…. We were working in her room all the time. It was not the best room to work in. It was pretty small and I don't really like working not on a table without a mouse but I guess I had to because there was only one - the reason why we work at Kimberly's was she has a really big desktop computer that's very fast and has two screens. And so she was able to render [video] really quick. (Holly 179-183)*

Holly cites a number of reasons why collaborating in Kimberly's cramped basement room was less than ideal. However, the only thing that truly mattered to the team at that point in the academic quarter was rendering video as quickly as possible so they could see the results and adjust the video content as needed.

Holly continued by explaining how the collaboration around Kimberly's desktop computer worked in practice.

> *We sort of set a schedule in the mornings. I would do the color correction of the video and edit it a little bit. And then Norbert would come in a little later and then he would take over the computer and start doing his animations and stuff. So we had sort of like a time schedule and Kimberly usually was there all the time. And if she wasn't there then she would just let us in, like, Kimberly lives with three other girls. And Norbert could just come by and use the room. And then Abraham usually came by [too]. (Holly 185-189)*

When asked for more details about how the scheduling process worked, Holly described it as casual rather than a rigid, documented process.

We were there all the time so at the end of the day we'd just be like, 'Hey, I'm gonna come in the morning. You really don't have to be there until 1:00 or whatever.' It was pretty casual. It wasn't like we set up the whole weekend and talked about the whole of what we had to do. I think we kind of set a timeframe but it was very casual, like it'd be great to finish by Sunday. (Holly 193)

These quotes reflect how the members of Team C tailored their task work around one particular digital hardware tool: Kimberly's powerful desktop computer and its dual monitors. Without that computer, this team most likely would have resorted to scouring the on-campus computing centers for desktop computers that could render video efficiently enough for their needs, as both Team D and Team F did.

Laptop computers. All students on all six teams owned a personal laptop computer, nearly always an Apple MacBook Pro, partly because the School of Art mandated that all of its students own laptops and recommended Apple laptops running both Apple and Microsoft operating systems. The students nearly always had their laptops out and either open or closed while working with teammates, but they rarely used them during team discussions. They mainly used their laptops when they were working on individual tasks and did not actively need to communicate with other team members, or when they wanted to show teammates specific information that could not be conveyed any other way.

The following photo shows what collaboration typically looked like among the teams of students in this study.

Figure 9. Example of Team E working around laptop computers.

As this photo shows, all of the members of Team E owned personal laptops; however, only Clarissa (far right) had her laptop open during their team discussion. This photo was taken during the second week of the academic quarter when task work was focused around initial discussions of design directions that the teams might take. The following photo is indicative of how collaboration looked and functioned while students actively used laptops, which occurred later in the quarter.

Figure 10. Example of members of Team A collaborating while working with laptops.

In this photo, Nancy, Anne, and Khloe from Team A all have their personal laptops open. They are all working individually on specific tasks, but they are also viewing Anne's laptop screen from time to time as they work because she is performing video-related tasks and Nancy and Khloe are interested in how their video prototype looks so far. These three students worked in this way for over an hour; notably, this photo was taken during the final week of the academic quarter when the students were doing prototyping and preparing to present drafts of their video prototypes. At that point in the quarter, they had heavier workloads with respect to individual tasks, most of which they needed to complete on their computers.

The task work pictured above was extremely rare during the first few weeks of the quarter, which was when the teams were primarily performing ideation tasks such as brainstorming specific design concepts. For those tasks, the teams worked around analog tools and relied on digital hardware tools to record their progress or look up specific information relevant to the topics of discussion. The final few weeks reflected much more task work with and around digital hardware tools as the students were prototyping their videos and were pressing to get their projects completed.

Tablet computers. Of the 28 students in the class, three owned Apple iPads: Anne from Team A, and Nathaniel and Peter from Team B. No other tablets were used during the entirety of the study, and none of the students reported owning any other tablet computers. The following photo shows Anne from Team A working on her iPad during a team discussion, which was essentially the only time any of the students were observed to be using a tablet computer in support of collaborative project work.

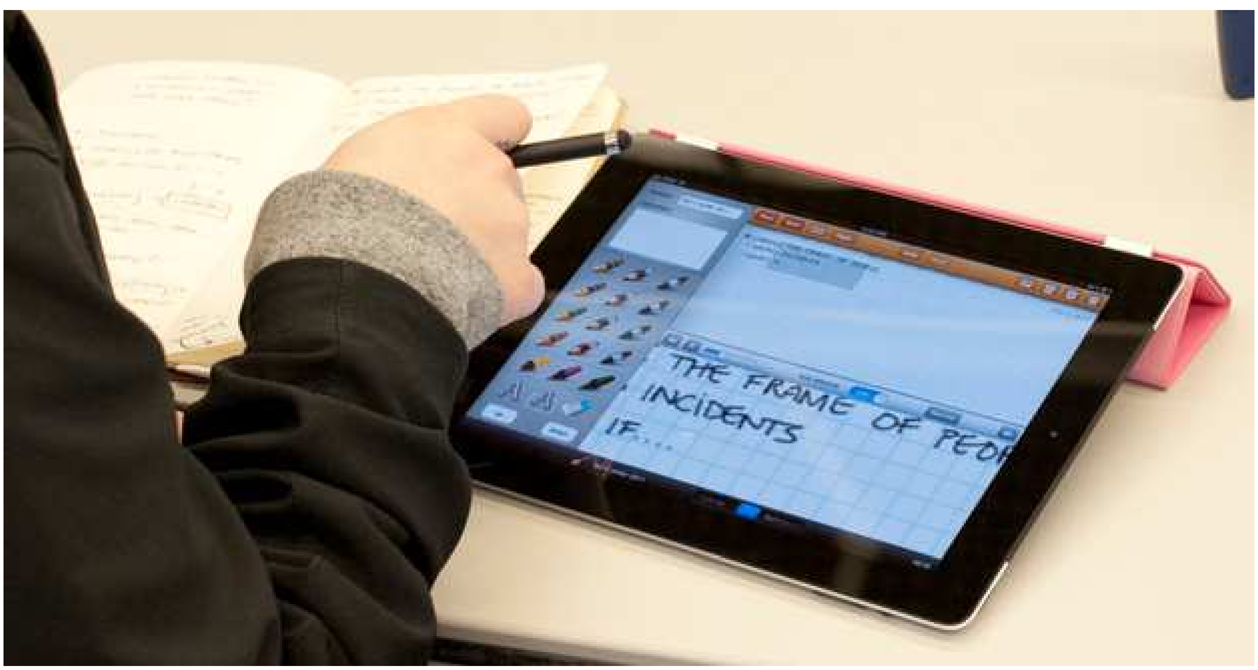

Figure 11. Anne (Team A) using her Apple iPad during team meeting.

In this photo Anne has taken a photo of the handwritten notes she wrote in her paper notebook and is editing them digitally on the iPad using a stylus. Observation notes indicate that Anne only used her iPad for this purpose on one occasion; she never took notes again on her iPad during a team meeting, nor did she share these digital notes with the rest of her team according to comments she made during our interview.

Anne also said during her interview that she used her iPad to take photos of the work her team performed using sticky notes and whiteboards, as well as occasionally create audio recordings of team discussions. As the photo shows, Anne kept a paper notebook with her notes and sketches, which was her primary note-taking tool throughout the quarter. She described how she used her notebook to track her team's progress.

> *I take really intense notes and section them off by date and link it up with where we should be at and where we aren't at, so it's almost like a calendar sketchbook sort of a thing. So that's how I tracked our progress manually. (Anne 083)*

Unfortunately, Anne had destroyed her notebook immediately after the class ended, so she was unable to show her work at her interview; however, the previous photo provides a glimpse of the combination of text and sketches that typified the contents of her notebook.

From Team B, the following photo (taken on February 23, 2012) shows the only time Peter used his iPad during class: He is reading an article for leisure during a break between collaboration sessions.

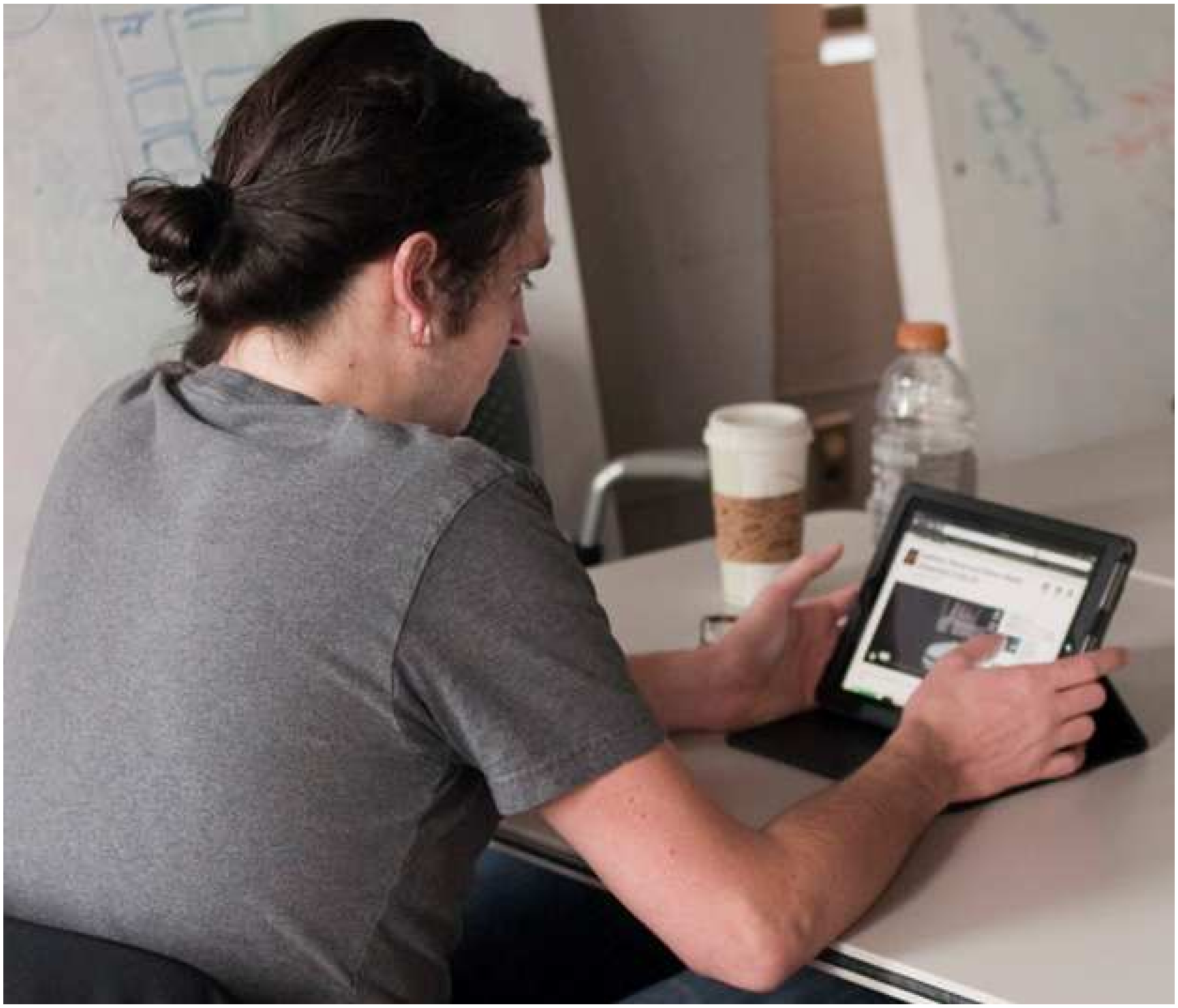

Figure 12. Peter (Team B) using his Apple iPad between collaborative work sessions.

As this photo shows, the iPad was useful for very specific tasks that were not always relevant to the task work being performed each day. Peter's overall workspace and set of tools are represented in the following photo.

Figure 13. Example of variety of tools that Peter (Team B) brought to class.

This photo shows the number of tools Peter had with him during class. In this photo, from left to right, are loose-leaf paper, whiteboard pens, a mechanical pencil, an iPad, a camera lens, a paper notebook, an Apple laptop computer, a smartphone, and more paper of various form factors. This photo is included to indicate that the iPad is one of several tools that Peter had at his disposal, and he chose to use his iPad only on rare occasions and only for leisure purposes.

Finally, both Logan and Molly from Team B stated in their interviews that Nathaniel and Peter used their iPads during their video recording sessions as a way to silently view their written scripts. Because paper made noise when they turned the pages of their script, and because the microphones they used picked up that sound, they decided to use an iPad to view their scripts. They also downloaded an application for the iPad to indicate the scene number, the date, and other information that makes video editing easier.

Overall, while students used their laptops and smartphones quite often, Peter or Nathaniel never used their iPads during team meetings to further their project-related task work, although as mentioned earlier they did use their iPads to assist with specific tasks during video recording. When iPads were visible during observation sessions, they sat unused and turned off.

Mobile phones. Nearly all of the students owned smartphones, with only three or four exceptions where students owned “dumb” phones (as Kylie described her older mobile phone). Those students who did own smartphones kept them close at hand or, on occasion, in their hands while having quick discussions with each other. Unlike laptop and tablet computers, smartphones are small enough to fit in a pocket and are always connected to mobile data or wireless networks. Therefore, students wanted to have these tools readily available in case they received a text message, phone call, or email, or in case they wanted to take a photo of something they were doing.

During the study, students used their mobile phones for three reasons, listed below from most common to least common:

- **Text messaging –** All of the teams used text messaging as a means of communication, although the quantity of messages and the reliance on texting as a primary means of communication varies from team to team
- **Taking photos of work in progress –** Those students whose mobile phones included cameras occasionally took photos of the work they performed in teams, often of whiteboard or paper sketches and notes created during collaborative work sessions

- **Calling other team members –** All of the teams relied on phone calls on occasion, but often only as a last resort when they were wondering where specific team members might be located (e.g., if they were late to a meeting)

With regard to texting and calling, Anne described the order of operations she ran through whenever she needed to get in touch with one or more of her teammates.

> *I would normally go to…Google Groups just to send out a mass [email] if I was talking to everybody, and if like one person or two people weren't responding I would text them. And if they didn't answer me, I would call them. So it was kind of like a string of options to go through if they're hiding. If I wanted to get in touch with just one of them, I would just text them. Or two of them, I would just text them. That was the easiest way to get in touch with most people, especially since I had three grad students, so they were just so busy. They were always like, 'Just text me, and I can get back to you.' (Anne 181)*

Of the 16 students interviewed, 14 students (representing all six teams) explicitly described their reliance on text messages to stay in touch with each other. Those students told very similar stories as the one above: They mainly texted when performing task work related to team formation and meeting coordination, or to send quick messages when other modes of communication were not convenient, practical, or allowed (e.g., a phone call made while at work). They resorted to making phone calls only when something unexpected happened (e.g., a shift in meeting location) or when a particular team member was inexplicably absent.

Summary of digital hardware tool use. There was a greater diversity of digital hardware tools used in support of collaborative project work than analog tools, although the next section describes the even wider variety of software and online tools that the students used. Three factors explain this diversity of tools.

First, the students in this study represented seven different academic disciplines and departments, all with their own guidelines and best practices for digital hardware use. The choice to own an Apple laptop rather than a Dell laptop running Microsoft Windows, for example, was made for the IxD students because their department mandated the use of Apple digital hardware.

Second, some students lacked the personal resources to obtain the digital hardware they truly wanted. Kristal cited cost as the reason why she did not own a newer laptop.

> *I always use the school computers because it was an investment I decided not to make because I knew I was going to replace my computer in the near future, but I wasn't financially ready to do it, so I always use the school's resources because they are free. They are quicker. And they have larger screens so I can get more done quickly. (Kristal 023)*

Because Kristal was a senior undergraduate from the School of Information, she had no requirement to own a new Apple laptop. Instead, as with the members of Team D, she chose to use school resources whenever possible. Similarly, all of the teams attempted to borrow DSLR cameras and lenses from the School of Art and from the university's technology center, as those tools are expensive to purchase.

Third, some students had more real-world experience than others with different digital hardware tools. Peter from Team B worked for Adobe on the Premiere Pro team, so he had far more videography experience and exposure to the corresponding digital hardware than most of his teammates. Therefore, he had a lot more digital hardware experience compared to Fiona, Logan, or Molly, none of whom had worked extensively on video projects prior to this course.

Finally, it is worth noting that laptops were more popular among students in this study because they worked in a variety of locations and needed to use a computer nearly all the time. Desktop computers were helpful for processor-intensive tasks, such as rendering video, that students could ignore in favor of completing other tasks while those intensive tasks completed. By contrast, most of the students' laptops were not powerful enough to render video files in an efficient way, so they tried to avoid such tasks on their laptops. The few students who had tablet computers did not use them for any tasks other than writing notes or sketching during team meetings, or taking photos of analog design artifacts. All of the students used their mobile phones to text and call one another, but they did not attempt to perform any project-related task work on their phones (aside from taking photos of their analog design artifacts).

Student Collaboration with Software and Online Tools

The following table lists all of the teams and identifies the most commonly used software and online tools the students on those teams used for their collaborative project work.

Table 4. List of software and online tools used by each team.

Tool Name	***Team A***	***Team B***	***Team C***	***Team D***	***Team E***	***Team F***
Adobe After Effects	**X**	**X**	**X**	**X**	**X**	
Adobe Flash			**X**		**X**	
Adobe Illustrator	**X**	**X**	**X**	**X**	**X**	
Adobe InDesign	**X**			**X**		**X**
Adobe Photoshop	**X**	**X**		**X**		
Adobe Premiere Pro		**X**	**X**			
Apple Final Cut Pro	**X**			**X**	**X**	**X**
Dropbox	**X**	**X**	**X**	**X**	**X**	
Email (any client)	**X**	**X**	**X**	**X**	**X**	**X**
Facebook		**X**		**X**	**X**	
Google Docs	**X**	**X**			**X**	
Text Messages	**X**	**X**	**X**	**X**	**X**	**X**

Note that while students used other tools to collaborate, this chapter focuses on the tools that students across multiple teams used consistently and visibly for specific tasks and activities during the academic quarter. For example, because Team B was the only team that attempted to use Pinterest in support of their collaborative work, and because they abandoned that tool after two weeks of spotty usage, Pinterest is not discussed in this chapter. Additionally, the email clients that the students used are conflated here as a single category called “Email.” Although it is true that email clients can be quite different in design and function, the specific details of email client usage among students were not studied in sufficient detail to draw comparisons or derive conclusions across clients.

The remainder of this chapter provides an overview of how the different teams in this study used the tools listed in the table above. Where appropriate, tools are grouped into a single section because students used certain software and online tools for the same tasks and not for other tasks. For example, the first section describes how students used Adobe After Effects, Adobe Flash, Adobe Premiere Pro, and Apple Final Cut Pro because they worked with video editing and visual effects tools such as these in tandem.

Adobe After Effects, Adobe Flash, Adobe Premiere Pro and Apple Final Cut Pro. All six teams in the study used either Adobe Premiere Pro or Apple Final Cut Pro for their video editing task work, although multiple teams tried each tool before settling on a preferred tool. Premiere Pro and Final Cut Pro are both designed to integrate with Adobe After Effects as well as Adobe Flash, two popular visual effects tools. Five teams used After Effects and two teams used Flash to generate and edit visual effects and animations; fewer teams used Flash because fewer students were adept with that tool compared to After Effects.

The video prototype assignment added a level of difficulty to the students' lives because of resource constraints. For example, Premiere Pro can be used with either the Apple or Microsoft operating systems, while Final Cut Pro is an Apple-only tool. Although all IxD students were required to own the Design & Web Premium Creative Suite (CS) package, neither After Effects nor Premiere Pro are included in that package. As of August 2012, the list prices for After Effects and Premiere Pro as stand-alone software tools are $999 and $799, respectively, while Final Cut Pro costs $299. The only way to obtain all of the necessary Adobe software tools at a discount is to purchase the Master Collection CS package through the university, which costs nearly $600 and which includes many of the same tools that IxD students already own as part of the required Design & Web Premium package.

The instructor also provided guidance about how to structure video editing and visual effects tasks around specific video editing tools. On at least one occasion during a class session, the instructor advised students not to use Adobe Premiere Pro because of the video output that they could generate using that tool. Specifically, on February 9, 2012, the instructor cited the fact that, at the time when the course occurred, Premiere Pro could only output interlaced video files rather than progressive scan video files. Nevertheless, two teams did use Premiere Pro while the other four teams used Final Cut Pro.

The process of creating video prototypes was complicated by the way the video editing and visual effects tools function in parallel. Specifically, when the students in this study used After Effects, they were also trying to use either Adobe Premiere Pro or Apple Final Cut Pro at the same time on the same computer. This simultaneous usage of both tools (in addition to any other software tools that were running at the same time) requires a lot of processing power, and not every student's laptop could handle that. Anne describes how the computing resource requirements associated with these tools impacted her choice of tools.

> *The only reason I chose Final Cut Pro was because Premiere Pro is a lot larger of a system, and it basically just bogs down my computer. So I can't run Premiere Pro and After Effects at the same time, but I am able to run Final Cut Pro and After Effects on my computer at the same time. So that was basically where I was like, 'Okay. Maybe I should do this,' because I only have my laptop so I didn't want to bog down my computer too much. (Anne 035)*

Video editing and visual effects tools require a great deal of processing power even when used on their own. Using two of these tools at the same time requires even more processing power, and not every student's computer was up to the task.

For this reason, Anne felt compelled to change tools and use Final Cut Pro rather than Premiere Pro *because* she needed to run After Effects at the same time. Although the user interfaces for both Premiere Pro and After Effects look quite similar, Premiere Pro is the tool that enables direct video editing whereas After Effects enables overlaying visual effects on top of already-edited video. Therefore, students like to switch between these tools as they identify scenes that need to be re-edited or shifted around within the order of all the scenes that comprise a specific video. In short, it makes the most sense to have both of these tools open at the same time because that provides the most convenient method for creating video prototypes.

The students persevered despite these resource constraints and created high-quality video prototypes. For example, Team E developed a design concept that enabled older members of the population to record unfamiliar terms that arise during conversation and then review what those terms mean at their leisure. Erica from Team E said they used Apple Final Cut Pro to edit the video files because that tool rendered video more quickly than Premiere Pro, and because her team wanted to integrate gestural animation effects into their final video prototype. The following screenshot shows a still image from that team's final video.

Figure 14. Example of Team E video output created with Apple Final Cut Pro.

To make this video, Team E used Flash to create a mockup of the user interface, which is visible in this screenshot. They then filmed a person using that interface mockup on an Apple iPad as if the interface actually existed as an application on a tablet computer. However, to simulate the response to touch, they used After Effects to add the visual effects necessary to make the interface appear to react to a person's gestures. The blue circle in this screenshot is an example of that animated reaction to the touch of the person's hand.

According to Isole from Team D, After Effects was the only tool that could be used for this purpose.

> *After Effects, I don't think there is anything else you can really use to do overlay graphics for interfaces the same way…[After Effects] felt like a given for making those types of [video] prototypes. (Isole 107)*

Given the emphasis on the quality of the final video prototype, all of the teams (aside from Team F) used After Effects to inject realistic-looking user interface elements into the videos they produced. Team F did not use After Effects because their design concept was essentially a Website that needed no visual effects or animation to showcase its functionality.

Finally, as with Team E, the members of Team C used a combination of After Effects and Flash while working on their video prototype. Norbert on Team C was extremely skilled with Flash, according to his teammates, and he decided to use Flash as the tool for developing animations that he would later integrate into the video content using After Effects. His teammate, Kimberly, describes how he added these visual effects to their video files.

> *Norbert had sort of a hacker way of doing his animation. He's really comfortable in Flash and he's not as comfortable in After Effects…. We have a lot of little squares that are kind of bobbing around, so [he] would do the little bobbling animation in Flash, and then import the Flash file into After Effects. Which, at first, I thought he was being crazy about that. But it ended up being really nice because then he could go back into the Flash file that was linked to it and just change that slightly instead of having to reanimate the After Effects thing. And he could easily just change the file, which you could probably works the same in After Effects, but that worked for him. (Kimberly 511-515)*

Because Norbert was the acknowledged expert on his team for all of the visual effects and animation work, Kimberly and the rest of the team deferred to his knowledge with regard to the tools to use for those tasks. His "hacker" style of approaching the visual effects and animation tasks worked for him, and his approach to designing visual effects and adding them into raw video files was unique among the students in this study.

In the quote above, Kimberly references squares that bob around within their video prototype. The following screenshot shows a still image taken from an early draft of the video prototype that Team C created, and demonstrates the addition of visual effects to video footage using After Effects.

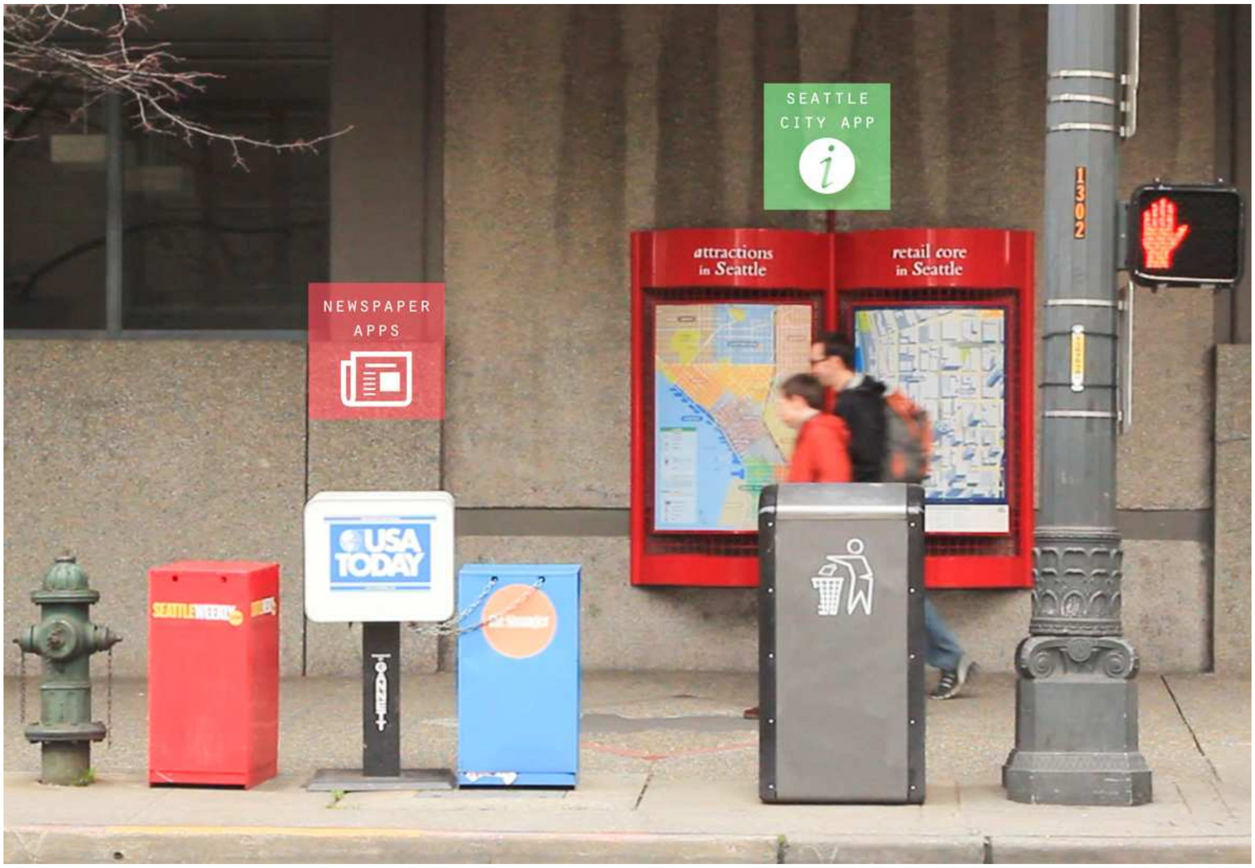

Figure 15. Still image from draft version of Team C video prototype.

In this image, the video content is overlaid with two visual effects: the “Newspaper Apps” and “Seattle City App” squares associated with the newspaper rack and the city map. In the actual video, these squares bob up and down to indicate that apps are available for those items in the city landscape.

Norbert created those squares using Flash, and then he exported the animation files into Premiere Pro, where he “attached” that content to the raw video files. He also added the team’s interface mockup into the raw video files using After Effects so that the smartphone user in the video would appear to actually be using their interface concept. That process, known as rotoscoping, is both technically challenging and time consuming. The following screenshot from the final Team C video prototype shows an example of how Norbert inserted the team's interface concept directly into their video files within Premiere Pro.

Figure 16. Example of interface concept inserted into Team C video prototype.

Note the slightly blurry fingers compared to the sharp text and icons on the white surface of the smartphone. The actor's hand was moving while he used the phone, which meant that Norbert had to spend a great deal of time using Premiere Pro, Flash, and After Effects in parallel to create the final effect he wanted.

> *[Norbert] was trying to do this thing called rotoscoping. You have to map something to something moving [within the video], and…he was erasing some fingers that were over part of the interface. But, anyway, I think it took him like five hours to do like a few seconds of it. (Kimberly 169-171)*

The scene depicted in the screenshot above lasts for less than two seconds, but as Kimberly points out Norbert literally spent several hours synchronizing the location of the interface mockup with the smartphone surface within Premiere Pro.

Adobe Illustrator, Adobe InDesign, and Adobe Photoshop. All IxD students are required to purchase Adobe Creative Suite (CS6), specifically the Design & Web Premium Suite edition of Adobe Creative Suite (CS). Version 6 is the most current version of CS as of 2012; that edition of the Design & Web Premium Suite includes Acrobat, Flash Professional, Illustrator, InDesign, Photoshop, and a few other applications that none of the students mentioned using during the study. CS6 does not include After Effects for creating visual effects or Premiere Pro for editing and producing video content.

The interfaces for Illustrator, InDesign, and Photoshop are visually similar. All three tools present a central "canvas" that can have different layers, with a primary menu system across the top of the interface and "palettes" of tools to the left and right of the canvas. The main distinguishing feature among these three tools is underlying support for the creation of either vector or raster art. Illustrator is a vector art tool, which means that files can be scaled up or down to any size without a corresponding loss of fidelity. Photoshop is a raster art tool intended for editing photographs and other photo-realistic images. Unlike vector art, fidelity is lost when raster art is increased in size. InDesign is a desktop publishing tool that can edit both vector and raster art.

The ability to create vector or raster art was very important to the students in this study, who worked with these tools in different ways depending on the tasks they were trying to accomplish and their own personal knowledge of each tool. Overall, however, the students in this study used

Illustrator far more often than InDesign and Photoshop. Khloe provided the best description of how Illustrator, InDesign, and Photoshop are different from one another, and how each tool can help students accomplish specific types of design-related tasks.

> *Everybody I know just uses Photoshop to edit their photos. I guess there's stripped down versions of it, but as far as I know, there's no direct competitors that have all the features that it has, and I don't know any other programs to use that creates vector art other than Illustrator. Then InDesign is really like a layout tool. You can create vector artwork in it, but usually you're creating your vector artwork in Illustrator and then importing that in InDesign…people also create presentations in Illustrator, so then at that point it just becomes personal preference. (Khloe 125-126)*

The remainder of this section explores how the students in this study used Illustrator, InDesign, and Photoshop in support of their collaborative work.

Adobe Illustrator. Five of the six teams used Adobe Illustrator in a variety of ways as they created design artifacts related to their projects. The only team that did not use Illustrator (Team F) relied on Adobe InDesign instead for their content creation and layout tasks. All of the IxD students owned Illustrator, and some of the students from other disciplines and department owned it as well.

Students used Illustrator for a variety of purposes beyond typical graphic design tasks. For example, although Illustrator was not developed as a text editing or presentation tool, the students in this study used Illustrator for those purposes as they worked on nearly all of their deliverables, beginning with the conceptual model deliverable. For that deliverable, the students were required to produce PDF files and present then to the class. Despite the availability of tools optimized for editing text and images, as well as for presenting visual ideas (e.g., Microsoft PowerPoint), Erica from Team E explains why she preferred to use Illustrator.

> *It's super easy to do it [in Illustrator]. It's really mindless and I can just copy and paste a bunch of lines and text strings and it's like rapid prototyping for me. I'm extremely fast with [Illustrator], and it's faster than any other program, so it was just like a speed thing. (Erica 250)*

In the context of their broader process for creating this deliverable, Team E turned to Illustrator once they were ready to formalize their design concept and prepare it for presentation.

> *This whole [process] started at the Post-It note session where we posted them on the whiteboard and then we were also writing stuff on the whiteboard, word maps on the whiteboard, and then we started writing down as a group the word maps on the big poster paper. And then we each took home a piece of poster paper and would write our own word map, and then we used the wall to pin them up at the end to make the final revisions to it. And then I used Illustrator to put this [deliverable] together, and then Carl sort of glamified it with the colors, and then he put it together in Illustrator as well for the presentation, and then we exported it to PDF. (Erica 308-310)*

The following screenshots show two examples of what the finished deliverable from Team E looked like.

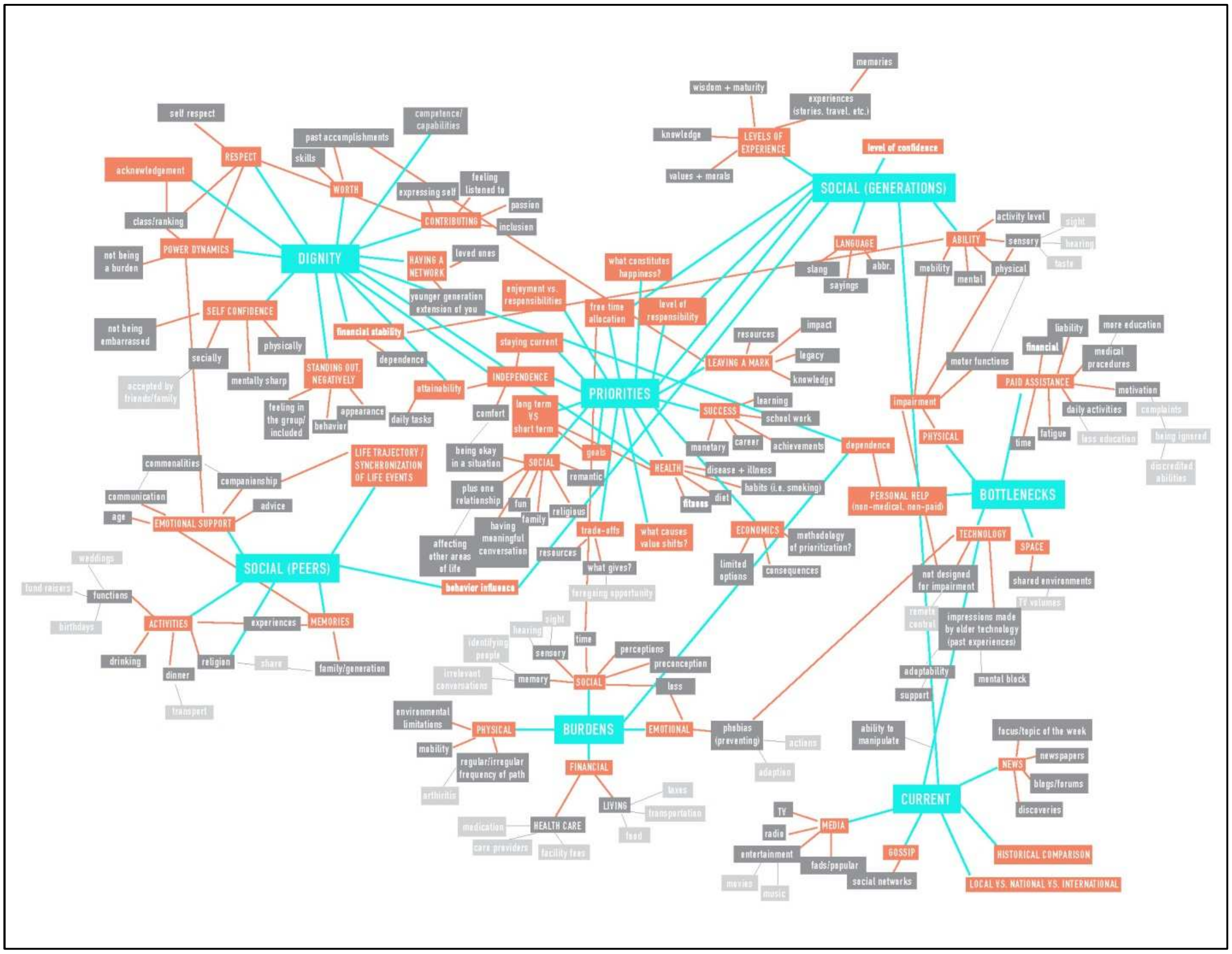

Figure 17. Example #1 of Adobe Illustrator output from Team E.

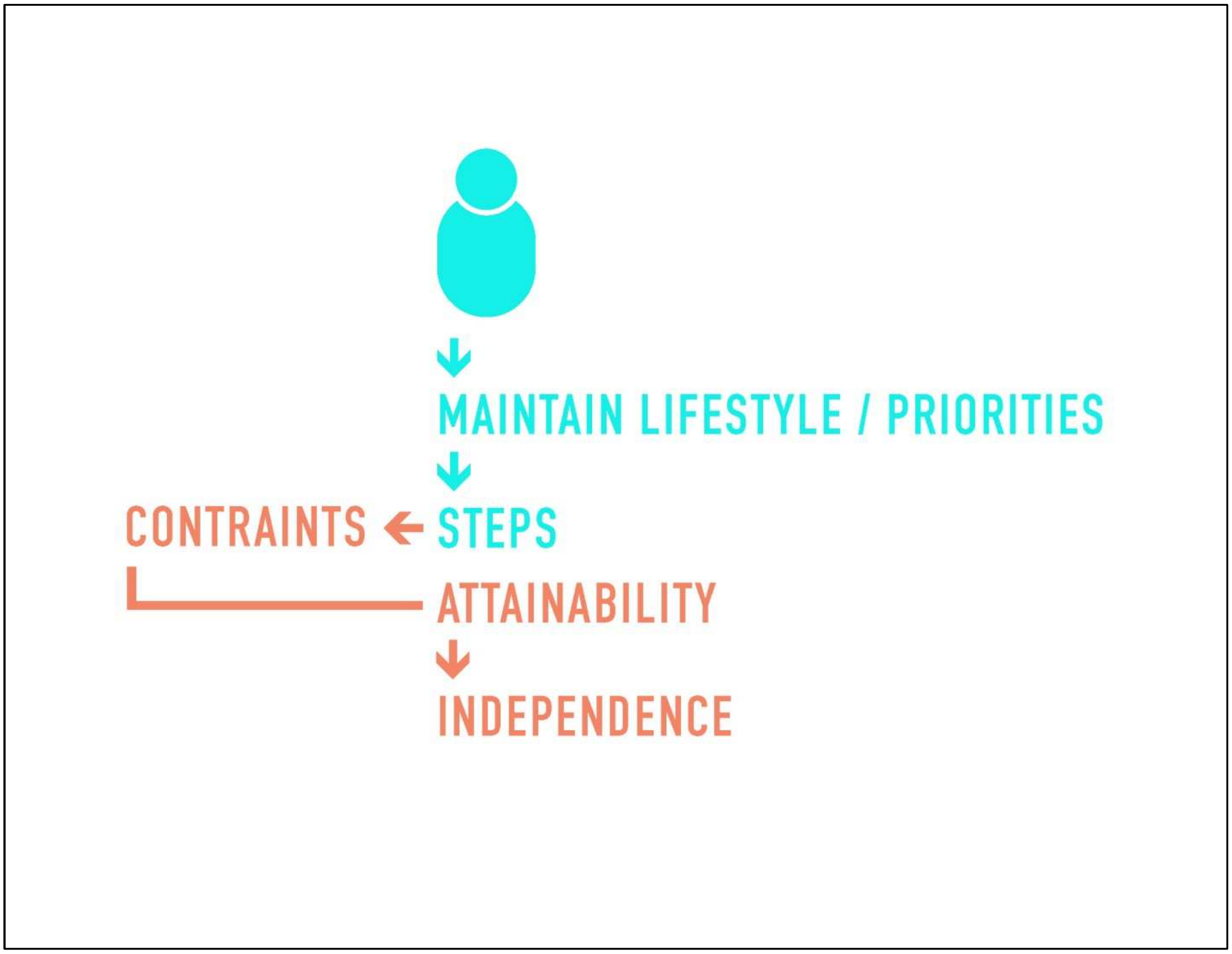

Figure 18. Example #2 of Adobe Illustrator output from Team E.

As these screenshots demonstrate, the students used Illustrator to create simple and complex depictions of their design ideas, as well as highly textual and highly visual representations of those ideas. The first screenshot above resembles a digital recreation of a word map describing ideas related to a central design concept, as Erica mentioned in the prior quote. The second screenshot reflects the distillation of that word map into a much more digestible image that summarizes the team's process for arriving at their final design concept.

Note the word “constraints” is misspelled in that screenshot, which highlights the fact that because Illustrator is intended as a graphic design tool rather than a word processing tool, it lacks integrated spell check functionality. That misspelling also reflects how users of Illustrator work with the tool: They must type text manually into individual text boxes, which they can move and place at any location within the canvas on which they are working.

Adobe InDesign. Three teams used InDesign in some capacity in support of their collaborative project work, although only Team F relied exclusively relied on InDesign instead of Illustrator to create their deliverables and presentations. As with Illustrator, the students who used InDesign did much more with this tool than text layout and other typical desktop publishing tasks. For example, the following screenshot shows a draft of the user experience walkthrough that Team A created.

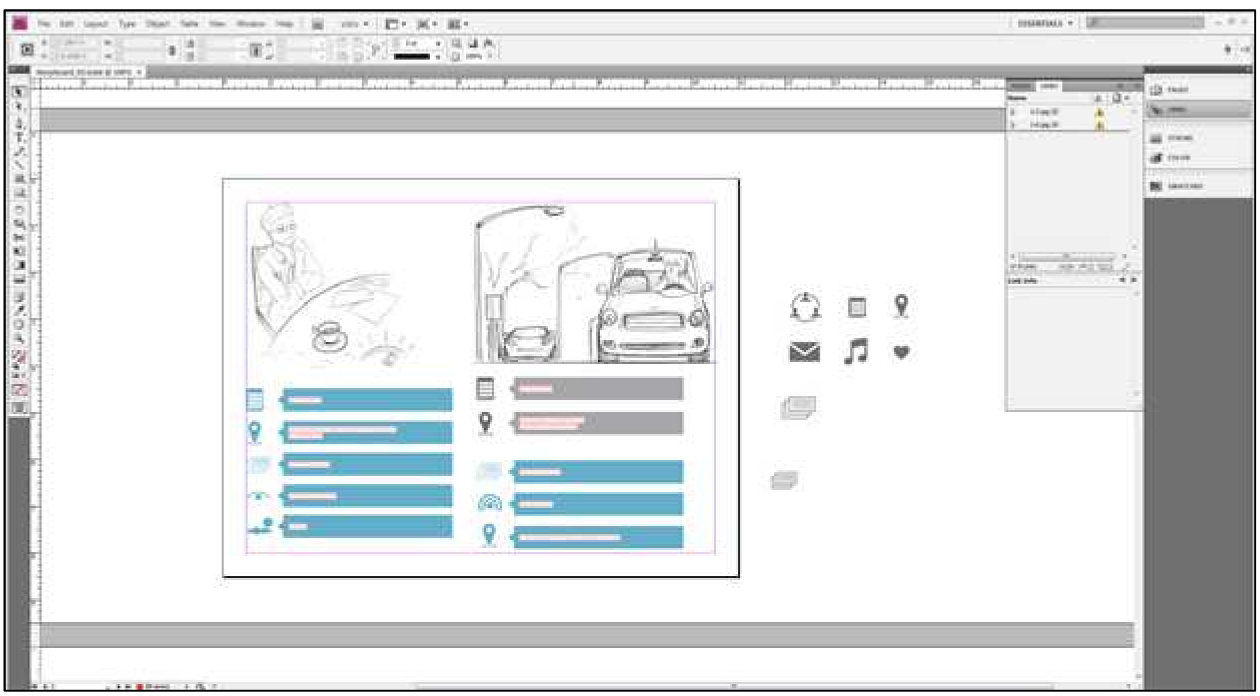

Figure 19. Example of Adobe InDesign interface.

As this screenshot demonstrates, Team A used InDesign to mock up the visual elements for their conceptual model. Note the inclusion of sketches that team member Bae created using his Wacom tablet and Illustrator. Note also the icons to the right of the sketches: That space is outside of the “printable” area of the canvas, which is bounded by the pink and black rectangles in the image above. Additionally, the blue boxes below the sketched images contain icons and text related to the team’s walkthrough, the details of which are unimportant here.

Adobe Photoshop. Members of three teams used Photoshop in support of their collaborative project work. The students who used Photoshop did so because they needed to digitize the sketches they had made using analog tools (e.g., whiteboards, paper, sticky notes). For example, Delilah explained the process that she and her team (Team D) went through to develop their conceptual model presentation, and the purpose of Photoshop within that process.

> *[We used] paper and pen. Then it would’ve been a…scanner, and then it would have been Photoshop, and then [Illustrator], and then we would have just checked that [the PDF file] opened properly in Acrobat. (Delilah 179)*

In this quote, Delilah explains that her team initially sketched ideas for the conceptual model using pen and paper. She took those paper-based sketches and used a scanner to digitize them. From there, she redrew the rough digitized images as high-quality drawings in Photoshop, which she then saved as image files that she imported into an InDesign file. She was able to make a PDF copy of the Illustrator source file; the team used that PDF when they presented their conceptual model to the class.

As with Delilah, Fiona from Team B and Anne from Team A also used Photoshop to create digital versions of sketches they and their teammates created using analog tools. However, Delilah used Photoshop in a way that was unique among the students in this study. She sketched a lot of design ideas by hand rather than using Illustrator, but as a result she needed to digitize the best sketches for use in her team's deliverables.

> *The other reason why I used Photoshop was because when I was putting the storyboard together, I would do multiple sketches of the same frame and then choose the best one, and then Photoshop something together to look like they were all one storyboard…. There's all these different [sketches], and so those [sketches] in some cases were scanned, and it was really because I would do them as a series, and then one of them would be bad so I'd resketch them and…Photoshop it in to replace the bad one. (Delilah 163-167)*

Note how Delilah uses the word "Photoshop" as a verb in this quote. She relied on sketching by hand because she found it less distracting to work that way, but then she relied on Photoshop to help establish a seamless flow among the sketches she selected for her team's final storyboard deliverable. In this way, she combined two tools that she preferred into a personal process for creating design artifacts.

Dropbox. Five of the six teams in this study used Dropbox to share files, and 13 of the 16 students interviewed described using Dropbox within their teams. Dropbox is a free online tool that enables users to share files with one another through dropbox.com, or through Internet-connected folders that reside on users' digital hardware tools and that automatically synchronize their contents with other users of the same folder. The following screenshot shows the Web interface for Dropbox as of September 11, 2012.

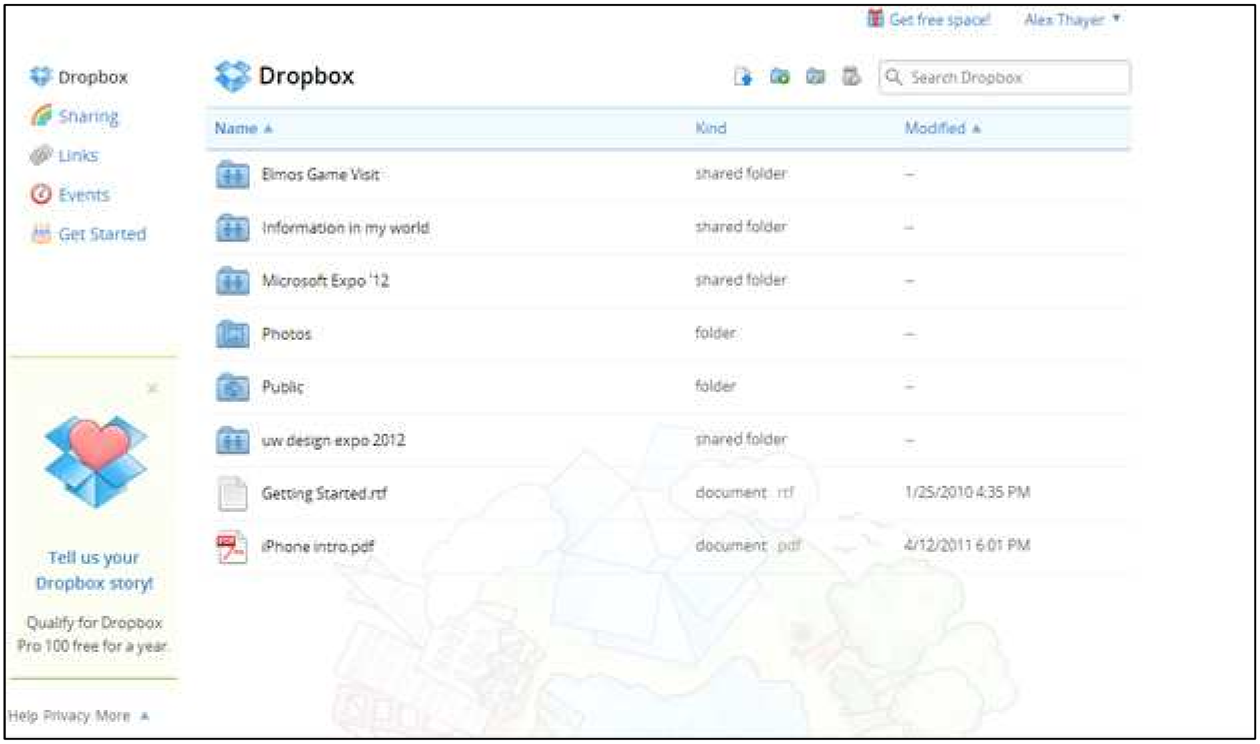

Figure 20. Example of Dropbox interface.

Although Dropbox is free, users must pay to receive more space for file storage; at the time of this study, users of the free version of Dropbox received 2 gigabytes of space. All of the students in this study who used Dropbox relied on the free version of this tool. Molly explains why Dropbox was her team's choice for sharing files.

> *Dropbox, I think there are a bunch of other programs out there that kind of do similar things, but Dropbox is really easy to use - like, extremely easy. It's just so convenient and we didn't really consider using anything else. It's just like, 'Oh. Well, Dropbox, obviously.' (Molly 051)*

When the students formed teams they also shared their Dropbox folders with one another, which is to be expected considering the students needed to collaborate with one another on their team projects. When Dropbox users share their folders, their space allocations combine as well and the 2 gigabyte limit for file storage applies to all users who share the same folder or folders.

As a result, all of the students in this study who used Dropbox struggled with space limitations, particularly once they began sharing video files during the last few weeks of the academic quarter. In some cases, teams relied less and less on Dropbox and more on other software and online tools such as email or on digital hardware tools such as external hard drives.

> *All our Dropboxes became full at one point or another, so we had to kinda work around that…. We would delete things from our own Dropboxes, or we would just email back and forth certain files. (Fiona 177-179)*

The most compelling stories about students' usage of Dropbox came when the students talked during interviews about how they used Dropbox to communicate with one another. Dropbox does not necessarily facilitate communication among users of the same folder. Part of the value of Dropbox is that, as an online tool, users can access the same shared Dropbox folders regardless of which operating system they are running on their computers. The Web-based interface for Dropbox is platform-agnostic, but does not provide notifications when files have been added, changed, or removed. For this reason, whenever the students within a specific team accessed their shared Dropbox folders, there was a possibility that new files would appear, or that iterations of the same file would have replaced previous versions without any clear descriptions as to what changed within those files.

Molly described how she and the rest of Team B worked around this issue of keeping one another informed about which files had changed, how they had changed, and which copies of the files should be considered the most current versions.

> *Nathaniel was like, 'Okay. Well, I can take the sketch. I have time. I can take the sketch and mock it up in Illustrator. I'll put a PDF in Dropbox so you can all look at it. Give me some feedback by Monday night and then, based on your guys' feedback, I can revise it Tuesday morning and we can get together on it right before class to make sure we're all happy with it.' [But] because Logan didn't have Illustrator, any Illustrator document that one of the design folks wanted feedback on had to be saved in the Dropbox as both an Illustrator document and as a PDF because Logan wanted to look at it but he couldn't modify it. But*

> *one of the other interaction designers might have wanted to also modify it, so we pretty much had double copies of everything - PDF and the original. (Molly 203-205)*

In this quote, Molly describes how her teammate Nathaniel volunteered to tackle the creation of a specific design artifact, and how he explained that he would inform the rest of the team once that artifact was ready for their feedback. Molly also describes how Logan, who was not an IxD student, did not have a copy of Adobe Illustrator with which to view the design artifact in its native format. Therefore, Nathaniel had to save the Illustrator file to Dropbox so Peter and Fiona could review it, and he had to export a PDF version of the same file so Logan and Molly (who also lacked a copy of Illustrator) could view it and comment on it too. Although Nathaniel set a timeframe for when he expected to have the design artifact ready for review and when he wanted to receive feedback on it, the members of Team B still relied heavily on email to tell one another when they had started or completed specific tasks such as reviewing this design artifact.

The free space limitation of Dropbox is also important in the context of student collaboration because that limitation impacted the ways in which teammates worked with one another, both in terms of the tools they used to share files and the decisions they made about which team members should even receive specific files. For example, Isole and Delilah worked together on Team D. They each described during their interviews how their team used Dropbox as a communication tool, and how they dealt with its shortcomings in that context of use.

> *There is a little bit of communication, I guess when you add things to Dropbox, you can see that [files] are being added, but indirect. (Isole 113)*

Isole makes reference to the "*indirect*" communication that happens when a team member uploads a new file to a shared Dropbox folder: Notifications about these occurrences are not always forthcoming from the Dropbox interface. Dropbox users only receive notifications of added or updated files in certain contexts of use (e.g., using Dropbox as a local folder rather than working with Dropbox through a Web interface).

Delilah clarified how she and her teammates handled the need to let one another know when files were added or updated.

> *When it came to actually producing files and producing visuals for things, we were using Dropbox, so we would see when people were uploading things…. In addition to dropping it in the Dropbox, we would send an email saying, 'Hey, I just dropped this in the Dropbox, so check it out.' (Delilah 031)*

In this quote, Delilah distinguishes between explicitly communicating about shared files using email and implicitly communicating availability by adding those files to a shared Dropbox folder.

Similarly, Abraham and Holly worked together on Team C and used Dropbox throughout the academic quarter. Holly established folder naming conventions within Dropbox to suggest where other team members should store the files they shared with everyone else, as well as how to categorize those files in a standard way to keep similar files grouped within the proper folders.

> *Holly…set up initially for us the file structure for our Dropbox using both numbers and titles, so this is our folder for presentations, one folder for identity. I think that was mainly because she wanted [folders] in a certain order rather than being alphabetical. (Abraham 141-143)*

Holly never explicitly told the team about her use of folder names as a way to communicate intent regarding where files should be stored within their Dropbox folders. Instead, she indicated her preference by communicating through the folder names she established. The following list reflects those names; note that Holly added a digit at the start of each name to order them in a specific way, as Abraham described:

- 0_Presentations
- 1_Identity

- 2_Meeting_Pictures
- 3_Storyboard
- 4_Interface
- 5_Video
- 6_EXPO

Unfortunately for Holly, the other team members did not comply with her information organizing strategy when they stored files in their shared folders.

> *I also had made [Dropbox] folders for all [deliverable] categories…so you could [see] for a project all the different folders that you potentially need. It'd be nice if [my teammates] could just use those because I had them set up. But then people just put stuff not in the folders where they belong but just - sort of like when you put stuff on the desktop. [They] just threw [files] in there and I was always upset [having] to organize it more. (Holly 337)*

Again, the way that Holly describes Dropbox is in terms of its shortcomings as a communication tool. She stated her expectation that her teammates would follow the folder structure she established, but instead they treated Dropbox more like an operating system desktop with files strewn everywhere without a discernible ordering system.

This lack of discipline around where the team stored files within Dropbox impacted their progress late in the quarter. Kimberly cited her team's use of Dropbox as a reason why they struggled to pull together process documentation for their final product.

> *I think it was just a matter of not knowing where everything was and having way too many files that we hadn't really named properly. We had a bunch of labeled Dropbox folders that weren't labeled very well, either. There was a bunch of research things that were in a folder called ideations, but then there was a folder called research. So we'd be looking in different folders. 'Where was that one file?' [Laughter] (Kimberly 205-209)*

Clearly Holly's attempts at naming the folders in a consistent way did not work out for her team. It is interesting that the folder names Kimberly cites are not actually the names of their shared

Dropbox folders, which indicates the messy and challenging nature of communicating among team members.

Finally, Delilah and her team did not attempt to organize their files within their shared Dropbox folder during the academic quarter. At the end of the quarter she and her teammates struggled to determine which files were important and whether each member had the right files.

> *You can lose track of who has the files or who you've already given them to, and so especially at the end of the project, like right now, we are all making sure that we have all of our files from the project, and so trying to figure out which ones people have and don't have, and you copy those. It's kind of a challenge. (Delilah 211)*

As Delilah pointed out, digital copies of design and social artifacts proliferated within her team, which meant that version control became increasingly challenging as the quarter wore on. Delilah provided some additional detail as to how she addressed this challenge.

> *I occasionally tried to use the little file labeling tool in Mac, the Finder thing, where you can like option-click and give it a color to keep track of whether something had been put on Dropbox, or put on an external [drive], or something like that. (Delilah 213)*

As these quotes indicate, the members of Team D had a poorly-defined process for saving and cataloging their work during their design project, which meant they had to perform a great deal of retrospective work to determine who had copies of the files they had made.

Email and text messages. All six teams used email and text messages extensively to communicate with one another. Students received free email accounts through the university, although nearly every student also had other email accounts (e.g., Gmail) that were free to establish and use. Email served three purposes for these students with respect to their collaborative project work:

- Coordinate team task work within and across activities
- Discuss sources of inspiration for design concepts and other ideas related to the project
- Send files back and forth, with or without contextual commentary in the message body

By contrast, students relied on text messages when they needed to know where a team member was, or whether they should begin a meeting without someone. Erica from Team E explains the order of operations with regard to email, text messages, and phone calls.

> *With email and text, if we didn't get a response via email for a couple of days, we would have to bug them and directly contact them by calling them or texting them, but that was the main way actually. Email is sort of you don't have to reply right away with email like there's not a social rule surrounding that exactly, but with texts or calling someone, it's much more polite to answer, so I think that's just where it came into play was like, 'Okay, we actually need you to reply now. We're gonna text or call you.' (Erica 302-304)*

With regard to coordinating the collaborative efforts associated with teamwork, students relied on email when they wanted to assign or volunteer for specific tasks, check in with others on their progress with those tasks, schedule meetings, send out notes that resulted from meetings, and so on. However, the students used email as one tool among several that facilitated coordination, discussion of ideas, and file sharing. Nancy from Team A described when she and her teammates would switch from one tool to another in the context of their effort to coordinate their task work within and across activities.

> *We would text people to figure out where they were or to schedule meetings or to check in about things if email wasn't fast enough. (Nancy 205)*

All six teams provided this same basic explanation as to why they would use email to communicate, and when they would use another tool. Email is well suited to longer, more thoughtful, more detailed messages that might not always require an immediate response, whereas text messages are brief and usually reserved for important inter-team communication events (e.g., asking one team member why she was late to a meeting). Students used phone calls when email and text messages failed to get the desired response quickly enough.

After the teams had formed, students used a combination of email, Facebook group pages, and blogs to share design concept ideas or to discuss sources of inspiration or relevant information. For example, Kristal reported that she and her teammates never used email to coordinate their task work, but they did use it extensively to share ideas about their project or to send files to one another.

> *Kristal: If we did collaborate over email, it was basically sending out existing technologies for people to look at because it's easier to do that on your own time than to have the conversations.*
>
> *Alex: Did you track any of that? What would it look like to set things up?*
>
> *Kristal: An email thread. It was just like one person would send it out and then someone else would 'reply all' with a different technology on an existing platform. (Kristal 078-082)*

Team F (Kristal's team) relied on email conversations to discuss ideas and possible touchpoints for design inspiration, whereas Team B shared ideas and discussed existing technologies using their private Facebook group. The members of Team C created their own blog to externalize this discussion process and to have something tangible to show at the end of the quarter. Again, these choices about which tools to use reflect students' contrasting assumptions and expectations about the tools themselves.

Facebook. Three of the six teams used Facebook to share ideas, photos they had taken of their artifacts, links to Websites and videos, and coordinative messages related to team planning tasks. For example, Team B used Facebook because it was a lowest common denominator in terms of how technically savvy the different group members were, and how skilled they all were with different info sharing tools. Peter explained the thought process behind this rationale for using Facebook.

> *I would say that some of the members of our group weren't as technologically savvy as others. Like I would put myself on the high end of tech savviness. I'm a nerd for technology. I came from computer science engineering and then went to interaction design. But I feel like Nathaniel, on the other hand, is on the opposite spectrum - like a great designer, but not tech savvy whatsoever. You know watching him use Facebook was almost painful. So like it made sense for us to have that as our tool. (Peter 293-295)*

Team B did attempt to augment their use of Facebook by creating two Pinterest boards where they could save links and images that served as sources of inspiration for their design concept. However, because of the team members' existing familiarity with Facebook as a tool, as well as a lack of interest in learning a new tool, Team B abandoned their Pinterest pin boards after about two weeks of spotty use.

It was unclear whether the other three teams that used Facebook defaulted to this tool due to technical skill limitations among their team members. The members of Team C used Facebook because they could share images of artifacts and links to useful information easily and in a threaded way without generating a lot of email.

> *[Facebook makes] it easy to communicate with people. I think people are more likely to respond on Facebook than via email, just because it's less formal or something, and then it's kind of halfway between email and text messaging. But people check their Facebook a lot. And then it's really easy to be like, 'I'm going on Facebook, yes, we're coming to the meeting, cool. That's a good article.' (Kimberly 229-231)*

However, after an initial attempt by members of Team C to use Facebook to communicate, they stopped using Facebook when it became clear that one team member did not have a Facebook account and seemed unwilling to create one.

> *I don't have Facebook, but I do have Google Plus so that's why we used that rather than Facebook for sharing things and messaging each other. So I was a pain for my group. (Abraham 233)*

Team C attempted to use Google Plus instead of Facebook for a while as Abraham had a Google Plus account, but none of his teammates had accounts with that online tool. Team C ultimately built a blog and relied on Google Docs and email as a way around using Facebook.

Team F rarely, if ever, used Facebook. Kristal said that her team avoided using Facebook to communicate for a few reasons. First, Facebook represented an extra step to share useful files or information compared to accessing Google Docs files via email, or simply emailing files to one another.

> *I think because we have all been on Facebook for so long, that Facebook has lost its appeal, like you use it for more personal things…[when] you are allowed to see more live updates and communicate that way, it just makes more sense to use email because you have to access Google documents from your email, whereas, with Facebook, it's just that extra step to go check and update. So you are already on your email for other purposes, why add an extra tool to the mix. (Kristal 220-222)*

Second, all of the members of this team had been using Facebook for some extended period of time before they took the course together, so Kristal claimed that Facebook lacked any novelty value as a newer tool that was cool to use. Finally, Kristal said that she and her teammates regarded Facebook as a site for more personal rather than professional or class-focused activities.

Interestingly, Teams B and C used Facebook as a communication channel through which core team members got in touch with other students who they wanted to invite to their teams. Two students referred to this process as "recruiting," and Kimberly from Team C explained how this process worked.

> *So before the quarter even started, [Holly] was planning what her group was going to be, and I hadn't actually talked to her before but we have a really good friend, and they had told her that she should work with me. So she Facebook messaged me, and was like, 'Hi, wanna be in my group for the Microsoft class?' I was like, 'Okay, sure.' And I'm usually one to not decide on the group until I see people's ideas. So we were communicating via Facebook, and we were talking to other people via Facebook about their experience working with Norbert, so we could get our third design person. And then, I guess Holly had a friend that knew*

Ziggy, so he joined our group, and we were all kind of Facebook messaging each other about strategies for how to pick our other team member, stuff like that. (Kimberly 237-241)

Team C also included Holly, who described her hesitation to use email as a tool to communicate with other students whom she did not know. She described in her interview how she used a combination of Facebook messages and text messages, but no email messages, to recruit members for her team.

I think I didn't want to ask anyone for email [addresses]. I think actually Facebook became the portal where it's most accepted to contact somebody you don't personally know that well. Like I think email would have been more strange than contacting someone on Facebook. Like [Facebook] felt…like the best way, I guess, or the least creepiest or whatever. Like I think when someone emails me I'm always wondering, 'How did you get my email?' So the thing about Facebook is it's acceptable to everyone. (Holly 105-107)

Holly's preference for Facebook as a coordinating tool is striking because she feels strongly that Facebook is a less "creepy" way to contact other students compared to sending an email message.

Finally, Facebook was a repository where students could store the photos they took of their sketches, notes, and other artifacts made while collaborating with one another. The following passage from Fiona's interview includes her explanation of how she and her teammates made files available to one another through their Facebook group page.

Alex: How'd you end up using the photos you took? Did you use those for anything else before the process book?

Fiona: No. Well, I posted them on Facebook just so everyone would see each other on there, and a lot of pictures were also of the boards themselves so that we could all refer to those images when we went to a meeting because some of them would be a task list or a calendar or just important notes for the meeting, so I put them on Facebook so we would all see them.

Alex: How did you work with them on Facebook? Were all your group members on Facebook?

> *Fiona: We made a Facebook group for our team, and then so I would shoot pictures in the raw and then process them through Adobe into a smaller JPEG format and then upload them.*
>
> *Alex: Were all the group members already using Facebook before you set up the group?*
>
> *Fiona: Yeah, they were.*
>
> *Alex: It sounded like sketchpads or sketch paper, or a large piece of paper on the wall, but then did the photos you put on Facebook replace that at all, the process of it?*
>
> *Fiona: Yeah, I took pictures of the whiteboards, of the paper and pen, and because there's no good way to scan them in or anything, and you can't hang them up on the wall, so it's nice to collect some documentation. (Fiona 135-151)*

As this exchange indicates, Team B tried to capture their work by saving digital images of the artifacts they generated on their Facebook group page. A segment of their group page is shown in the following figure with callouts added to explain the content that is too small to read.

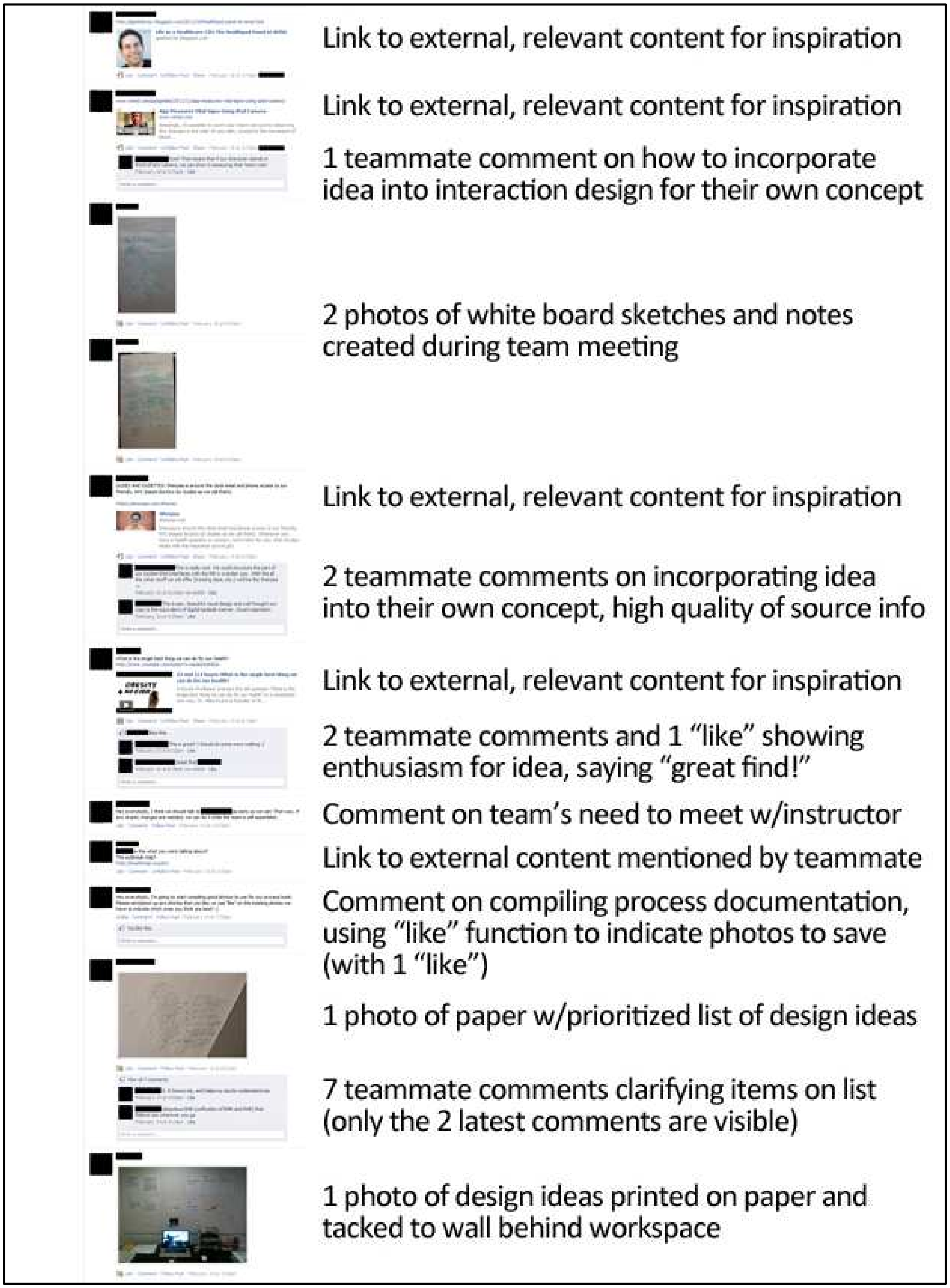

Figure 21. Segment of Team B Facebook group page with callouts.

As this image shows, and as the full set of entries in their group page reflects, Team B used their Facebook group page in the following ways:

- Publish “external” (not team-generated) content links describing ideas, systems, prototypes, and other information that seemed relevant to the team’s design project ideas
- Provide feedback on the quality, relevance, and possible usefulness of the external content as an influence on the team’s design project
- Publish captured images of artifacts that resulted from performance of task work, such as taking notes
- Rely on Facebook functionality (the “like” link) to indicate which captured images of team artifacts should be included in their final process documentation book, which was a required deliverable in this course
- Strategize around when and why the team should meet with the instructor
- Build on ideas presented in a captured image of a team artifact, as with the photo of the list of design ideas and the subsequent comments in Facebook clarifying what each list entry meant and what changes the team members wanted to make to the list items
- Use captured images to reflect the effort that at least one team member was expending with regard to team-related work and artifact generation
- Create an ongoing conversation about the team design project that could be referenced at the start of meetings as a way to kick off each discussion, recall what had already been discussed, or consider the potential applicability and usefulness of specific sources of inspiration
- Reduce reliance on email as the tool for coordinating meetings or sharing certain artifacts

In summary, Facebook served as a tool that facilitated communication in a number of ways. Further study into the use of Facebook among professional designers as well as students working on design projects would likely uncover more advanced task work performances than the ones that were traceable in this study.

Summary of software and online tool usage. This section described in detail how students used software and online tools in support of their collaborative project work. Of the three categories of tools introduced earlier in this chapter, students in this study used the widest variety of tools from the software and online category, which is an obvious point since there are far fewer analog tools that support collaboration. However, only two software and online tools (email and text messages) were used across all six teams.

As they made the deliverables for their projects, the students had to choose between Adobe Premiere Pro and Apple Final Cut Pro. Twice as many teams relied on Final Cut Pro partly because the instructor told them to use that software tool, but also because students were attempting to run video editing and visual effects software tools simultaneously. Even though Adobe develops both Premiere Pro and After Effects, the latter visual effects software tool runs more efficiently in parallel with Apple's Final Cut Pro video editing software tool. Anne from Team A noted this performance difference as the reason why she selected Final Cut Pro for her video prototype task work.

The students were faced with a similarly important choice between Adobe Illustrator and Adobe InDesign. Five teams relied primarily on Illustrator, while only one primarily used InDesign. Students made this choice based almost entirely on their personal preference for a certain tool, as both Illustrator and InDesign facilitated the same types of task work that students needed to accomplish despite the different ways that these software tools organize and present data. Again, Illustrator is a vector art tool whereas InDesign is a desktop publishing tool; however, both of these tools produce PDF files that look visually appealing, which meant that both tools were sufficient for the requirements of this advanced interaction design course.

Finally, students were forced to find alternative ways to collaborate when preferred tools were unavailable, or when the tools they needed to use in parallel required resources that stretched the students' ability to complete their tasks. Every team that used Dropbox ran out of free space, which interrupted or entirely stopped their ability to share new files with one another. Similarly, some software tools that the teams used (e.g., Adobe Premiere Pro) were less than ideal compared to other tools that facilitated the same task work (e.g., Apple Final Cut Pro). Faced with these limitations, students were forced to find workarounds, such as using external hard drives, email messages, or even Facebook messages to share files rather than cleaning out their Dropbox folders or working on a specific student's computer because it had the most processing power.

As the students filled their Dropbox folders and portable storage devices with digital design artifacts, they also struggled to keep track of where the most important artifacts had been saved. The next section describes in detail how a specific team developed each of their deliverables for the course, and provides some insights into how the members of that team tried to keep their work organized across the different activities within their arc of work.

Student Collaboration with and around Artifacts

Throughout the academic quarter, the students on each team created a significant array of design and social artifacts. As described in Chapter 2, an artifact is broadly defined as *anything created in support of collaborative project work, including a process or practice that is made tangible*. The beginning of this chapter further distinguishes among four kinds of artifacts: analog design artifacts, analog social artifacts, digital design artifacts, and digital social artifacts. This typology is useful as a way to characterize the different kinds of work that students performed with and through each artifact they created throughout the quarter, as well as how they collaborated during the processes of creating, iterating, and using artifacts throughout their projects.

The purpose of this final section of the chapter is to provide an overview of how a particular team collaboratively created each of the 10 deliverables required for the course. The assignments that correspond with the 10 required deliverables were described in the syllabus as follows; the due dates are added to show the limited time that the students had to iterate ideas across assignments and to complete each assignment before moving on to the next one:

1. Design project description (1 presentation slide) – due January 17
2. Conceptual model presentation (2-3 presentation slides) – due January 31
3. Interaction sketches and user experience scenario walkthroughs (several slides) – due February 7
4. Digital wireframes of user experience walkthroughs (source files, several slides) – due February 14
5. Video prototype visual narrative (source files) – due February 21

6. Video prototype demonstrations (edited video recordings about 3-6 minutes long) – due February 28
7. Multimedia presentation of the envisioned design (several slides) – due March 8
8. Final video prototype (edited video recordings about 2-3 minutes long) – due March 13
9. Final multimedia presentation of the design (several slides) – due March 13
10. Comprehensive design documentation (bound, hardcopy book; CD or DVD with all documentation provided as PDFs, video files, Flash wireframes, digital photos and videos taken of the process of working collaboratively) – due March 13

The following two figures represent a visual timeline of the deliverables listed above; the figures also include a representative thumbnail image of each course deliverable that Team A created throughout the quarter.

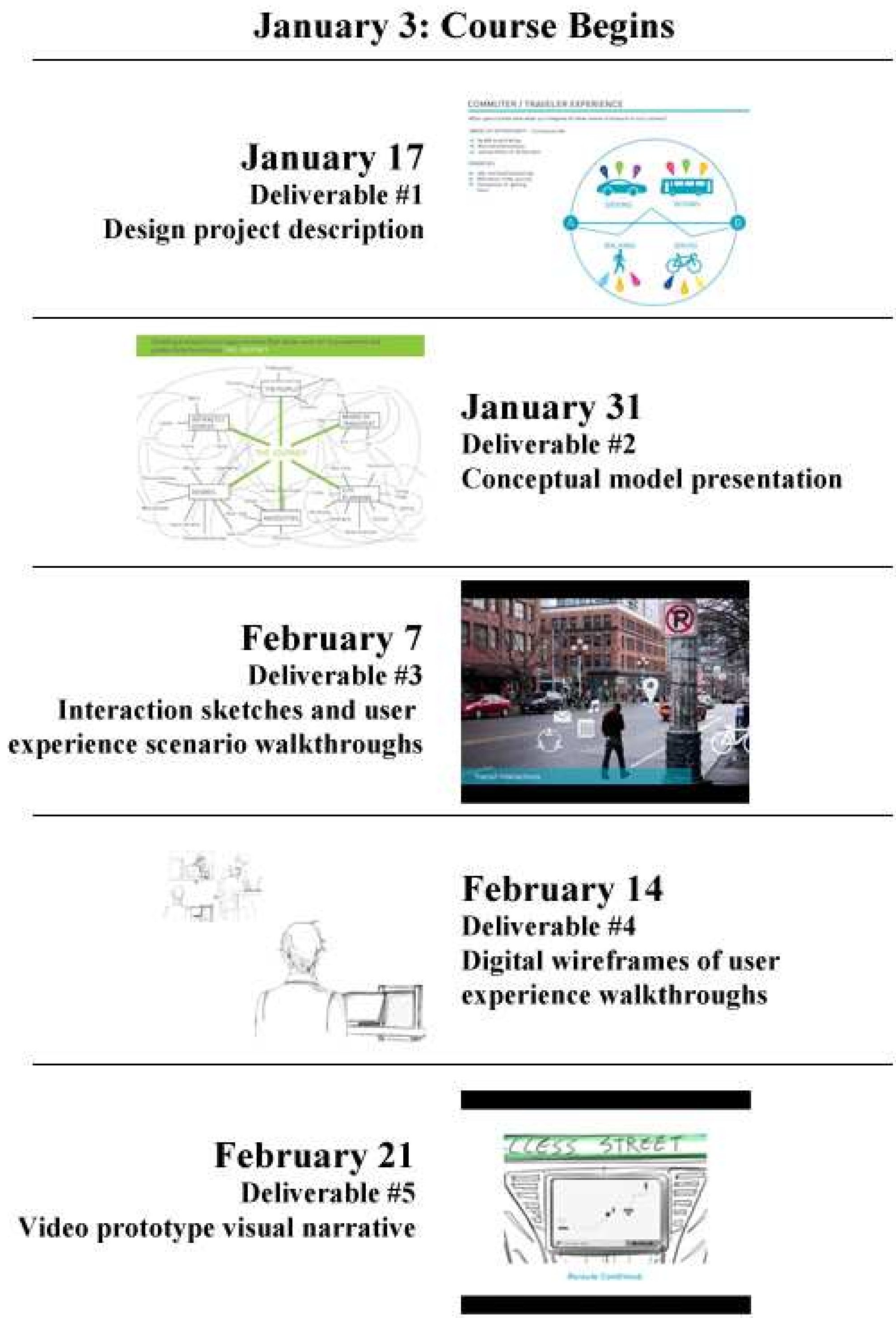

Figure 22. Visual timeline of course deliverables (part 1 of 2)

February 28
Deliverable #6
Video prototype demonstrations

March 8
Deliverable #7
Multimedia presentation of the envisioned design

March 13
(Deliverables #8, #9, & #10)
Deliverable #8
Final video prototype

Deliverable #9
Final multimedia presentation of the design

Deliverable #10
Comprehensive design documentation

March 13: Course Ends

Figure 23. Visual timeline of course deliverables (part 2 of 2)

These visual timelines illustrate the rhythm of the deliverables throughout the quarter, as well as the state of completion of the overall design project at each milestone. The evolution of Team A's design concept is evident in these timelines. For example, the first deliverable that the team members produced shows a car, a bus, a bicycle, and a person walking in order to suggest possible methods of transportation during a specific journey. The thumbnail of the final multimedia presentation (deliverable #9) shows the route that a user of this application might take, as well as the combination of transportation methods that make the journey as fast as possible given local traffic conditions. Additionally, these timelines illustrate the progression from relatively low-fidelity sketches and mind maps during the first few weeks of the academic quarter to high-fidelity visualizations of the final design concept by the end of the quarter.

The rest of this section traces the history of how the members of Team A developed the final deliverable for each of these assignments. Indicative illustrations for each deliverable are presented in each section; examples of the different design and social artifacts that team members made are also presented when possible to provide a clearer understanding of how they produced their deliverables. Team A was the only team among the six teams of students for which a complete set of artifacts was compiled; therefore, Team A is the only team discussed in this section.

Design project description. All of the students in this course conducted their first work sessions with their teams on January 12. The next course session was on January 17; at that session, each team was required to present a single slide or depiction of their preliminary design concept. Team A produced the deliverable shown in Figure 24 (below).

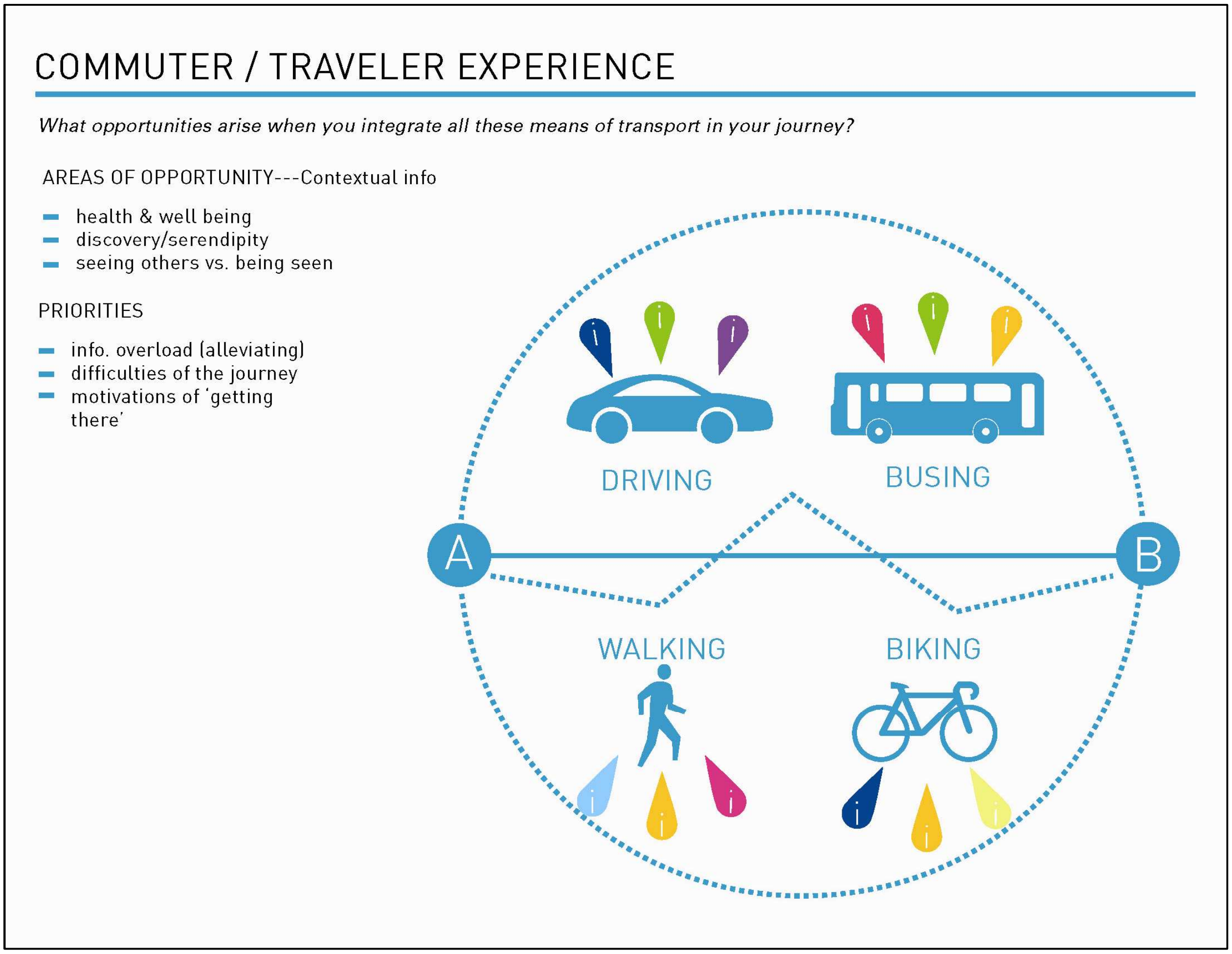

Figure 24. Final design project description deliverable.

The instructor attempted to keep the scope of this deliverable small because of time constraints and because all of the teams would significantly modify their preliminary design concepts. The deliverable shown in Figure 24 indicates the initial path that Team A wanted to take with their design concept. At this point in the quarter, the members of Team A were still deciding what a better travel or commuting experience might be, and whether to focus on helping people get to their destination more rapidly or making the interactions associated with commuting more enjoyable.

The following photo taken during this work session depicts Team A in the act of recording their production of analog design artifacts using digital hardware tools, and reflects what typically happened across all teams at the end of every collaborative work session.

Figure 25. Members of Team A recording their work session results.

In this photo, three of the five members of Team A are taking photos of their whiteboard notes from the day's collaboration session. These photos were digital social artifacts that documented the results of the team's research and ideation task work from that particular work session. Two of the students (Khloe, left and Nancy, middle) used their mobile phones to take photos, while Anne used a DSLR camera that she borrowed from the instructor (she is reviewing the photo she just took). Kylie (not pictured) and Bae did not take any photos.

Field observations and notes from that collaborative work session indicate that members of Team A photographed the notes they took using analog tools because they were concerned those notes would be erased and all of their work for the day would be lost. However, the team members never discussed how they would share the photos they took, or what they planned to do with those photos or the notes they recorded. Additionally, they did not set out to record their collaborative work, but rather they realized that they needed to document their process and the results of that process. Members of Team A later reported in their interviews that they made some of the photos available through a shared Dropbox folder, although it remained unclear how often they referred to these digital social artifacts, or whether they were even helpful to the team's ongoing tasks and activities.

When the members of Team A presented their design project description deliverable at the course session on January 17, the details of how they described their deliverable focused on two possible areas for exploration throughout the quarter. First, they talked about their interest in exploring opportunities around enabling multiple modes of transportation during the same journey. As Figure 24 shows, the team considered what a commuting experience might be like if the commuter could walk, drive a car, and ride a bike in order to get from home to work in the morning. Second, they described their interest in making the commuting experience more exciting. They talked about the "stretch goal" of how to leverage the time that people spend as they engage in "comprehensive journeys" from one place to another.

Team A situated their discussion in the context of using a mobile phone to engage with different possible modes of transit, as well as different ways to use the "wasted" time that people spend commuting every weekday. The feedback they received from the instructor encouraged the members of the team to think more deeply about what people might *want* to do with their extra time if they were to take the bus to work rather than drive their car. Further, the instructor suggested that people have different motivations for using different forms of transit to commute: Driving a car alone might be a chance to feel a sense of independence and control, for example. Over the next two weeks, the members of the team thought about these comments and continued meeting to work on the next assignment: the conceptual model presentation.

Conceptual model presentation. The students had two weeks to complete and submit their conceptual model presentation deliverables for assessment. In that time, the members of Team A refocused their design concept around the journeys that people make every day, particularly as they travel to and from work. Figure 26 (below) shows an analog design artifact that the team sketched during their January 12 work session, and which represents their initial thinking about their design concept.

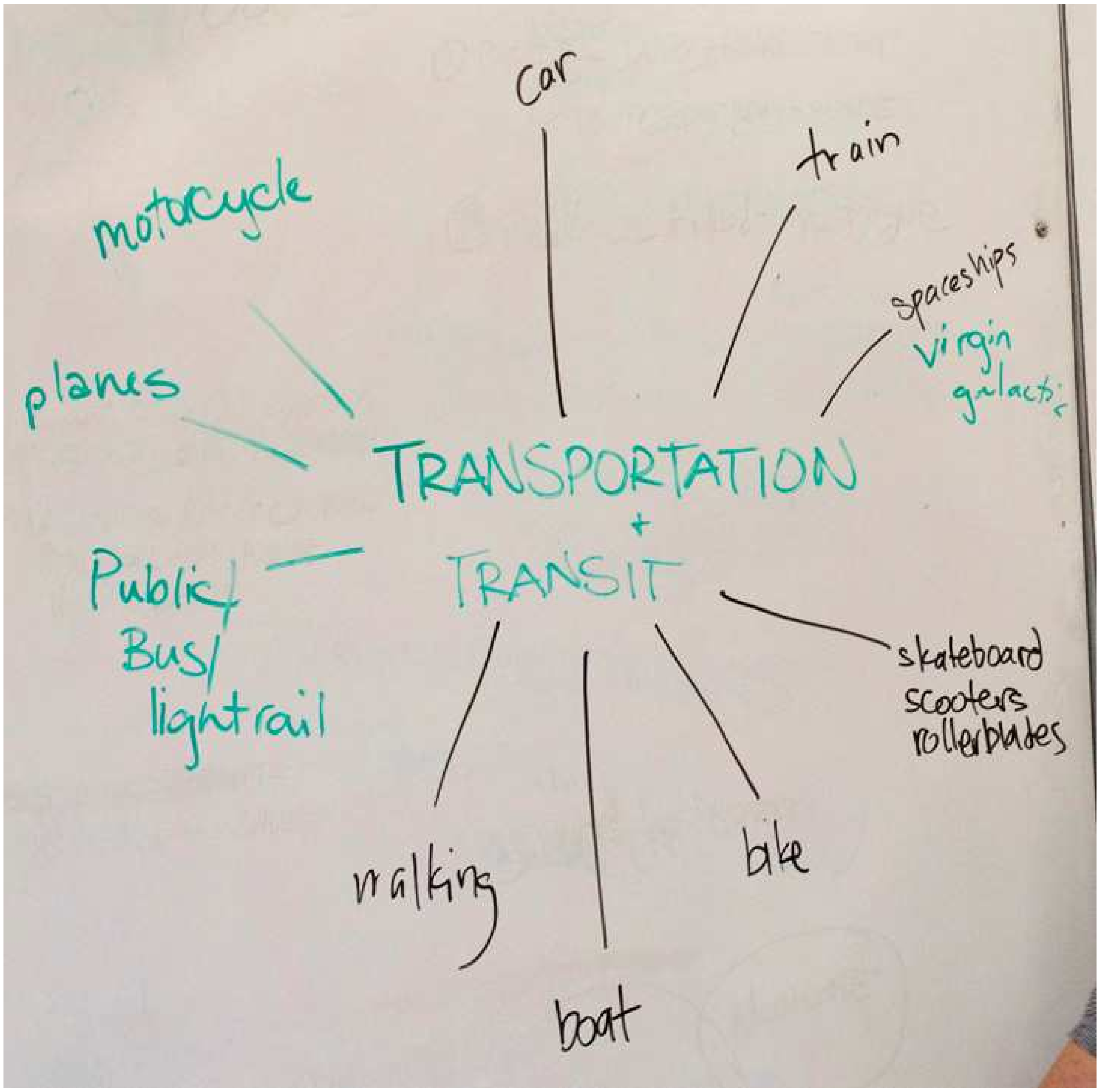

Figure 26. Sketch that informed final conceptual model presentation deliverable.

This analog design artifact served as the basis for the final conceptual model presentation deliverable. The following figure shows the first page of the deliverable they turned in, which closely resembles the sketch pictured above.

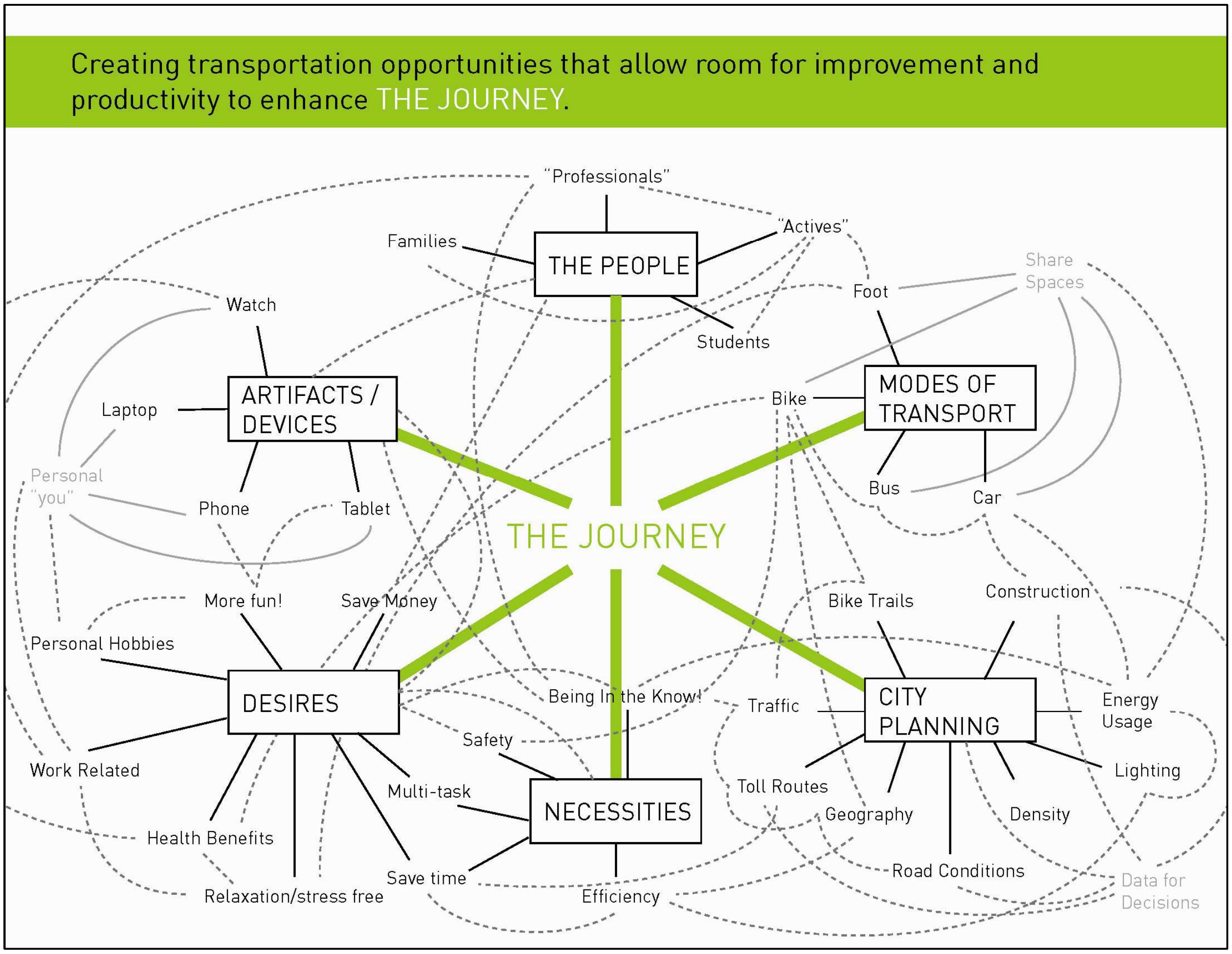

Figure 27. Page 1 of 5 from final conceptual model presentation deliverable.

In the top right corner of Figure 27, there is a box that has the text "MODES OF TRANSPORT" printed inside it. The members of Team A derived that content, along with the organizational structure whereby types of transportation were connected to that text box, from the whiteboard sketch shown in Figure 26. The second and fifth pages of the deliverable are shown in the following two figures; pages three and four are omitted because all of the details from those two pages are included on page five.

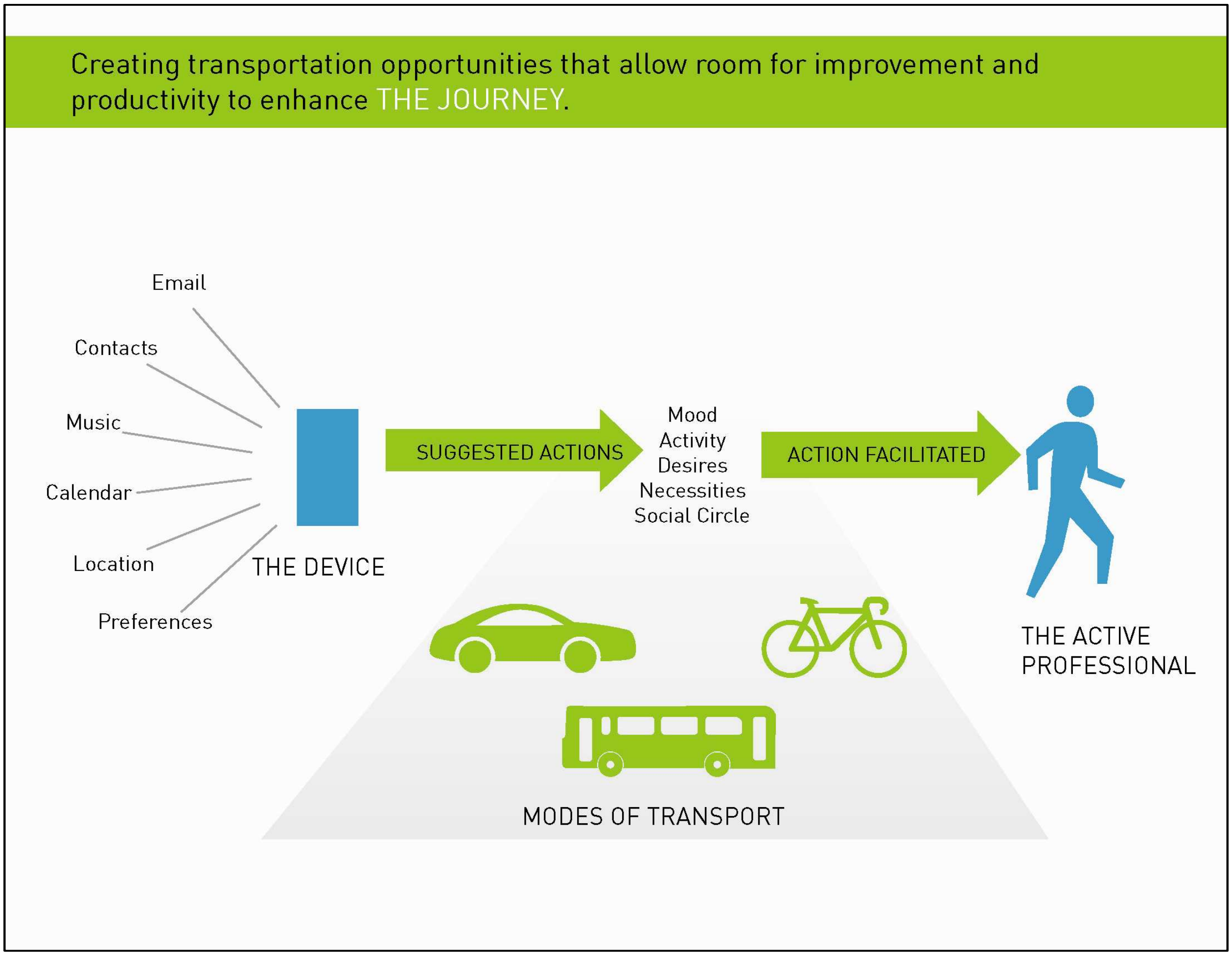

Figure 28. Page 2 of 5 from final conceptual model presentation deliverable.

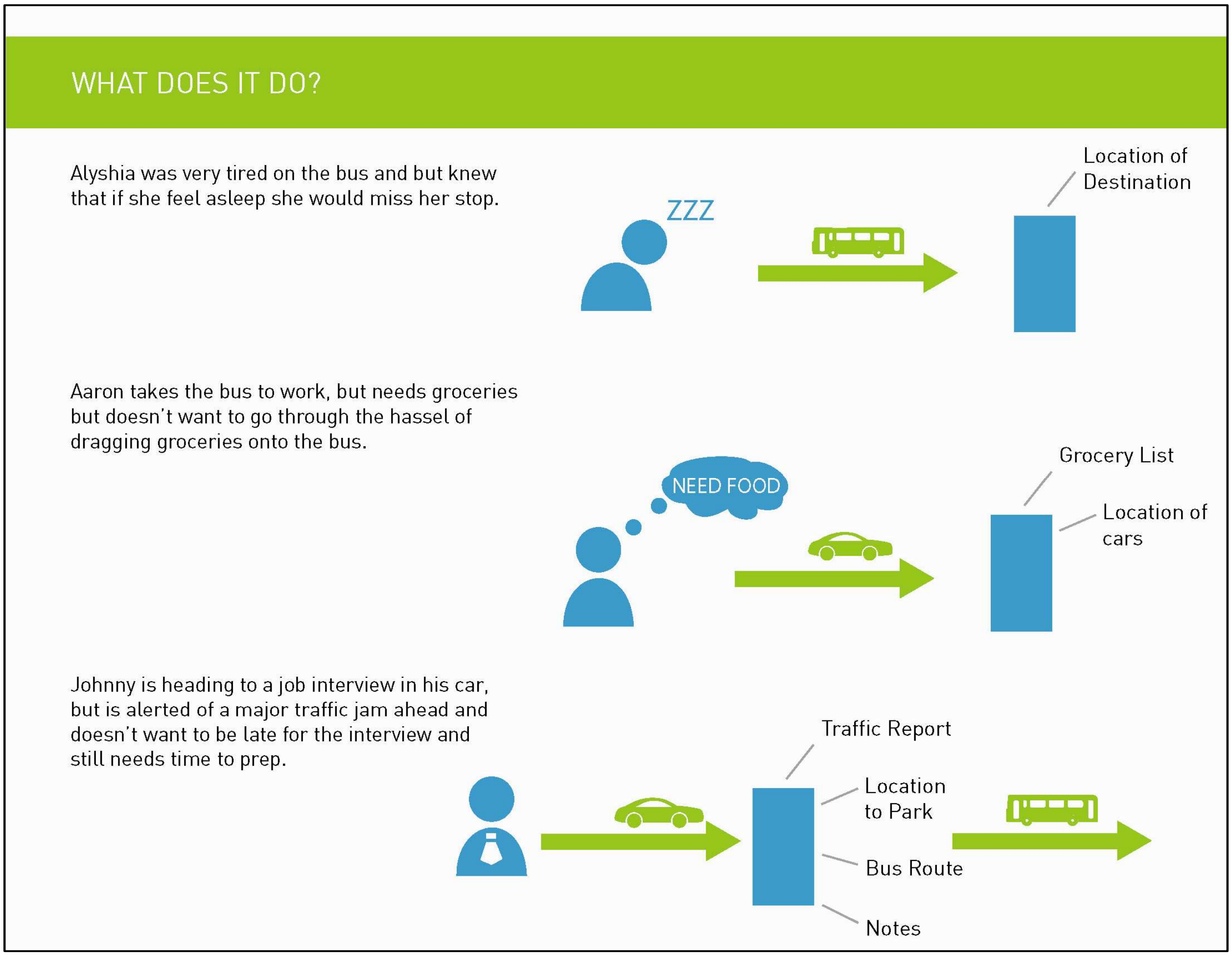

Figure 29. Page 5 of 5 from final conceptual model presentation deliverable.

Team A took their research and ideation work, which they performed across whiteboards, sticky notes, and large pieces of paper, and converted all of the associated analog design artifacts into the digital design artifact shown in these three figures. Figure 27 illustrates just how closely the team members tried to create a digital version of their earlier ideation work; Figure 28 and Figure 29 were also derived from notes that members of the team wrote in their personal notebooks. Unfortunately, those pages were thrown away before any photographs could be taken to capture the contents.

This deliverable resulted from discussions among all of the team members at multiple work sessions, as well as the prototyping work that Anne, Bae, and Khloe performed. Specifically, they produced this deliverable as an Adobe PDF file using primarily Adobe Illustrator, although Khloe preferred to work with this deliverable using Adobe InDesign. However, Anne controlled the source files and preferred to use Illustrator, so the final deliverable was saved as an Illustrator file.

According to Kylie, the instructor saw a draft of the diagram shown in Figure 27 and expressed concern because there appeared to be a lack of information being conveyed through the categories and content that Team A had included. Kylie explained that the team responded to the critique from the instructor by retaining that diagram, but also adding the content shown in Figure 28 and Figure 29 in order to provide more contextual detail about their design concept.

> *We talked about what we would add, what we would take out, what was most important, and all that kind of stuff. And so Anne went back and made another revision and…that one [showed] the device that goes to the actions that goes to the man, and all the transport that filters into that [journey]. (Kylie 081)*

This quote indicates how Team A responded to the instructor's assessment of their progress and attempted to provide more detail about their vision for their project. Specifically, the team focused their attention on delivering transit-related information through a mobile phone application. Figure 28 and Figure 29 suggest how a user of that application might learn about different modes of transit for a specific journey, although the details were still far from fully formed at this point during the academic quarter.

Interaction sketches and user experience scenario walkthroughs. Team A met twice outside of course hours to ensure they completed their next deliverable on time, which was essentially a presentation of possible interactions and user experience scenarios related to their design concept. That deliverable was due at the February 7 course session; the team met on February 2 as part of the regularly-scheduled course hours, as well as February 3 and February 5 to discuss how to complete the deliverable.

According to field observations and notes, the February 2 work session was unproductive and led to no particular progress on this deliverable. On February 3, the team brought ideas they had created independently back for team-wide discussion. At that work session, the team decided to focus on creating personas for the potential users of their mobile phone application. They spent much of the meeting collaboratively discussing the details of two personas and creating an analog design artifact that would later become the centerpiece of their final deliverable for that assignment. The following figure shows part of that analog design artifact, which Anne sketched during the work session as Khloe and Nancy spoke with her about the details she should include.

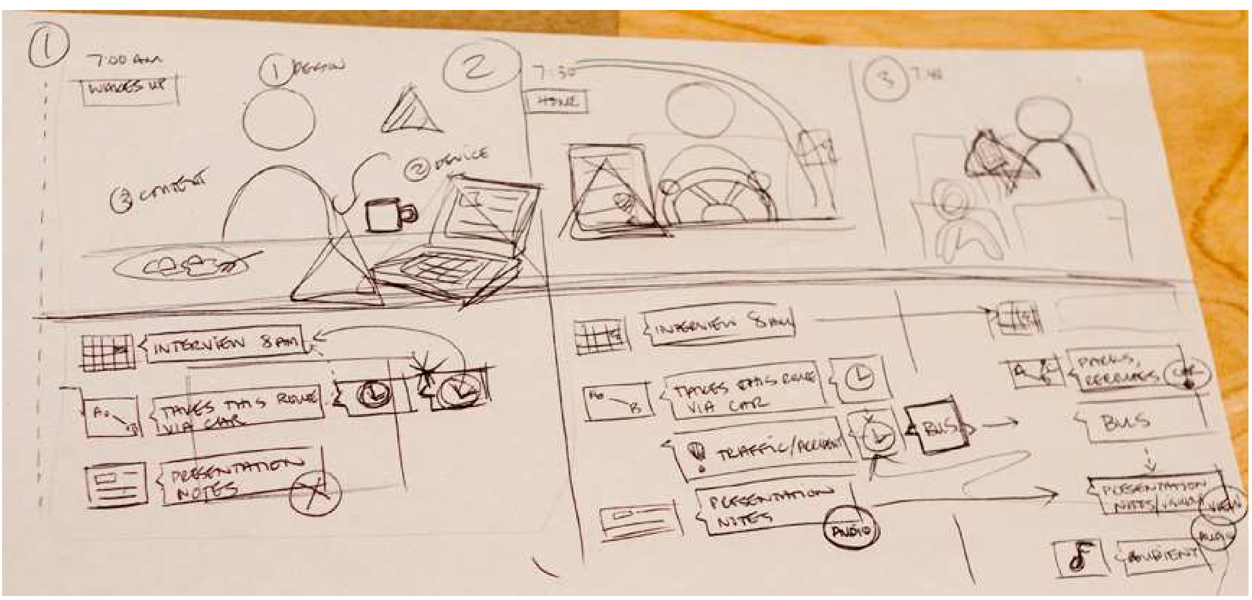

Figure 30. Detail of analog design artifact created during February 3 work session.

This image shows a detail of Anne's sketch of the "Max" user persona. Specifically, this image illustrates a day in the life of Max as he eats breakfast, prepares for a job interview, and begins his journey from home to the interview. Along the way, the mobile application that Team A envisioned warns Max that there is a traffic jam, and suggests that he park his car and take a specific bus instead in order to arrive on time for his job interview.

Anne handed off this analog design artifact to Bae, who created a digital design artifact based around the details included in Anne’s artifact. Bae produced his digital version in time for the team to discuss the details at their next work session on February 5. Figure 31 shows a specific detail from Bae’s digital design artifact as all of the members of Team A reviewed and discussed the content of that artifact.

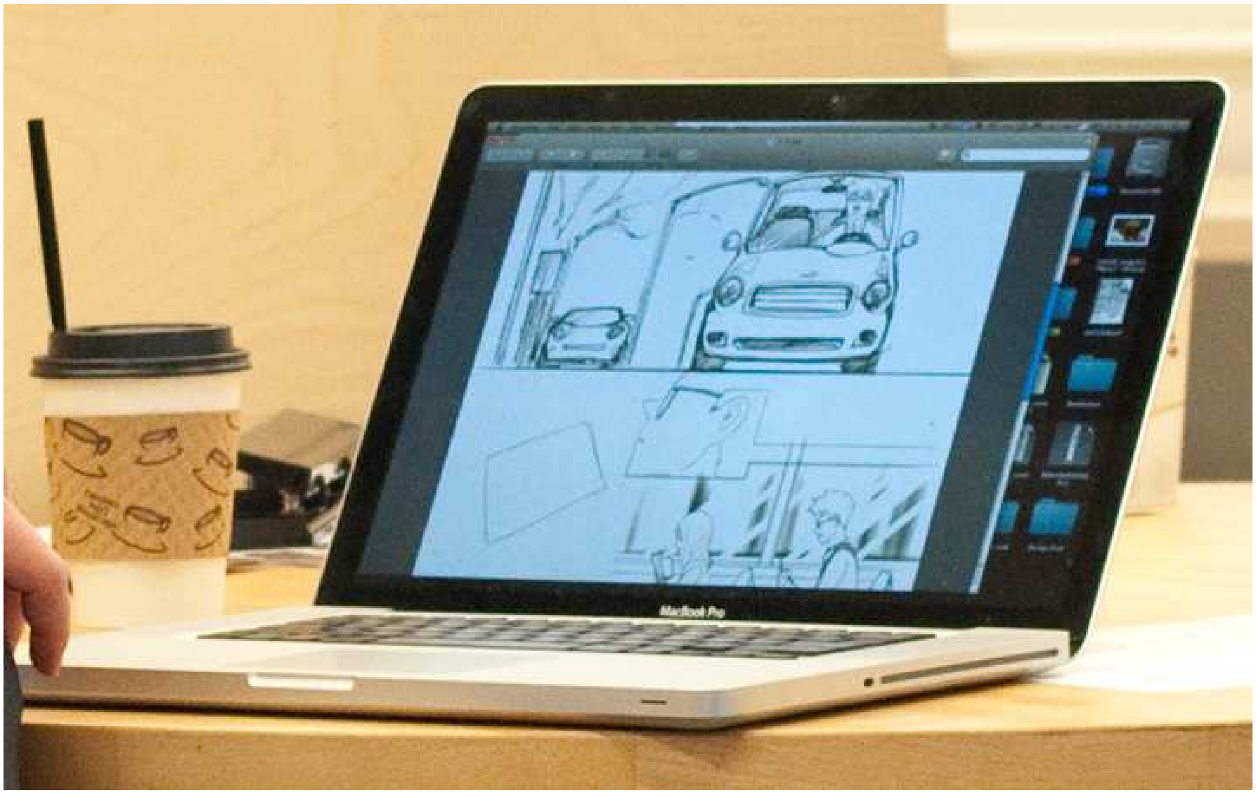

Figure 31. Detail of digital design artifact being discussed during work session.

Note that Anne has Bae's digital design artifact open on her laptop: The team sat around Anne during this work session as they determined what they still needed to do in order to complete their next deliverable.

The meeting concluded with a great deal of concern and confusion among the members of Team A regarding what exactly they were supposed to show at their next course session on February 7. They were also confused about the assignment and distribution of tasks across all of the team members. While it was clear that Bae needed to iterate his sketches and that Anne wanted to create a presentation that would serve as their deliverable, Khloe, Kylie, and Nancy all wondered aloud what they should do during the two days between that work session and the next course session. Ultimately, Anne and Bae completed nearly all of the tasks on this deliverable after that February 5 work session, partly because Anne continued using the source files from the prior deliverable to create the presentation for this deliverable, while Bae was regarded by his teammates as the best sketch artist among all five of them. Therefore, he was assigned the task of visualizing the user persona and use case that served as the basis for the user experience scenario walkthrough of their design concept.

The following figures show six of the 12 slides that Team A included in their final deliverable. The omitted pages show additional details about "Max" and how his use case with the team's mobile application played out.

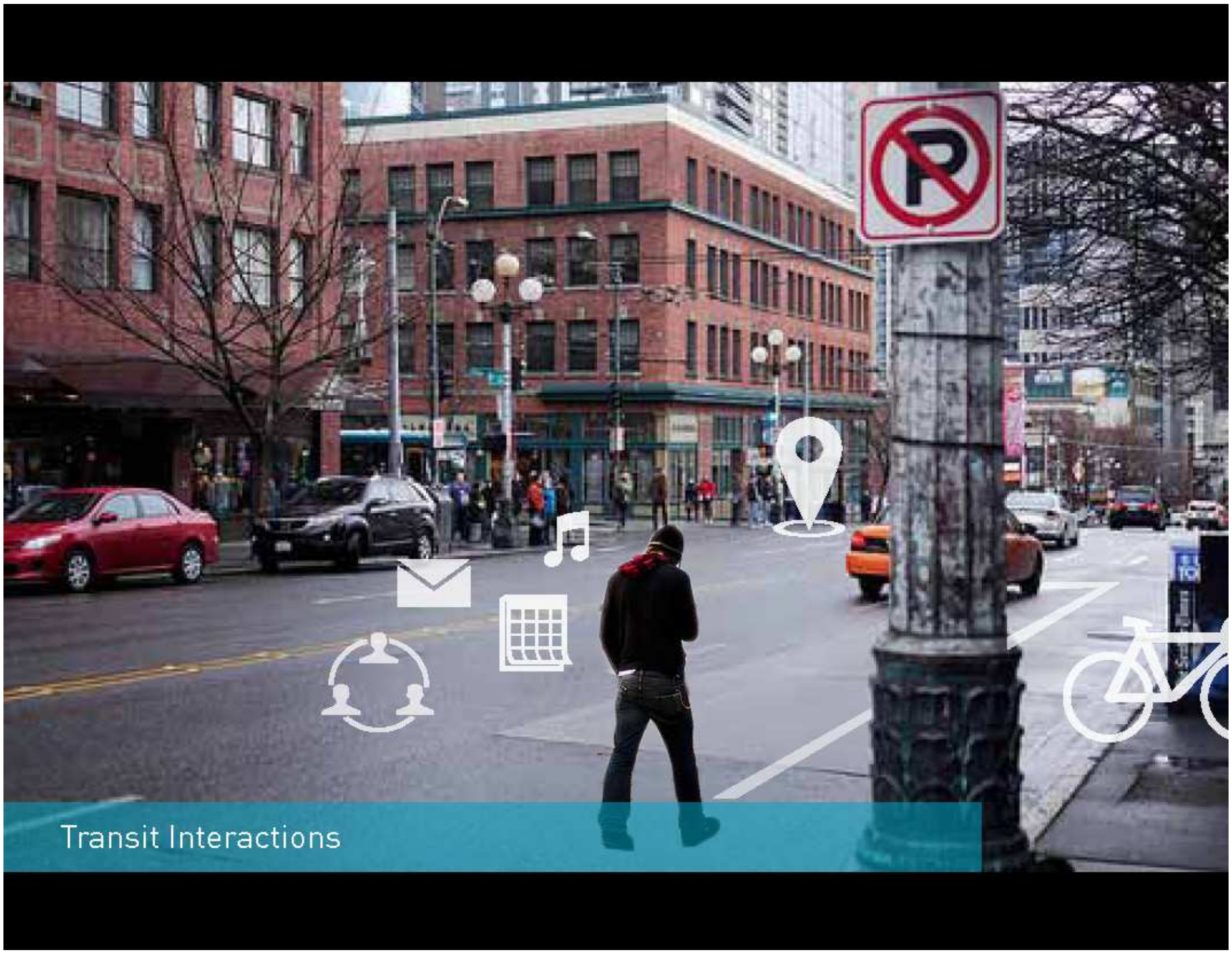

Figure 32. Page 1 of 12 from interaction sketches deliverable.

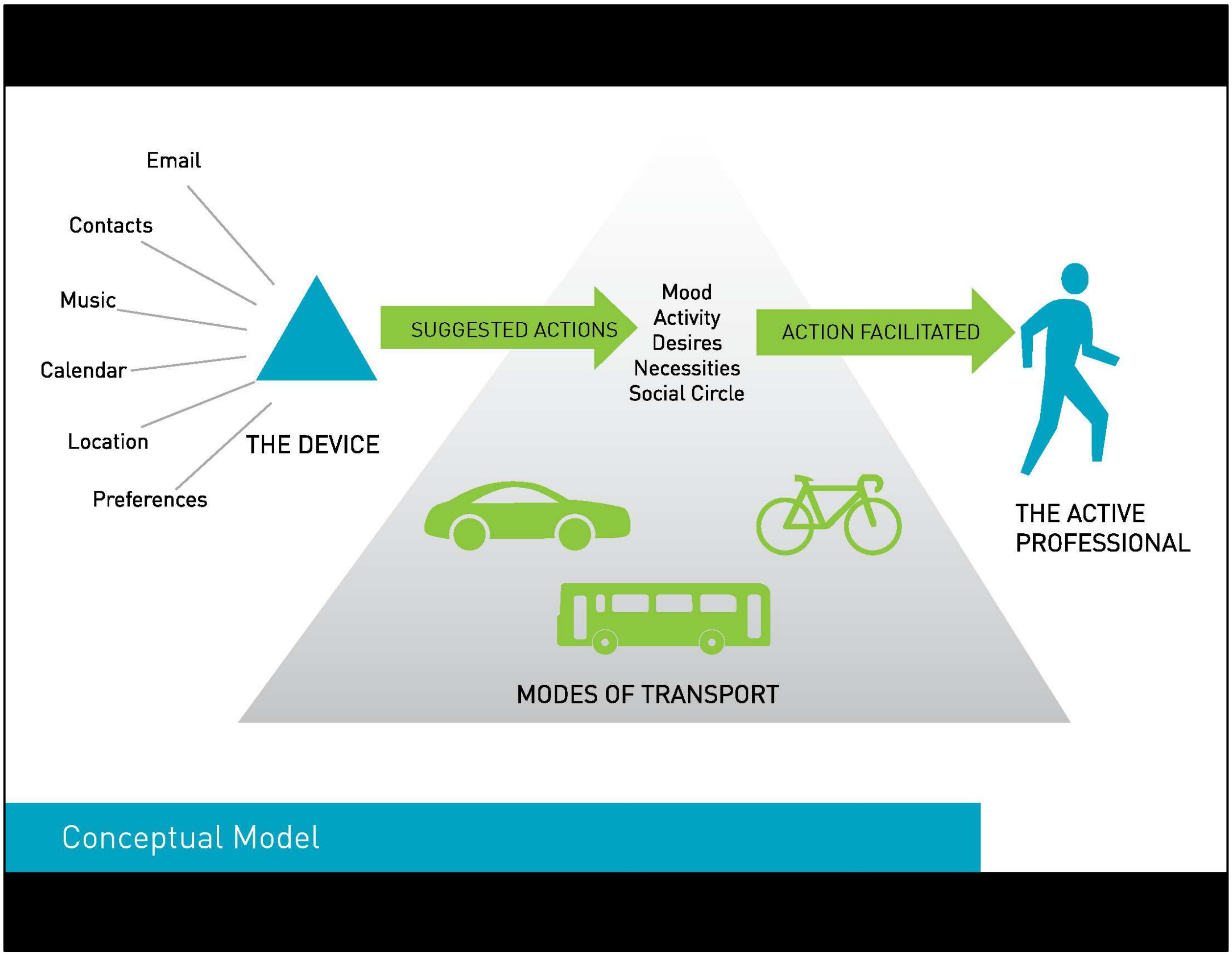

Figure 33. Page 2 of 12 from interaction sketches deliverable.

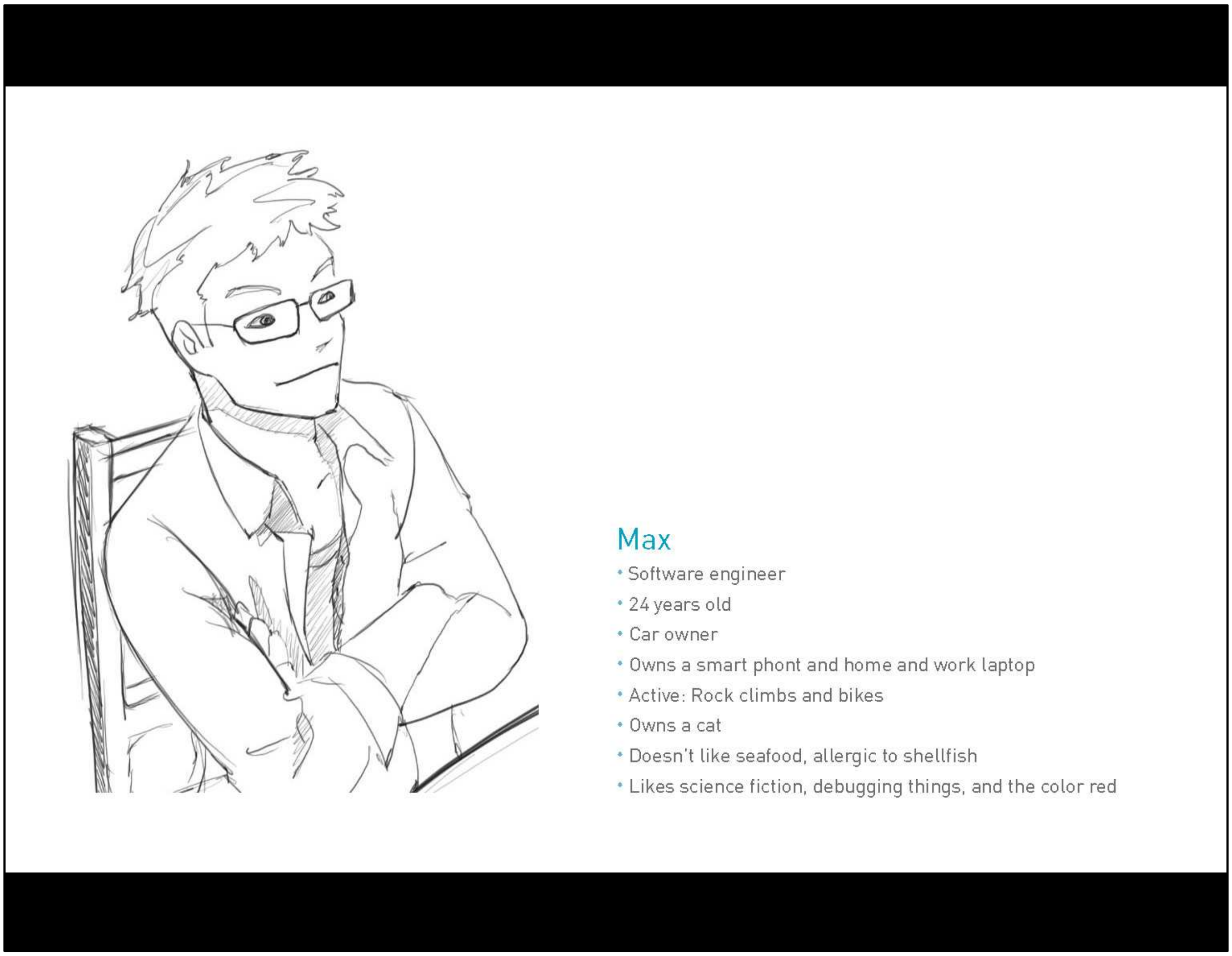

Figure 34. Page 3 of 12 from interaction sketches deliverable.

Figure 35. Page 4 of 12 from interaction sketches deliverable.

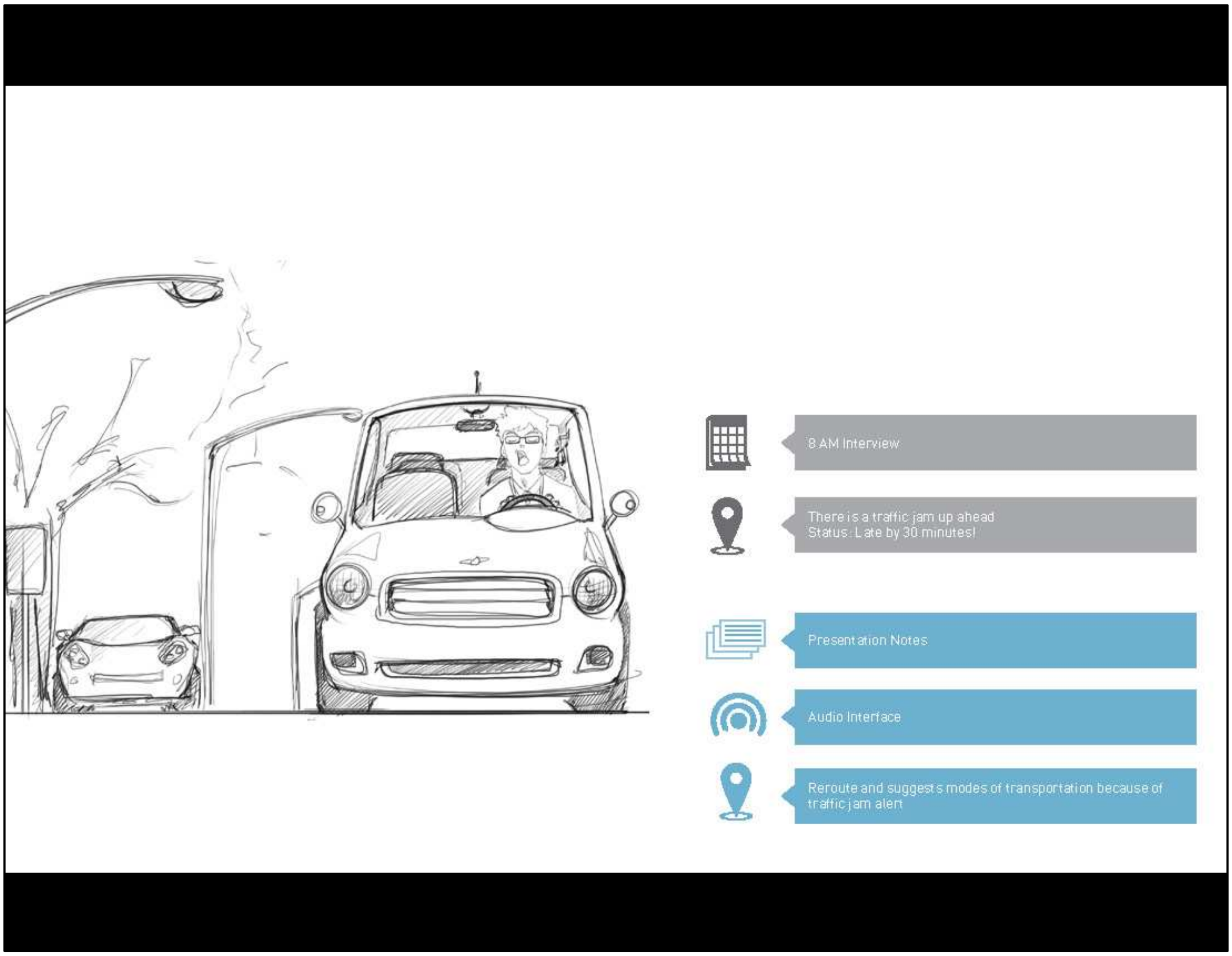

Figure 36. Page 5 of 12 from interaction sketches deliverable.

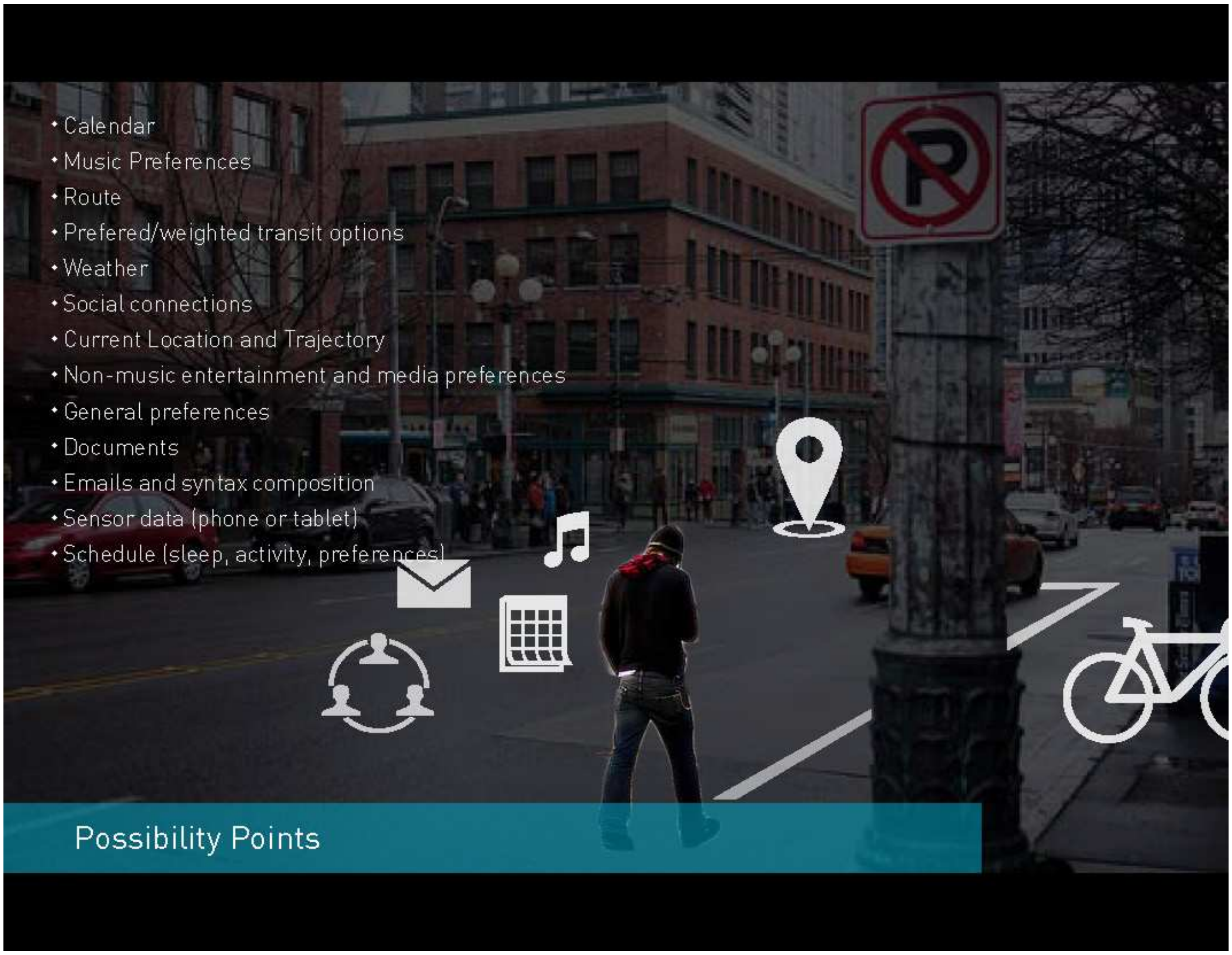

Figure 37. Page 12 of 12 from interaction sketches deliverable.

Figure 32 and Figure 37 serve as bookends for this deliverable and have a distinctly different visual style than the rest of the pages included in the Adobe PDF file that the team produced. Figure 31 shows a detail from the conceptual model that the team created as their prior deliverable (shown in Figure 28). All of the other pages in this deliverable combine the digital design artifact that Bae made with application-specific notifications and details, which Anne made using Adobe Illustrator. She imported the sketches that Bae made into her Illustrator source file and saved the final version as a PDF file so that the instructor and other students could view the deliverable without having to use Illustrator.

When they presented this deliverable to their instructor and the other students, the members of Team A said that they had refined the focus of their design concept. In particular, the user experience walkthrough focused on facilitating “seamless travel,” and on reducing the stress of the traveler as he or she went about their day. The instructor provided them with generally positive feedback, but warned them about creating a mobile application that was like a Swiss army knife, in that it appeared to do everything for everyone. The team was tasked with honing their design concept further into a more manageable project for the academic quarter.

Digital wireframes of user experience walkthroughs. For their next deliverable, the team extended their design ideas further and developed a more detailed version of the use case for “Max.” The team met again on February 9 during the next regularly-scheduled course session. They spent three hours discussing how to modify their prior deliverable in time for the February 14 course session, when each team was required to discuss updated, more detailed versions of their user experience walkthroughs with the instructor.

During their work session on February 9, the team struggled to reign in all of the possible directions that their design concept and mobile application could take. As they attempted to narrow the scope of their project, the members of Team A realized that each of them had a slightly different vision for their final product. Halfway through the meeting, the team explicitly appealed to Anne for her thoughts on the direction of their project. She began creating an analog design artifact to help her focus her thoughts. The instructor then spent about 40 minutes with everyone on the team to assist them as they worked through their concerns about the excessive scope of their design concept. Ultimately, the work session concluded with Anne outlining a concise set of next steps for everyone on the team; everyone agreed to abide by those next steps.

Bae ultimately shouldered the bulk of the task work between February 9 and the next course session because he had already made a digital design artifact that represented the team's user experience walkthrough. The following five figures show all of the sketches that Bae produced for the user experience walkthrough deliverable, which the team showed to the instructor on February 14 so they could receive feedback about the state of their design concept.

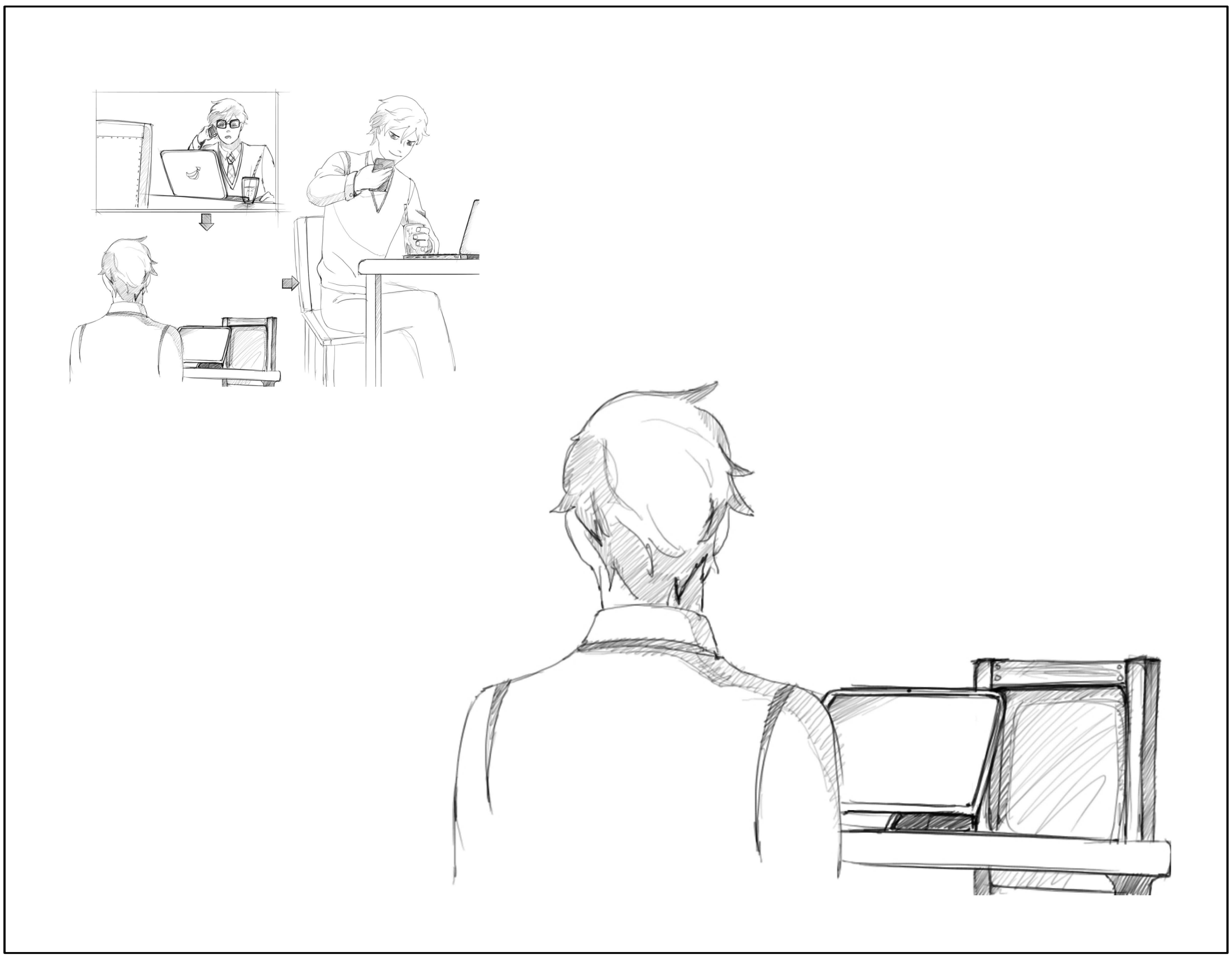

Figure 38. Page 1 of 5 from user experience walkthrough deliverable.

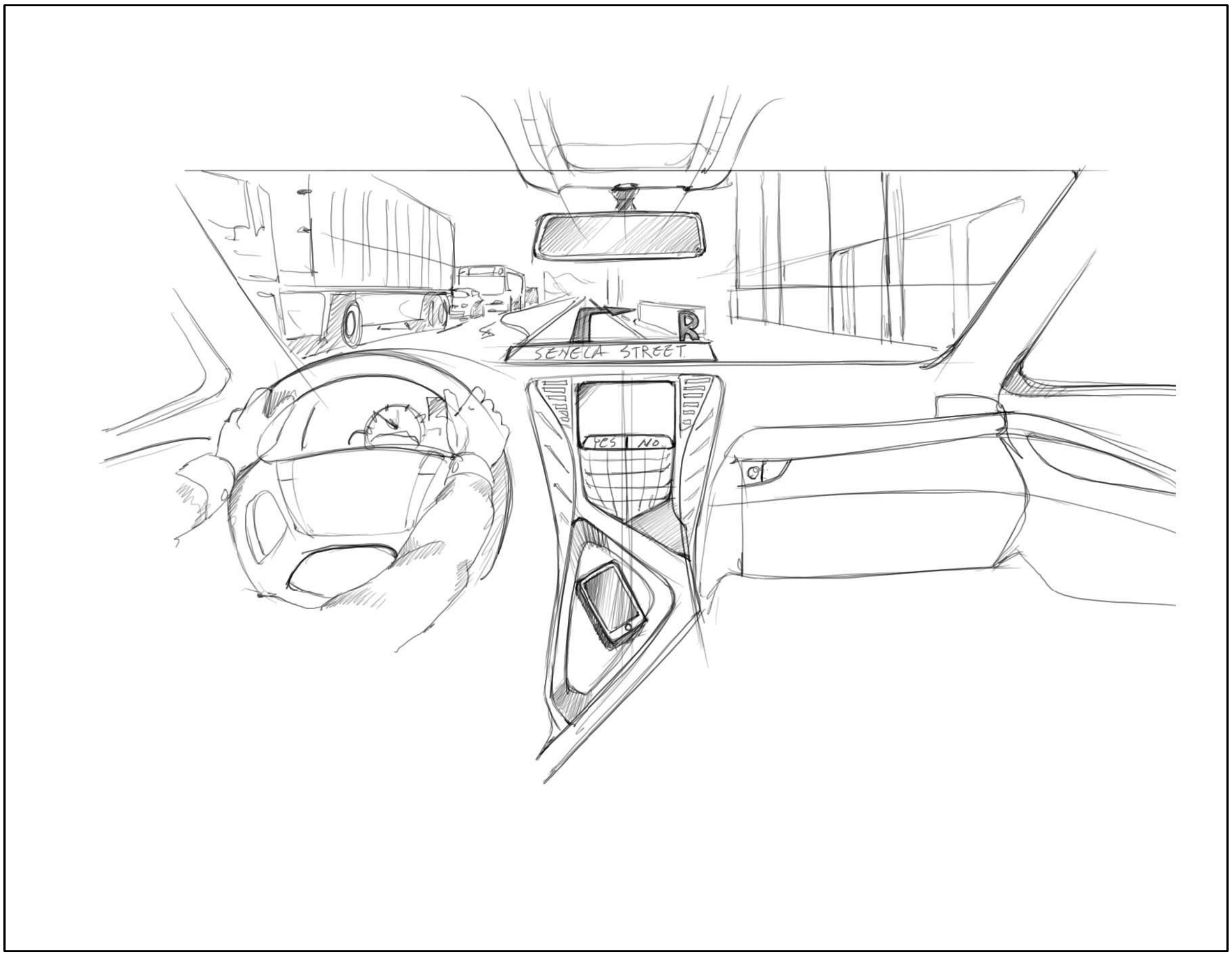

Figure 39. Page 2 of 5 from user experience walkthrough deliverable.

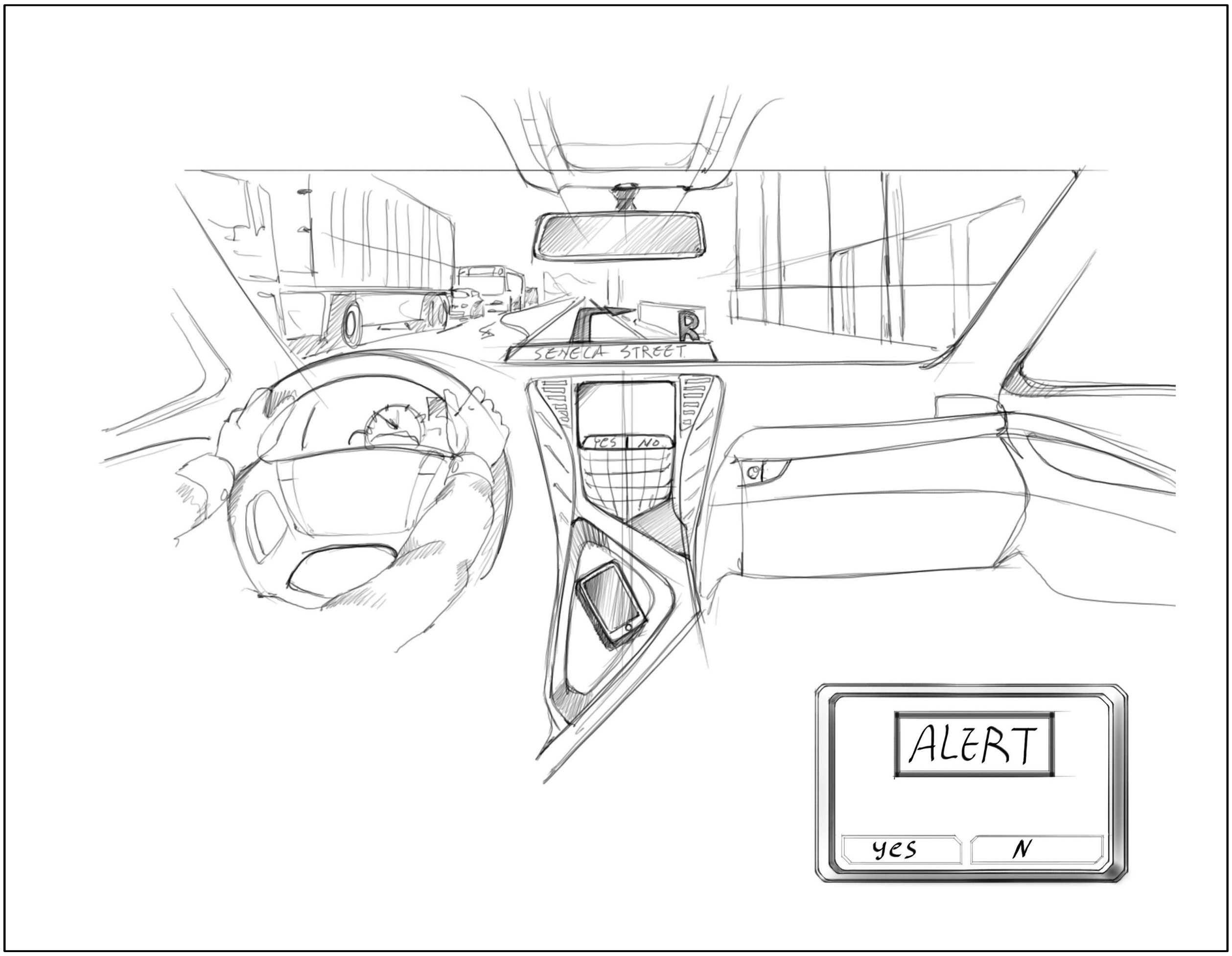

Figure 40. Page 3 of 5 from user experience walkthrough deliverable.

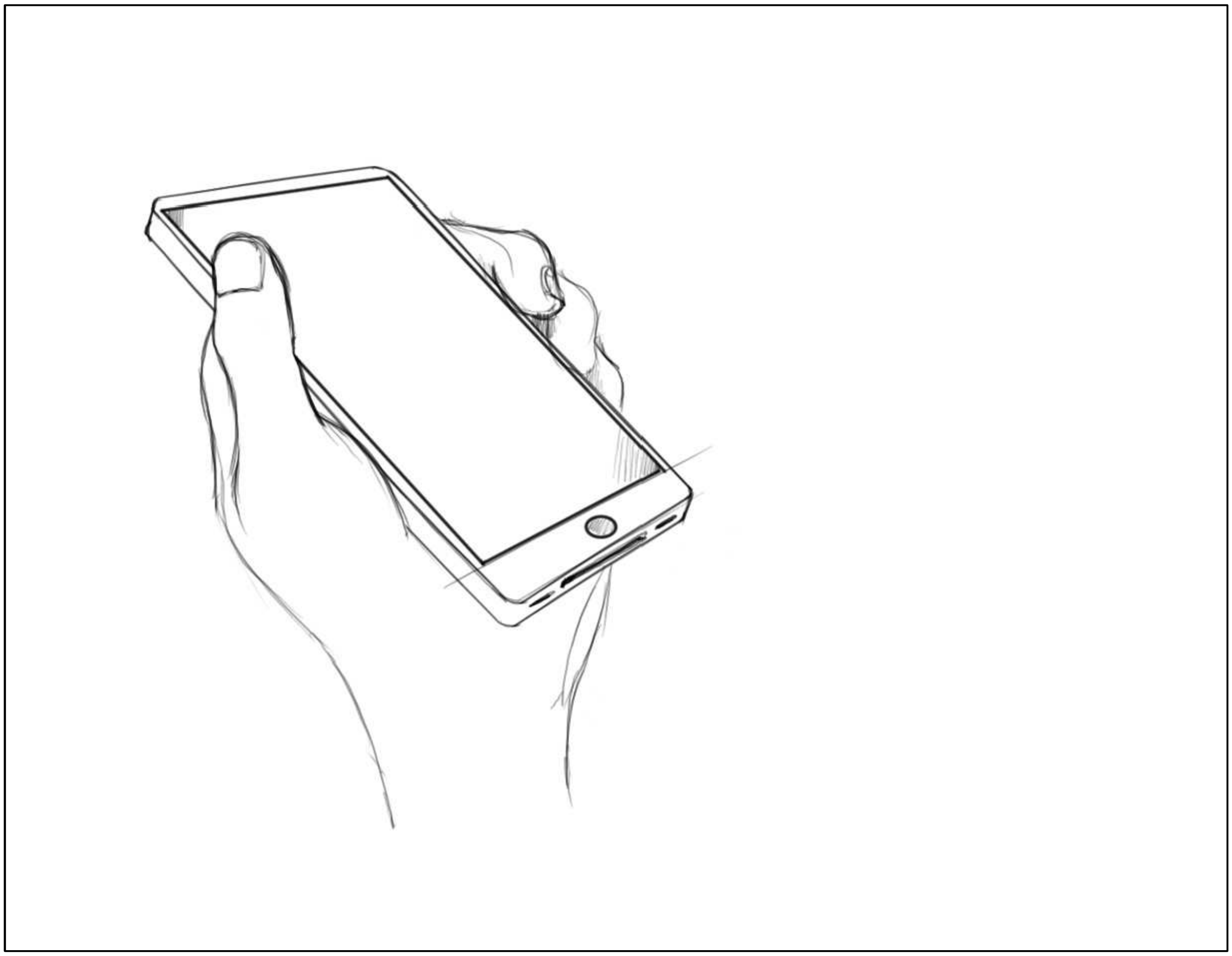

Figure 41. Page 4 of 5 from user experience walkthrough deliverable.

Figure 42. Page 5 of 5 from user experience walkthrough deliverable.

These five figures indicate how Bae tried to shift the visual details of the user experience walkthrough to show how the mobile application would be used in the context of a person's everyday life. The limited discussion with the instructor around this deliverable encouraged Team A to move forward with development of their mobile application interface. At the same time, the team members worked in parallel on the ways in which their application would integrate with data sources that users would already have and that could be mined for personal information. For example, the team decided to try and leverage users' calendar entries so that the application would know where they were supposed to be at different times throughout each day. After February 14, Bae continued to focus his attention on creating use case sketches as needed, while Anne managed the process of creating the mobile application interface as well as the descriptive vision for how to connect the mobile application to users' lives through their data.

Video prototype visual narrative. The instructor asked the students to produce a visual narrative that described how they thought their video prototypes would eventually look. This deliverable was due on February 21, and was an important milestone because all of the teams were required to present draft versions of their video prototypes during the February 28 course session.

The deliverable that Team A produced for this assignment contained a morass of ideas that reflected the diversity of opinions among the team members about their overall design concept. Rather than showing each of the 22 different pages from the Adobe PDF file that Team A submitted as their deliverable, this section includes three figures that represent the massive scope of their design concept at this point in the academic quarter.

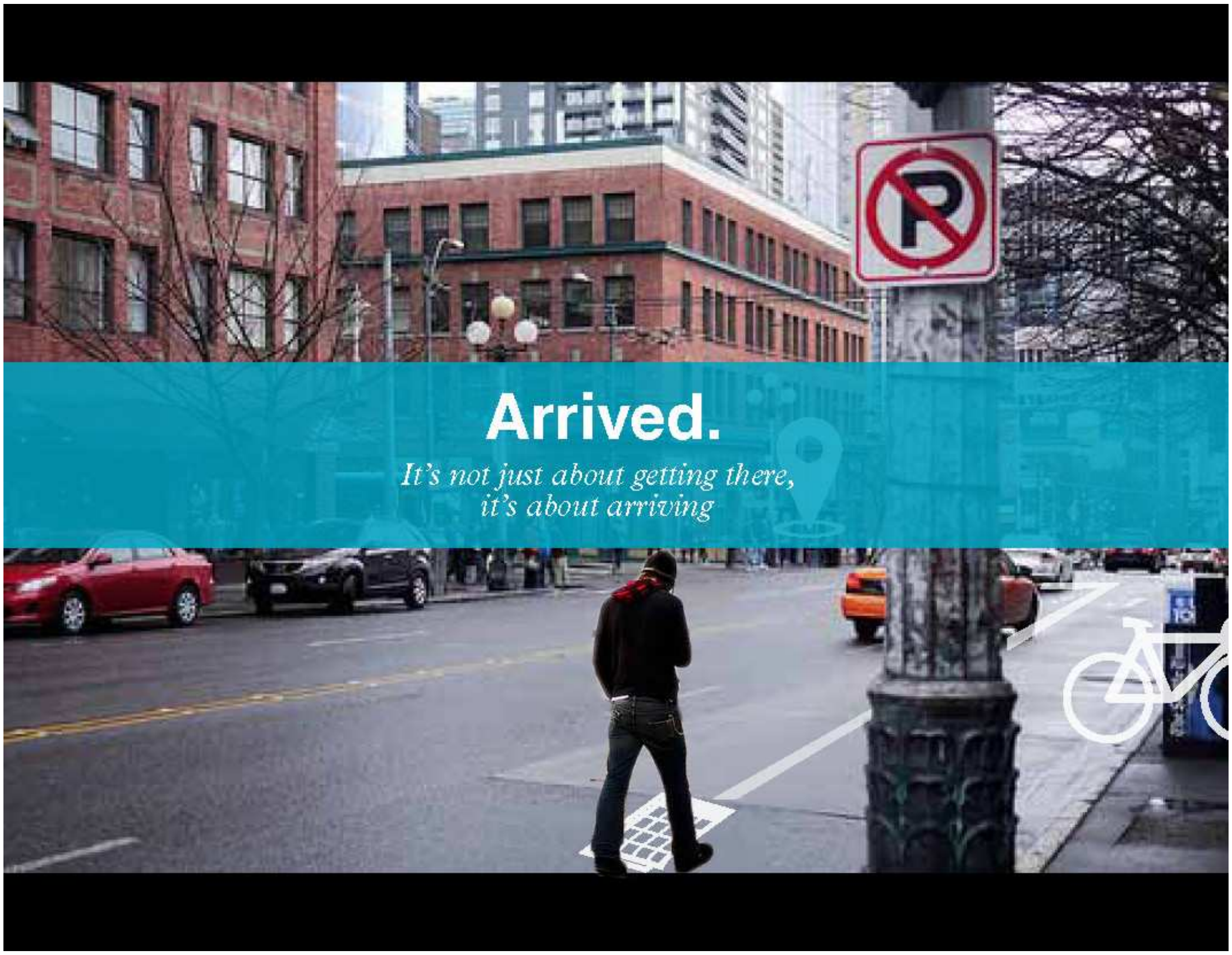

Figure 43. Page 1 of 22 from video prototype visual narrative deliverable.

This first page from Team A's deliverable looks similar to the first page of their interaction sketches deliverable, which they submitted for assessment two weeks earlier. Again, because Anne continued using the same set of Adobe Illustrator source files as she produced each deliverable for her team, she essentially kept iterating the same digital design artifact. However, the revisions she made among deliverables were significant. The next six pages of this deliverable contained overview statements about the problem that the team's design was intended to address. At this point in the academic quarter, Team A was promoting a design concept that centered around bringing all of the different ways in which people travel around "under one umbrella," which was their mobile application that they had named "Arrived."

The seventh page from the video prototype visual narrative deliverable (shown in Figure 44) indicates the scope of their design concept.

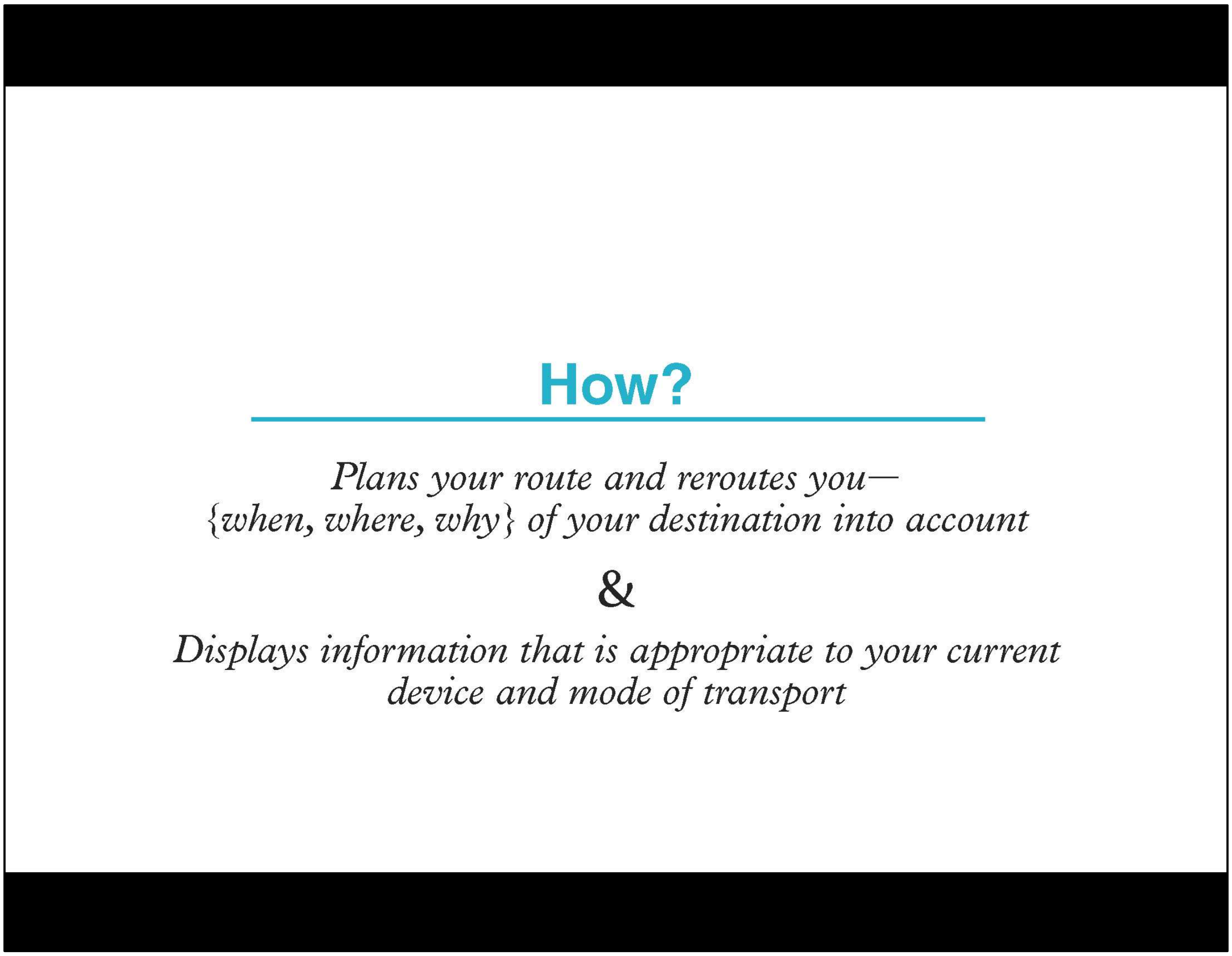

Figure 44. Page 7 of 22 from video prototype visual narrative deliverable.

As this figure indicates, Team A intended their "Arrived" application to plan routes for users, reroute users when needed to other forms of available transportation, and provide timely notifications across multiple systems and devices when necessary. The twelfth page of the deliverable shows just how complicated the team's design concept had become as they attempted to extend their application into users' calendars and across devices (e.g., laptop computer, in-car GPS, and smartphone).

Figure 45. Page 12 of 22 from video prototype visual narrative deliverable.

This page of the video prototype visual narrative deliverable exemplifies the significant confusion among the members of Team A regarding what their application was supposed to do. Pages 8 through 21 of this deliverable were digital versions of an analog design artifact that

Anne had produced as a description of her vision for the team's design concept. This artifact was essentially the single tangible thing around which everyone on Team A was basing their work.

The following figure shows a detail from that analog design artifact, which the team discussed at their February 16 work session held during the course hours.

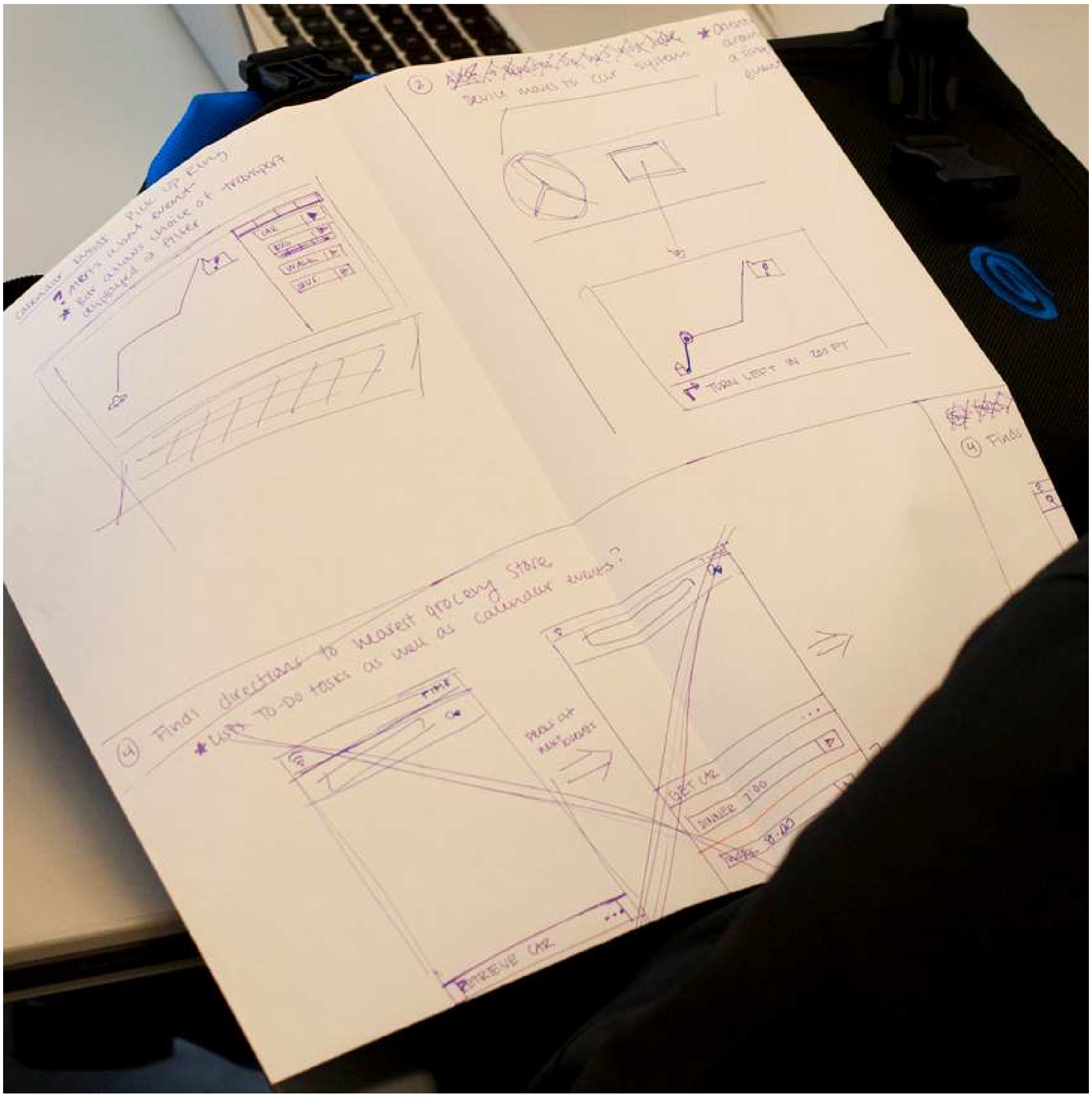

Figure 46. Detail of analog design artifact discussed during February 16 work session.

In the top left corner of this figure, the basis for page 12 of the final deliverable is visible (refer to Figure 45). Additionally, in the bottom right of this figure, there is a large “X” drawn through step 4 of the team’s use case for their application. Field notes indicate that the team had redone that part of their use case; the new step 4 is not visible in the figure above.

By the time the team met on February 16, they had also begun recording video footage for their next deliverable: the video prototype demonstration. Anne showed the rest of the team some of the footage she had created for that next deliverable. She was in the process of making two different videos. The first was a 30-second animated visualization of the “Arrived” application. She had not yet recorded any footage for the second video, which was going to be a live-action movie that represented their use case, whereby real people would interact with a mockup of their application as they played out the different scenarios described in their video prototype visual narrative deliverable.

During their February 16 work session, the team divided their attention between two primary tasks: creating the storyboard for the video prototype, and sketching ideas for the user interface that they would develop for their mobile application. Anne, Bae, and Khloe spent about 60 minutes during that work session sitting around a large piece of paper on which Anne had written the word “Brainstorm” in big letters. They spent that time discussing ideas for the application interface and looking at digital design artifacts that Khloe had already made for that purpose. At the same time, Kylie and Nancy were creating a new version of the analog design artifact pictured in Figure 46. After an hour had passed, everyone on the team congregated around the same table and discussed all of the progress they had made on the two different tasks.

Finally, by the end of the work session, Anne and Nancy decided that the team should split into two smaller teams so they could get more work done. Kylie and Nancy were tasked with developing the team's user interface design concept, while Anne, Bae, and Khloe worked on completing the storyboard for their video prototype. The team continued to complete their task work using this agreed-upon distribution of labor until they presented their next deliverable during the February 21 course session.

Video prototype demonstrations. All six teams were required to show their progress with their video prototype deliverables on February 21. In all cases, these video prototype demonstrations were incomplete in multiple ways. For example, the following figure shows a still image from the video prototype demonstration deliverable that Team A created and displayed during the February 21 course session.

Figure 47. Still image from video prototype demonstration video.

As this image makes clear, the user interface for the “Arrived” application was not completed yet by the time Team A had to present their video prototype demonstration deliverable. The laptop screen was made to look blank so that the interface elements could be added later in the quarter. All of the teams’ deliverables had similar blank elements during the videos, within which they were planning to insert mockups of their interfaces once those digital design artifacts were ready to insert. The instructor understood that this aspect of the teams’ videos would not be ready for the February 21 course session.

However, all of the teams’ deliverables were incomplete in another way: None of the videos told a coherent message about a specific design concept. All six teams had a great deal of work left to do at this stage of the academic quarter; the mood among the students was solemn by the end of that course session. The next deliverable was due just over two weeks later on March 8, when each team had to show new versions of their video prototypes. Without exception, all of the students across all of the teams worked their hardest between February 21 and March 8 because their design concepts required significant revision and refinement.

Multimedia presentation of the envisioned design. On March 8, all six teams presented the updated versions of their video prototypes. They were also required to deliver multimedia presentations that helped tell the story of their design concepts; the video prototypes were only a part of this deliverable. All of the students were stressed out as they pushed to complete their multimedia presentations in time for the March 8 course session.

Between February 21 and March 8, Team A iterated their user interface design and recorded video footage for their video prototype. Anne also worked on the multimedia presentation, which was again based on prior work she had completed for previous deliverables, particularly the video prototype visual narrative deliverable. The following two figures show Team A’s progress when they delivered their multimedia presentation on March 8; note that they again made an Adobe PDF file, the contents of which were incomplete when they gave their presentation.

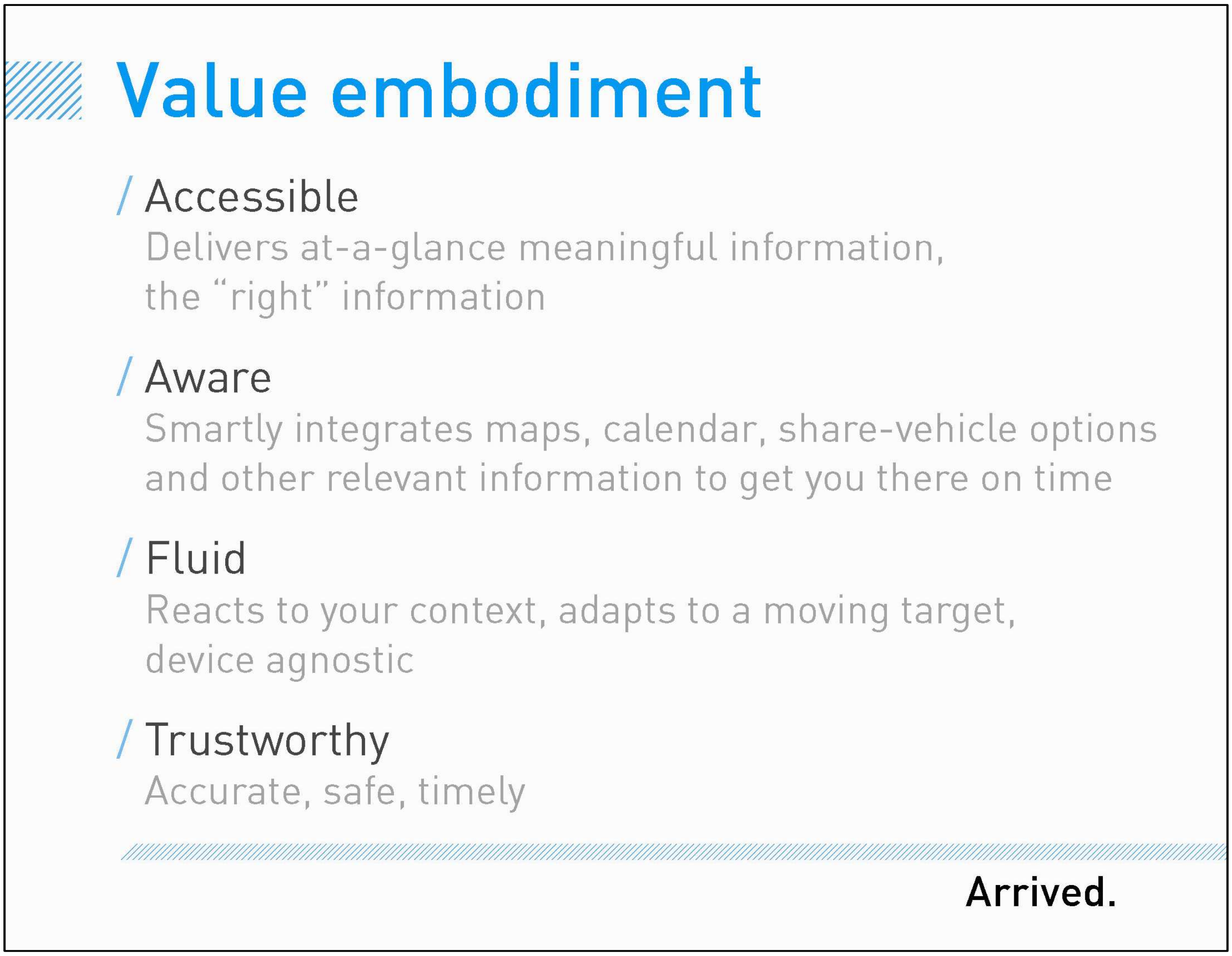

Figure 48. Page 4 of 11 from multimedia presentation deliverable.

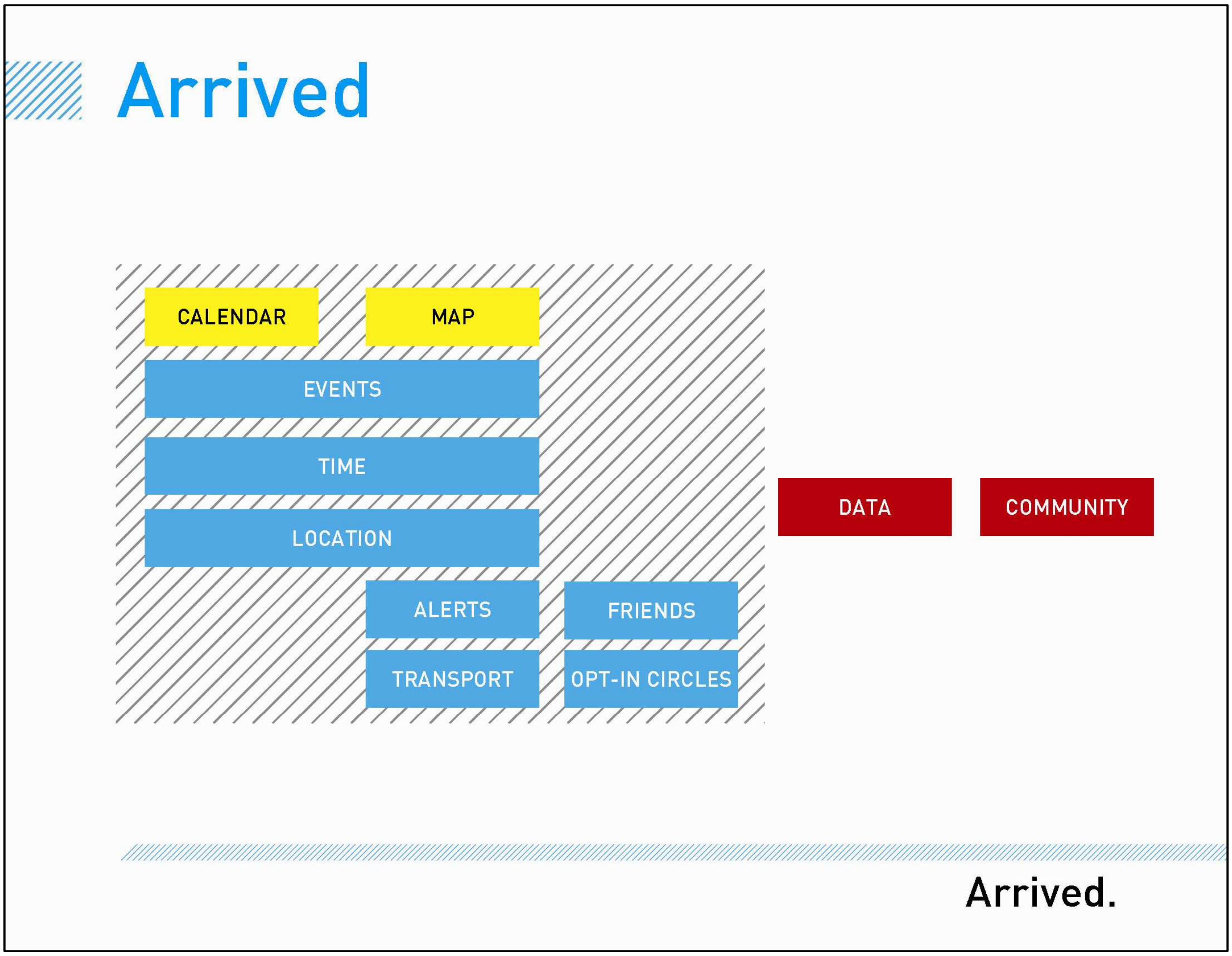

Figure 49. Page 10 of 11 from multimedia presentation deliverable.

These two figures show the most salient pages from this deliverable; pages 1, 2, and 3 restate content previously included in prior deliverables regarding the problem and solution statements related to the team's design concept. Pages 5 through 9 are almost entirely incomplete and devoid of detail. Figure 48 illustrates how Team A decided to focus the value proposition for their design concept around four specific terms: "accessible," "aware," "fluid," and "trustworthy." Further, Figure 49 indicates how the members of Team A were still struggling to hone their design concept into something manageable and specific. That page from their deliverable represents a high-level, system-wide view of the “Arrived” application, but as with the team’s previous deliverables there are still a number of different sources of data, different possible outputs that users could interact with, and no clear connection between the data, the interactions, and the interface for the application itself.

Team A clearly struggled with the issue of deciding how to effectively scope their design concepts so that they could complete their work on time and in a way that was satisfactory to everyone within the team. This challenge was not unique to the members of Team A; Logan from Team B intimated during an informal interview on March 13 that splitting up the work and doing it in parallel led to some significant issues with regard to completing the project. This comment from Logan aligns with the field notes and observations made of Team A as well: Even though Anne attempted to control which tasks each person on her team would complete, there appeared to be a lack of consensus around the actual design concept. Again, field observations indicated that after Team A made the decision to divide the labor across the five team members such that three members worked on the video prototype while the other two worked separately on interface design, everyone on this team did not spend enough time attempting to mesh the outcomes of their tasks in a systematic way.

One of the most visible results of this lack of alignment around the team’s tasks was that the user interface mockups were not ready in time to be included in the video prototype presentation on March 8. Team A showed a video that still included blank spots on each device where they would later insert mockups of the different interfaces they were still developing for their “Arrived” application. In particular, they needed to develop different versions of the same interface to show how users would work with their application on a laptop and on a mobile phone. Eventually, Bae was able to complete those mockups using Adobe After Effects, and he handed off the completed digital design artifacts to Anne so she could incorporate them into the Apple Final Cut Pro source files from which she created the final video prototype.

Final video prototype and final multimedia presentation. At the last course session on March 13, all of the teams were required to present their final video prototypes. They embedded these prototypes into their final multimedia presentations, which described the overall vision and scope of each team's design concept. All six teams made tremendous progress with their video prototypes in just a few days, and all of the final video prototypes received universal praise from the instructor as well as the three industry design experts who came to judge the final projects and decide which team would win the competition.

The following two figures show still images from the completed video prototype that Team A produced.

Figure 50. Still image from final version of introductory video.

Figure 51. Still image from final video prototype.

As part of their multimedia presentation, the members of Team A had an introductory video that outlined their overall design concept using animated text and abstract visualizations. Figure 50 shows a still image from that introductory video, which was about 30 seconds long and which set the stage for the video prototype that they showed next. Figure 51 shows a still image from the completed video prototype, which is essentially the same image as shown earlier in Figure 47 but with the user interface mockup added over the laptop screen. This still image indicates the amount of progress that Team A made with their user interface design in just a couple of weeks. The image shows a much more polished-looking interface design than anything the team had previously prepared as they created digital design artifacts.

The remainder of the multimedia presentation showed specific screens and interaction flows that the team had developed for their “Arrived” application. The following figure shows an example of one of the interface designs that Team A created for their presentation.

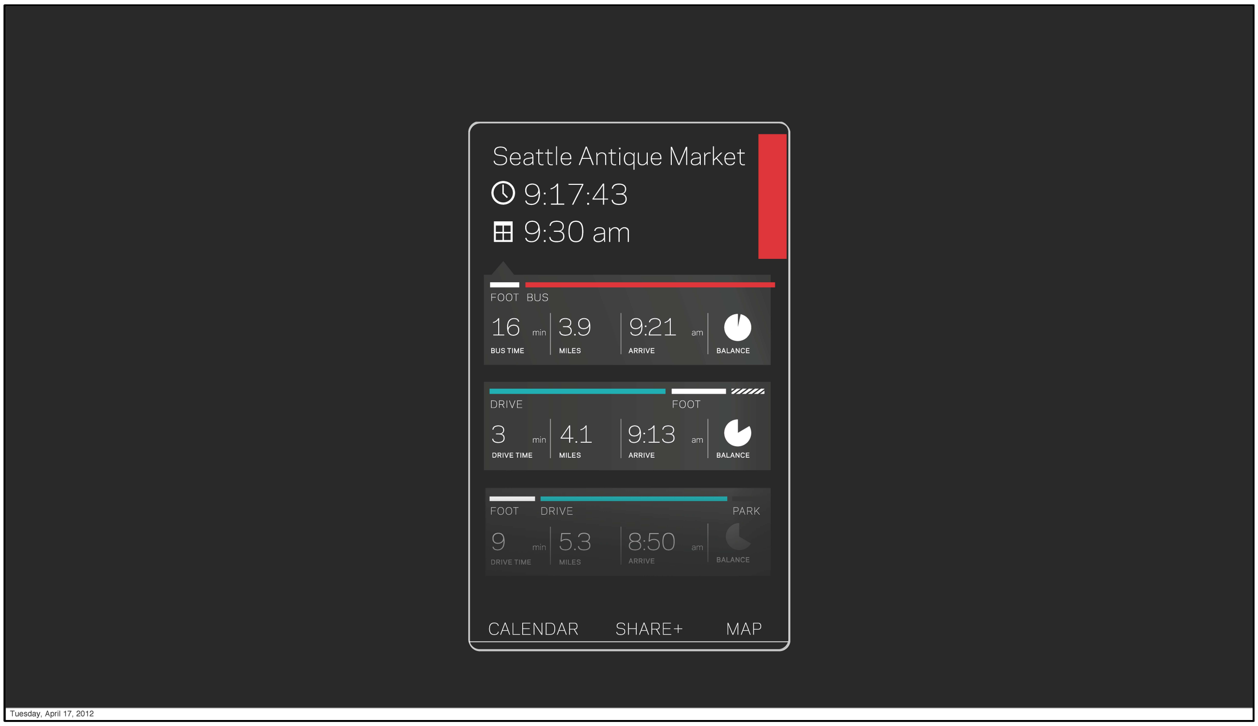

Figure 52. Example of content from final multimedia presentation.

The team discussed how their application enabled a specific user experience related to efficient trip planning based on calendar entries and local traffic conditions, as well as cross-device support plus adaptable, trustworthy information provided in real time.

Comprehensive design documentation. When the students presented their final video prototypes, they also had to turn in a set of comprehensive design documentation as part of their final product for the course. Team A created two different Adobe PDF files for this final deliverable. The first was a process book; the second page is shown in the following figure.

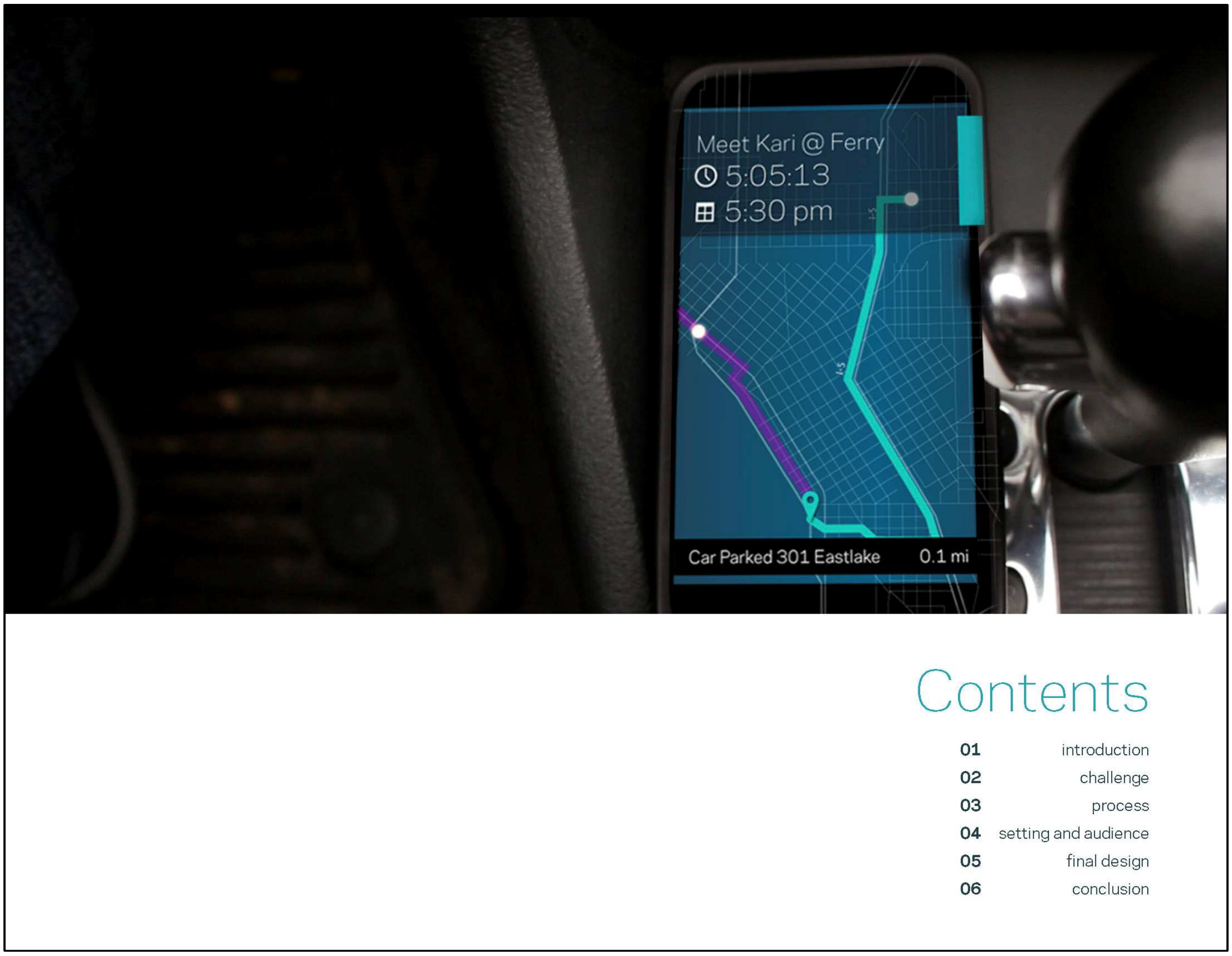

Figure 53. Page 2 of 16 from process book.

In this figure, the table of contents for the process book is visible. Team A discussed their project by introducing the problem space as described in the original Microsoft Design Expo brief, defining the challenge associated with helping people travel more efficiently, highlighting aspects of their design process, defining their design concept setting and audience, and showing details of how their “Arrived” application was intended to function. The process book contained 16 slides and was a succinct representation of the team’s output for the entire academic quarter.

Team A also produced a 34-page “supplemental documentation” PDF file that described how they developed their design concept. The second page of their supplemental documentation is shown below; note that Khloe created both the process book and supplemental documentation using Adobe InDesign because she specifically wanted to use a software tool that enabled her to control the visual layout of images and text, and because she was familiar with that tool.

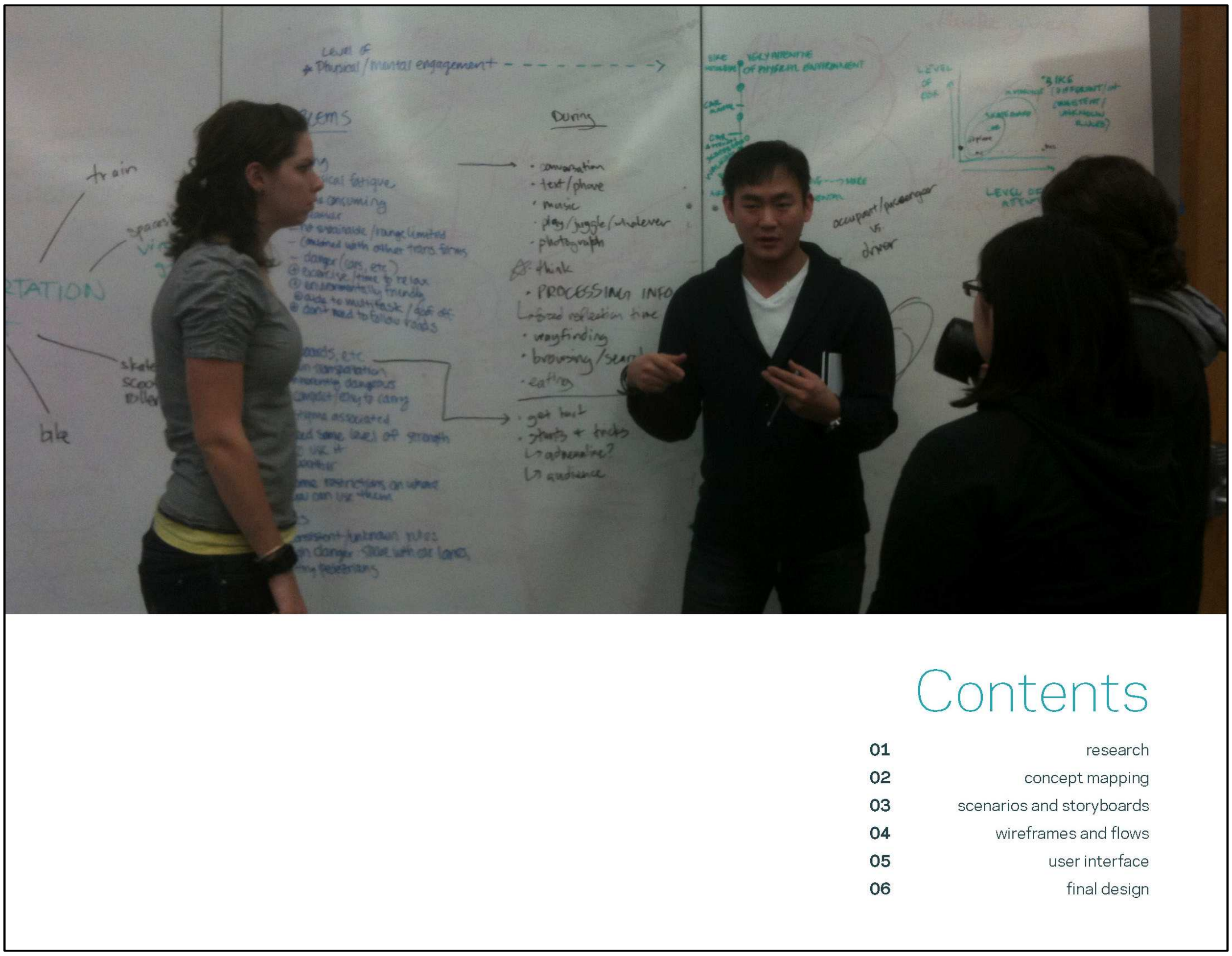

Figure 54. Page 2 of 34 from supplemental documentation.

The purpose of the supplemental documentation was to demonstrate how the team approached their collaborative work. By showing examples of the different stages of their research, ideation, and prototyping work, the members of Team A attempted to satisfy a course requirement that they make their design process visible for the instructor to assess.

Although the instructor's intent was for all of the teams to track their progress throughout the quarter and save copies of key design artifacts, in practice none of the team members did a good job of saving important examples of their work as they iterated their designs. When asked how they used the photos that they took of their analog design artifacts, Khloe explained that they returned to those photos at the end of the quarter when they needed to sift through a number of "*hazy iPhone photos*" (Khloe 106) in order to compile the process book and supplemental documentation.

Other teams tried to track their salient design artifacts using different social artifacts. For example, Team C created a blog for their project so they could trace and externalize the sources of information that influenced their design process. Team B created a Facebook group page through which they published and discussed analog design artifacts when they felt that particular artifacts represented their design concept or required additional clarification between work sessions. These examples indicate how teams used specific tools to generate and update digital social artifacts as the quarter proceeded, although even with those durable records of their work every team scrambled to complete the comprehensive design documentation deliverable as the quarter drew to a close.

Course conclusion and selection of the winning design. This section has traced the specific deliverables that Team A produced as they attempted to win the design competition and proceed to give present their "Arrived" application at the 2012 Microsoft Design Expo. Unfortunately for the members of Team A, their design concept was not selected by the panel of judges, which included the instructor and a few members of design teams across Microsoft. Team C was the winning team, although at first Teams C and D were both selected to proceed to the Design Expo. However, it was against the rules to let two teams go, and after further consultation Team C was declared the ultimate winner.

Team C developed a system called “Apt” that challenged the model of forcing smartphone users trying to locate interesting applications, and instead broadcast applications in location-specific ways so that smartphone users could engage with specific applications only when those applications were relevant to them. “Apt” aggregated all of the applications on a smartphone into three categories: “permanent,” “remembered,” and “unexplored.” The “unexplored” applications would be automatically suggested to users as they approached a local café or bus stop, for example; it was up to them whether they wanted to interact with those applications.

The primary difference between the final video prototypes across the six teams was the aesthetic quality of the video prototypes that the teams produced. Although all six teams were lauded for the strong visual quality of their video prototypes, Team C was recognized for having the nicest-looking prototype. The judges suggested during their post-viewing critique that the high quality of the user interface elements within the video, as well as their seamless integration with live-action footage, made the “Apt” design concept seem real already.

All 16 students were asked how they felt about the project that was selected for the Design Expo. Among the members of Team A, Anne thought the winning design was a good choice because it was not simply an application but a different way of thinking about how to access information across types of applications. Kylie and Nancy were less satisfied, primarily because they felt that the presentation Team C created was quite visually appealing but the underlying idea was not as good as other design concepts developed by other teams. Khloe thought that the winning project was a surprise because she expected the health system that Team B developed would win the competition. She felt that the richer social value of that design concept would help it win, although in the end she considered all six projects worthy of selection for the Design Expo.

Chapter Summary

This chapter has documented the constellation of tools and artifacts that students used and created, respectively, as they collaborated on their design projects. The students relied on a variety of analog, digital hardware, and software and online tools to create the array of deliverables required for the course. Along the way, they generated thousands of analog and digital design artifacts, and they tracked their progress using various analog and digital social artifacts. As stated earlier, digital hardware tools serve as the interface to software and online tools, which means that the students had to use devices such as laptop computers whenever they used software tools such as Adobe Illustrator.

With regard to the task work performances described in this chapter, the students shifted from analog to digital tools when they needed to transition their hand-drawn sketches or notes into digital form so they could include their best ideas in their final deliverables. The next chapter explores the decisions that students made when they shifted from analog to digital tools, why they preferred certain tools over others, and how issues of control factored into choices about which tools to use.

Chapter 5. Understanding Students' Tool-Related Decisions

In order to understand how the students in this study performed metawork while collaborating on their projects, it is necessary to understand the task and articulation work that they performed as they made tool-related decisions. The central contributions of this chapter are to explain how students performed task and articulation work during the study, as well as how their performance of both kinds of work and their use of personal toolbelts informed their tool-related decisions. These contributions are accomplished by analyzing specific examples of how members of Teams A and B decided to use specific tools while creating the conceptual model and video prototype deliverables. These teams and deliverables receive focus in this chapter due to the richness of supporting data describing how members of those teams worked on those particular assignments. As a reminder, the following table lists all of the student and team names.

Table 5. List of student names, academic programs, and team memberships.

Team	***Student #1***	***Student #2***	***Student #3***	***Student #4***	***Student #5***
A	**Anne** IxD Senior	Bae Industrial Design Master	**Khloe** IxD Master	**Kylie** Informatics Senior	**Nancy** HCDE Master
B	**Fiona** Industrial Design Junior	**Logan** HCDE Master	**Molly** HCDE Master	Nathaniel IxD Senior	**Peter** IxD Senior
C	**Abraham** HCDE Master	**Holly** Industrial Design Senior	**Kimberly** IxD Senior	Norbert IxD Senior	Ziggy Electrical Engineering Senior
D	**Baron** Informatics Senior	**Delilah** IxD Senior	**Isole** IxD Senior	Karla IxD Senior	N/A
E	Arlene IxD senior	Carl IxD Senior	Clarissa VCD Senior	**Erica** IxD Senior	Timothy Informatics Senior
F	Adele IxD Senior	Astrid IxD Senior	**Kristal** Informatics Senior	Missy IxD Senior	N/A

This chapter first revisits the definitions of task and articulation work as well as the concept of the toolbelt. These topics are reintroduced and discussed as a way to frame students' decisions about which tools to use while collaborating with other students. The different stages of the students' design processes are also reconsidered in order to situate students' tool-related decisions in the context of their progress while working on two particular deliverables: the conceptual model and video prototype deliverables. The remainder of the chapter discusses the creative processes that Teams A and B performed while working on those deliverables, including the decisions they made about which tools to use and how those decisions affected their progress from one design stage to the next.

Revisiting the Definitions of Task Work, Articulation Work, and Toolbelt

The students in this study produced numerous examples of all four kinds of artifacts as they performed task and articulation work within their projects. Chapter 2 defines task work as the completion of specific actions within an activity, where a "task" is a discrete unit of work that must be completed for an activity to proceed as planned. As the students worked through each stage of the design process for each of the deliverables they were required to produce, they completed a variety of tasks that they defined, assigned to themselves, and completed independently and collaboratively. The artifacts they produced reflected their attempts to complete the tasks they set for themselves as well as the other members of their teams.

By contrast, the students performed articulation work when they identified and obtained the resources they believed they needed to complete their task work, and when the local circumstances associated with an activity changed such that they had to adjust their strategies for completing the tasks associated with that activity (cf., Gerson, 2007; Schmidt, 2011; Strauss, 1985). The students dealt with changes in circumstance in a variety of ways, such as by redefining certain tasks so they could keep making progress on their projects or by shifting task responsibilities to different team members. The latter example of an articulation work performance delineates the division and redistribution of labor within an arc of work; this chapter will present and interpret detailed examples of that phenomenon.

The students also performed articulation work when they were compelled to decide on alternative tools to complete a specific task because the tools they wanted to use were unavailable or otherwise inadequate for the task. If artifacts are interfaces to students' ideas, tools are the interfaces to the artifacts that students produce. However, of the thousands of tools that exist in the world, individuals can be familiar with only a subset of those tools. Therefore, the concept of the toolbelt is reintroduced in this chapter as a way to characterize students' tool-related decisions as they performed their task and articulation work.

Sumner (1995) introduced the toolbelt concept as a way to characterize professionals' development of "different design representations" (p. 179). Specifically, when designers "assemble collections of off-the-shelf software tools as needed to create the necessary design representations" (p.179), they are creating toolbelts. As an example, she cites Microsoft Word as a word processing tool that enables the creation of text documents; her participants relied on Word to create documents such as test plans. By contrast, the designers who participated in her study used purpose-built software tools (e.g., TopDown, MacFlow) to create flowcharts so they could communicate a variety of design concept details to non-designers with whom they were collaborating.

The toolbelt concept offers a way to understand the totality of tools that designers apply to their collaborative project work. However, inherent in Sumner's definition of the toolbelt is the fact that designers have preferences for specific tools based on their applied experience with those tools. Therefore, the toolbelt concept is defined in this dissertation as *the aggregation of all the tools from which designers select preferred tools to perform task work within and across activities*. Design students and professionals alike develop personal toolbelts of their own as the result of lifetimes of experience, varying levels of interest in or awareness of certain tools, and a wide variety of other factors too numerous to trace here. They also hear about new tools and decide to try using them while working on certain tasks as a way to determine whether to include those tools in their toolbelts moving forward.

Sumner also points out that certain tools are more useful than others for externalizing design ideas depending in part on the required outputs of the task at hand and the desired format of the resulting artifacts (p. 178). As designers work through their projects, they must decide how to represent the current state of their design concepts for themselves as well as for others on their immediate and extended teams. Given the proliferation of specialized tools that can be applied to the stages of the design process, it is up to the designers themselves to decide which tools are best suited to particular work situations.

This chapter will show how the students in this study made, and attempted to make, tool-related decisions based on their tool-specific knowledge and preferences. Their decisions were not always final because, as the local circumstances of their task work changed, they performed articulation work to ensure they could complete their assigned tasks as expected. They also performed articulation work within specific activities when they aligned and realigned team members and tasks such that the next set of tasks could proceed. This process (introduced in Chapter 2) of "meshing" facilitates ongoing, successful collaboration (Strauss, 1985).

The meshing process was made more challenging for the students because they did not always agree on which tool was best suited to a specific task, or which tools should be used in parallel for the task work associated with a specific activity. As described in Chapter 4, the members of Team B struggled to align team members around a particular tool (Adobe Illustrator) because Logan did not own a copy of that tool and could not view Illustrator-formatted files unless they were saved as Adobe PDF files instead. As Molly from Team B pointed out, the team had to realign their task work when sharing Illustrator files in order to accommodate Logan's lack of access to Illustrator. Therefore, while students' toolbelts did influence their choices about which tools to advocate or use in specific situations, and their personal preferences for particular tools predisposed them to favor certain tools over others, their tool-related decisions also required them to perform articulation work and mesh actors with tasks when necessary to keep their projects on track.

The following tables enumerate the tools that the students on Teams A and B brought to and used for their collaborative project work during this particular course. Note that tools listed in italics are the specific tools that students reported adding to their personal toolbelts during the academic quarter.

Table 6. Team A students' toolbelts for their advanced interaction design course.

Name	***Analog Tools***	***Digital Hardware Tools***	***Software/Online Tools***
Anne	Collective paper form factors Personal paper notebook *Sticky notes* Whiteboard	Apple laptop Apple iPad tablet Apple iPhone smartphone Camera lenses Camera stabilizer Camera tripod DSLR camera (Canon T2i) External hard drive	Adobe After Effects Adobe Illustrator Adobe Photoshop Adobe Premiere Pro Apple Final Cut Pro Dropbox Google Docs Google Groups *Keynote* Skype Vimeo
Bae	Collective paper form factors Personal paper notebook *Sticky notes* Whiteboard	Apple iPhone Dell (Windows) laptop Wacom digital sketchpad	Adobe After Effects Adobe Illustrator Adobe Photoshop
Khloe	Collective paper form factors Personal paper notebook *Sticky notes* Whiteboard	Apple laptop Apple iPhone	Adobe After Effects Adobe Illustrator Adobe InDesign Adobe Photoshop *Adobe Premiere Pro* Google Docs Vimeo
Kylie	Personal paper notebook *Sticky notes* Whiteboard	Apple laptop (older model) Mobile phone (not a smartphone)	Adobe Illustrator Adobe Photoshop
Nancy	Personal paper notebook Sticky notes Whiteboard	Android smartphone Lenovo (Windows) laptop	Dropbox Google Docs Keynote Microsoft PowerPoint Vimeo

Table 7. Team B students' toolbelts for their advanced interaction design course.

Name	***Analog Tools***	***Digital Hardware Tools***	***Software/Online Tools***
Fiona	Collective paper form factors Personal paper notebook Sticky notes Whiteboard	Apple laptop Apple iPhone DSLR cameras (assorted)	Adobe Illustrator Adobe Photoshop Dropbox Facebook Google Docs Microsoft Word Skype
Logan	Collective paper form factors Personal paper notebook Sticky notes Whiteboard	Android smartphone Apple laptop	Dropbox Facebook Google Docs Microsoft Word Skype
Molly	Chalkboard Collective paper form factors Personal paper notebook Sticky notes Whiteboard	Apple laptop Apple iPhone	*Dropbox* Facebook GarageBand Google Docs Microsoft Word Skype
Nathaniel	Collective paper form factors Personal paper notebook Sticky notes Whiteboard	Apple laptop Apple iPad tablet Apple iPhone Camera lenses Camera stabilizer Camera tripod DSLR cameras (assorted)	Adobe Illustrator Dropbox Facebook GarageBand Google Docs Skype
Peter	Chalkboard Collective paper form factors Personal paper notebook Sticky notes Whiteboard	Apple laptop Apple iPad tablet Apple iPhone Camera lenses Camera stabilizer Camera tripod DSLR cameras (assorted)	Adobe After Effects Adobe Illustrator Adobe Photoshop Adobe Premiere Pro Dropbox Facebook GarageBand Google Docs Skype

These data are derived from a combination of sources: the surveys in which students described the different analog and digital tools they use for school-related work, the field observations of students working with specific tools, the students' interview responses, the artifacts they generated individually and collaboratively, and even the file format of certain artifacts. Additionally, the contents of these tables list only the tools that students specifically used in this course; these tables do not cover the totality of tools with which the students were familiar, or which they used regularly outside of their collaborative work for this course. For example, although the members of Teams A and B knew how to use Facebook, that software tool is not listed for any of the members of Team A because they did not use that tool for their collaborative project work, nor did members of that team advocate using Facebook together.

Finally, as the students collaborated on their project work and finished their deliverables, the sequences of tasks and activities they completed generally followed the design stages that the instructor outlined for them at the start of the academic quarter. Those stages are as follows:

- Research
- Ideation
- Prototyping
- Presentation/Assessment

Field observations and interview comments indicate that students consistently worked on research and ideation tasks before working on prototyping tasks. They also engaged in iteration throughout their design processes, which sometimes required them to revisit the research and ideation task work they had already performed. Finally, the kinds of tasks and the tools needed to complete those tasks differed depending on the stage in this design process in which the students were working.

The remainder of this chapter explores the decisions that the members of Team A and B made with regard to the tools they felt were best suited to their collaborative work. This exploration discusses artifacts that were important to the students’ collaborative work on the conceptual model and video prototype deliverables in order to surface their tool-related decisions, their use of personal toolbelts, and their performance of task and articulation work across the stages of the design process. These deliverables receive focus in this chapter because the six-week spread separating the due dates of these deliverables exposes differences in tool-related decisions across design stages and teams. The students were still learning to work together when the conceptual models were due, whereas they had been collaborating for about two months by the time they presented their final video prototypes.

Creating the Conceptual Model Presentation

The students in this study formed teams by the end of second week of the academic quarter, which was 11 weeks long in total including finals week. Due to inclement weather (a snowstorm that shut down the university and caused the cancellation of course sessions), the due date for the conceptual model presentation was pushed to January 31 (course session #9 of 21). The course syllabus described this assignment as follows:

> *Each team presents a detailed conceptual model of their design concept selected for design detail and prototyping. The model captures workflows and information requirements/flows as insight from initial contextual research.*

This deliverable was the most important team milestone that the students had yet to create. Although they had already produced their first team-wide deliverable (the design project description), which outlined their design directions, project scope, and design seeds, the students' conceptual models required the exploration and definition of each team's design concept in far more detail.

This section describes how the members of Teams A and B created their conceptual model deliverables. As they created and iterated drafts of these deliverables, the students on these teams made decisions about which tools to use for their task work, decisions that were influenced in part by their personal toolbelts as well as their perception of which design stage they were working within. Further, as they produced a variety of design and social artifacts leading up to their conceptual model deliverables, the students made tool-related decisions based on the need to perform articulation work to keep their projects on track. The data tell the story of these decisions, a story set in the context of the toolbelts that students brought to their teams.

Team A. During the fourth course session on January 12, 2012 (#4 of 21, Week 2 of the academic quarter), the members of Team A started working on their conceptual model deliverable by having a discussion around a couple of tables in the classroom. Each team member talked about his or her academic background and technical skills before the discussion shifted to their design concept, which at the time was about making the process of commuting to and from work more enjoyable. This initial discussion preceded the team's first performance of research-related task work together.

The team began their task work by inscribing various words and sketches on the whiteboard as they brainstormed ideas related to different methods of transportation. Figure 55 (below) shows Khloe (left) and Nancy (right) writing on the whiteboard as Bae (left), Kylie (right), and Anne (not pictured) look on.

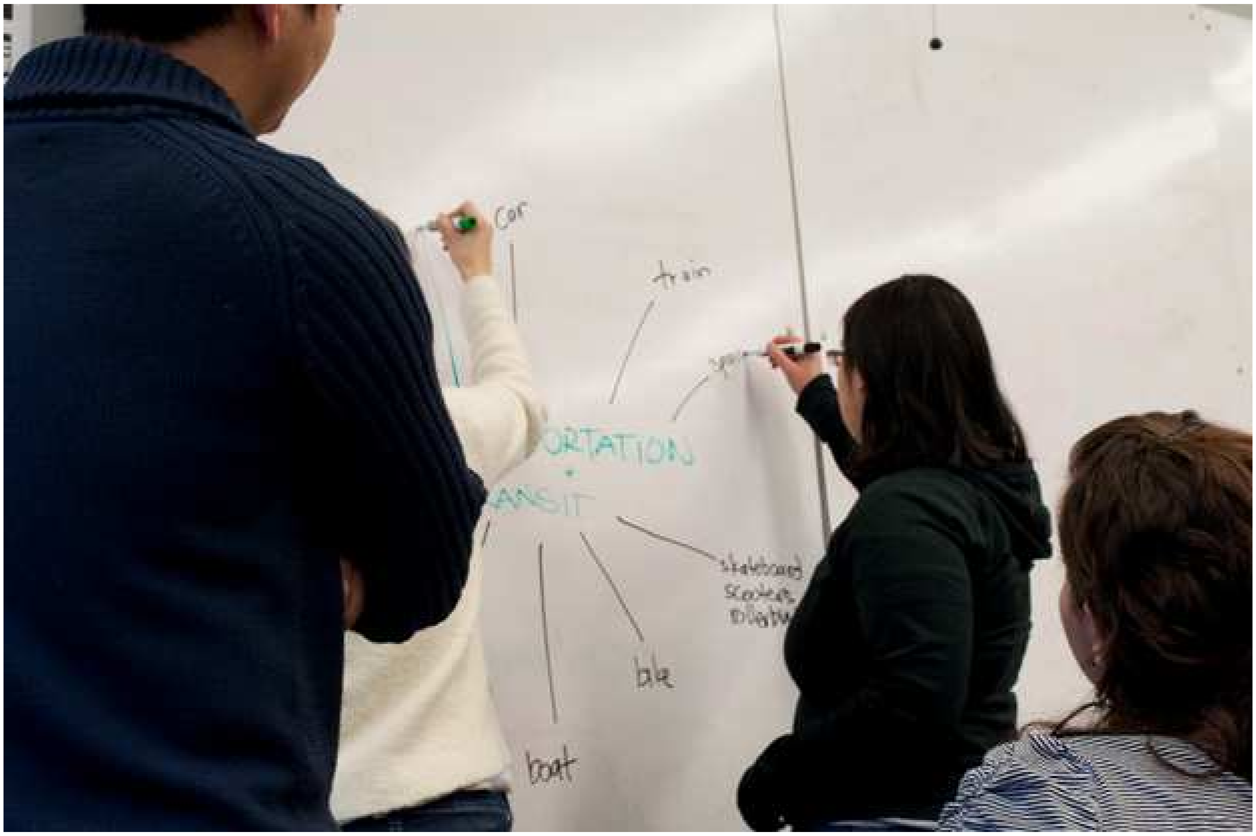

Figure 55. Members of Team A collaboratively creating design artifact on a whiteboard.

The field notes for this work session show that Team A decided to use the whiteboard without any explicit discussion about which tool to use for their brainstorming-related task work. Instead, once the team members realized they needed to write and sketch ideas about their design concept, they spontaneously shifted their work to the whiteboards at the front of the classroom. The point of this example is to highlight the fact that Team A did not have a conversation about the tools they thought they should use for this task. Instead, they simply started working with the analog tools that were close at hand.

After working on the whiteboard for a while, Team A ran out of space to add any new inscriptions. When that happened, Khloe and Bae pulled out their paper notebooks and continued sketching and writing notes in those notebooks. The other team members continued working at the whiteboard, primarily trying to add layers of organization to the ideas written and drawn there. The discussion remained centered around the whiteboard: Khloe and Bae recorded their thoughts in their personal notebooks from time to time, but they did not read aloud from their notebooks. Additionally, they often kept their notebooks closed when they talked about the ideas being added to the whiteboard, and then they would open them again when others were talking and they had stopped actively participating in the discussion.

Just as they did not discuss with teammates which tools to use for their brainstorming task, Khloe and Bae did not state why they had decided to begin using paper notebooks. In her interview, Khloe explained that she relied on her notebook as a tool for taking notes during meetings such as the one held on January 12. She also used her paper notebook to sketch drawings of ideas and scenarios related to her team's research and ideation tasks. Again, as the field notes from the January 12 work session indicate, Khloe referenced her notebook but did not show it to her teammates, read aloud from it, or transfer any ideas from it onto the whiteboard around which her team was working.

The team's next work session occurred on January 16 (the day before the next scheduled course session) in a room that was down the hall from the classroom. Prior to this meeting, the team had primarily used two analog tools for their collaborative ideation tasks: whiteboards during their first work session, as well as large pieces of paper that students independently worked on outside of team meetings. On January 16 the team met in a room that had no whiteboards, which forced the team members to find a new tool to use during their work session. The team had sticky notes and large pieces of paper at their disposal; however, Nancy strongly advocated in favor of sticky notes as the best tool for that session. Kylie describes how Nancy drove this decision within the team.

> *Nancy was a big fan of the post-it note idea. Yeah, I think Nancy was…the head of the post-it idea just because we were getting off track a lot at that point, so we were getting really frustrated with each other 'cause we were all sort of going in different directions. And she just said, 'I want everyone to put your ideas down.' And we were like, 'Oh, I don't want to do post-it notes. That's dumb. It wastes paper,' and she was like, 'No, no, no, no. We're doing post-it notes now.' That was sort of how that one came about, and it turned out to be a really, really useful thing. That was a lot of what helped us scope down what we needed to do. (Kylie 107-109)*

Nancy explained in her interview that the sticky notes were a useful tool because she and the other members of her team were forced to reduce the scale of their ideas so they would fit onto the notes. Kylie alluded to this quality of the tool when she said that their use of sticky notes helped her team "*scope down*" their ideas. Field notes show that Team A struggled to pare their design ideas down and reduce focus their efforts on a manageable project given the time constraints of the academic quarter. By shifting their task work away from tools with large amount of usable space to relatively small, 3-inch by 5-inch sticky notes, they literally scoped down their ideas by writing a single idea on each note. They laid out sticky notes on a table and individually wrote specific ideas on different notes, and then came back together as a team to discuss what they had written and how to group the resulting ideas by attaching the notes to a wall.

Nancy was the only member of Team A who included sticky notes in her toolbelt before the academic quarter began (refer to Table 6). As Kylie pointed out, Nancy initially encountered reluctance among her teammates with regard to using sticky notes.

> *[It's] not that we didn't want to [use sticky notes]. I think we were a little bit frustrated with each other at that point, and we were in the middle of doing whiteboard stuff and writing stuff down on paper, and she sort of just wanted to stop us where we were and change tracks. It was like, 'No.' But yeah, it worked out well in the end. (Kylie 109-113)*

This quote effectively captures the challenge that Nancy encountered when she suggested a tool from her personal toolbelt that she preferred to use for a specific ideation task, but that her teammates did not include in their toolbelts. Ultimately, through Nancy's insistence on using this tool that day, she was able to convince her teammates to give sticky notes a try as they attempted to complete their ideation task work. The team left their January 16 work session with a clearer understanding of their design vision, which Kylie mentioned in her interview when she said that the team's use of sticky notes "*worked out well in the end.*"

This example also describes the articulation work that the members of Team A had to perform in order to get to the task work they had planned to do at their work session. The use of sticky notes at that specific session reveals their performance of articulation work because the local situation had changed: Their preferred tool was unavailable, so they had to modify the parameters of their task work around the tools that were available. It is noteworthy that the lack of available whiteboards sparked the discussion among the team members regarding which tool they should use instead for their ideation task work that day.

As a result of Nancy's successful argument in favor of using sticky notes, the team members decided to write down their research-derived ideas about transportation on sticky notes. Figure 56 (below) shows a photo from that session shows how that decision to use sticky notes led to the creation of over 30 different analog design artifacts.

Figure 56. Example of design artifacts that Team A created using sticky notes.

In the photo above, every sticky note is a unique analog design artifact. Each yellow sticky note documented a specific idea related to personal transportation, and each magenta sticky note represented a category under which similar ideas were placed. For example, one category described the accommodations that transportation systems must make for disabled users; the two yellow sticky notes within that category said "*access (if handicapped)*" and "*disabilities*." Those notes were then placed in a column (refer to Figure 57, far left column) that represented the team's thinking about transit accessibility.

This photo is interesting not just because it describes how the team used sticky notes, but because it also shows the wealth of analog and digital tools available to the team members as they worked with one another. In that photo, a variety of analog tools (loose-leaf paper, paper notebooks) and digital tools (two different laptops) are visible on the table along with the sticky notes. However, the students did not use those other tools as they wrote ideas on sticky notes. Instead, they occasionally referenced their paper notebooks and laptops when they needed to look up specific design ideas they had previously recorded, or when they wanted to find information online that related to their design idea.

The following photo was also taken on January 16, 2012, but an hour later than the previous photo. In this photo, the same sticky notes are visible but the students had moved them from the table to the wooden partitions that separated the desks in the room.

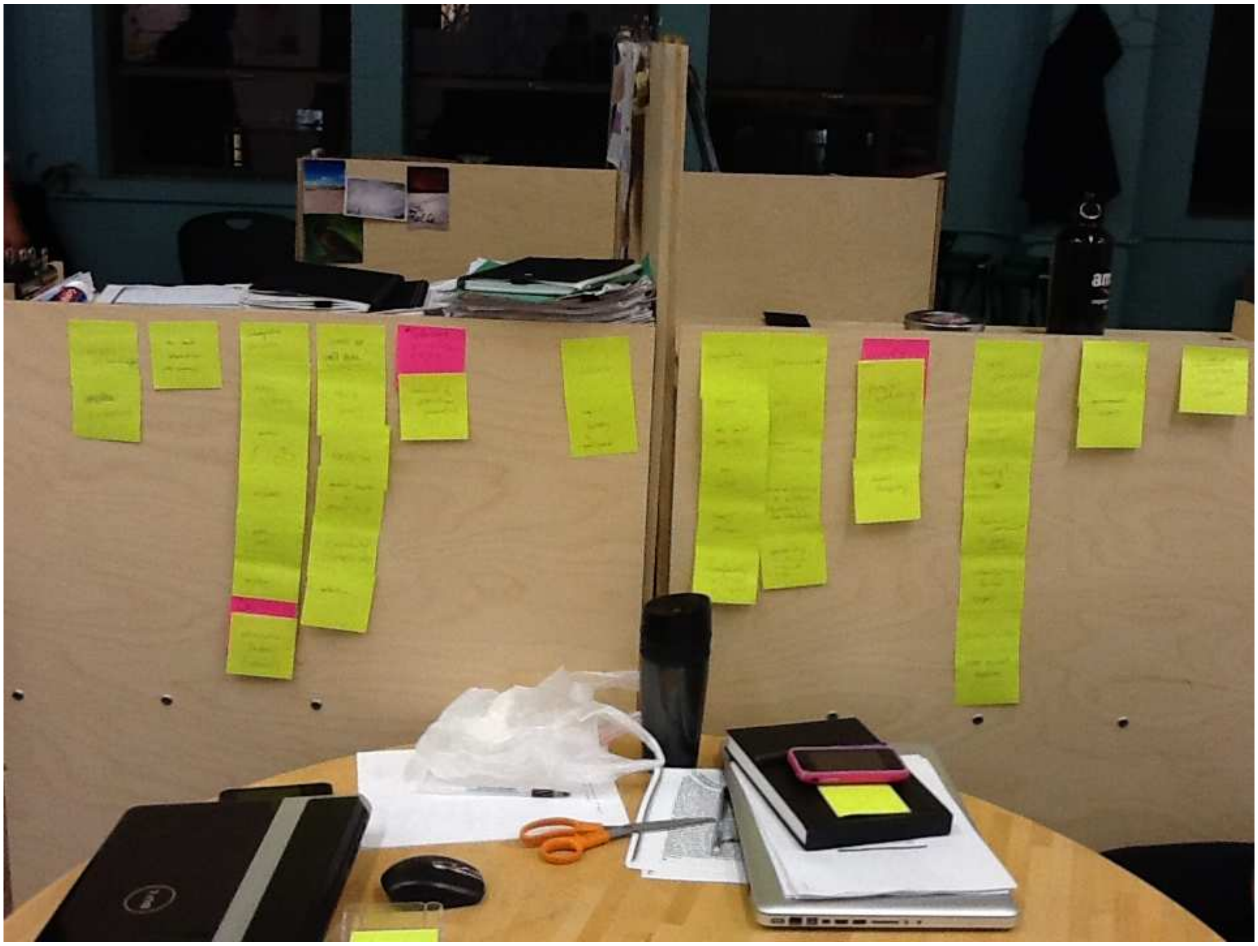

Figure 57. Team A workspace and collaboratively organized sticky notes.

This figure demonstrates how the team physically organized the sticky notes into categories after they wrote down a number of ideas. As before, the other analog and digital tools visible in this photo do not appear to be in use; although the students shifted them around on the table, the laptops remained closed and the mobile phone is turned off. This photo, therefore, is descriptive of the students' collective decision to focus their collaborative work around a specific analog tool: sticky notes.

Although the conceptual model deliverable was not due until January 31, each team had to provide a single-slide presentation of their design project descriptions in class on January 17.

This presentation was the first deliverable that the students had to create as the product of their teamwork, and was meant to help them lay the groundwork for their conceptual models. Given the tight deadline for the design project description deliverable, Anne took on the task of prototyping that deliverable using the analog design artifacts created during the January 12 and January 16 work sessions. She described how the team decided to shift from analog to digital tools when they began prototyping their conceptual model.

> *I don't remember if we had a whiteboard because it's just what was available in the classroom because most people took over the whiteboards immediately, so I think we were just on paper or the wall or something just putting up stickies. And then we were trying to draw connections, I think, on there, but it just became a mess. So that's when…we moved to the computer when we were like, 'I think we've got it. Let's move to the computer now.' (Anne 141)*

This quote pinpoints the moment when Team A decided to stop using whiteboards and sticky notes in favor of digital tools (e.g., "*the computer*"). Importantly, the team had not collectively settled on which tool they wanted to use to make the design project description deliverable; field notes and interviews reveal that Anne made the decision for the team to create that deliverable using Adobe Illustrator. That decision exemplified Anne's performance of articulation work: She stated in her interview that she felt Illustrator was the best tool to use for her prototyping task work on this deliverable because it facilitated sketching visual representations and connections among concepts more effectively than other tools. For those reasons, she decided to use Illustrator and create a draft of the design project description.

> *I am probably the fastest in that [tool]. I've been using Illustrator since it first came out when I was in high school, so I'm really quick in it. [Laughs] Probably the quickest of all the Adobe programs, and…it's one of the leading tools for graphic designers and graphics…. It's not really great for text, but for things like this [deliverable] where you have to draw a lot of lines and shapes, Illustrator is the best. (Anne 133)*

Anne described Illustrator as “*the best*,” which indicates her personal preference for this tool as a design prototyping tool. Field notes and interview comments reveal that Khloe preferred Adobe InDesign while working on the design project description source files with Anne; these two tools rely on similar file formats, so both Anne and Khloe could work with source files using their preferred tools. However, Anne took the lead on creating the deliverables for her team, so she was ultimately the team member who exerted the most influence over the choice of tools. Khloe indicated in her interview that as she passed InDesign source files back to Anne for her to revise, Anne would then make those files available again as Illustrator files, indicating her strong preference for that particular software tool.

After Team A presented their first deliverable (the design project description) on January 17, they continued to use those same source files as they worked on conceptual model deliverable. In this way, Anne’s earlier decision to use Illustrator impacted how her teammates could contribute to the conceptual model deliverable once the prototyping effort began. Specifically, Anne did not share the source files with everyone on the team: She only shared them with Khloe and Bae. Kylie said that Anne was the one who did all of the work to modify the digital design artifacts leading to the final deliverable.

> *Like I said, it was Anne, and she saw it the way she expected it to be, and so we let her sort of just go with it. And when she presented it to us, if we were happy with it, we were just like, ‘Okay. Looks good.’ It had all the content that we discussed, and it had everything that we expected it to have, and it looked nice, and so we left it. I’m sure Anne went through a million different revision processes but only showed us the final one. (Kylie 091)*

As Kylie points out in this quote, Anne did not show the rest of the team more than a couple revisions of the conceptual model presentation. Instead, she showed the team only a draft during a team discussion, as well as the completed PDF once she felt it was finalized. This situation foreshadows students' performance of metawork and their enlistment of tools as allies, which will be explored in detail in the next chapter.

Team B. As with Team A, the members of Team B kicked off their design process during the January 12, 2012, course session. The following photo from that session shows Team B meeting for the first time and discussing possible design concepts they could explore together.

Figure 58. Members of Team B conduct their first collaborative discussion.
In this photo, all of the members of Team B are present: Peter (left) is taking notes in his personal notebook, Fiona and Molly (top and bottom, respectively) are both listening to Logan (right) as he speaks, while Nathaniel (right, out of frame) also listens to the discussion.

Figure 58 shows a number of analog and digital tools, all of which the students set on tables or in their laps as they talked with one another. Logan and Nathaniel both have their laptops open, but they are not actively using those tools. Instead, they are engaged with the conversation.

However, for much of this work session the team members sat around the cluster of tables pictured in Figure 58 and wrote down their design concept ideas on the large piece of paper visible in the same figure. All of the team members wrote or sketched their initial design topic ideas on that piece of paper; those ideas served as the focus for their work session that day. The final version of that analog design artifact is shown in Figure 59 (below) in order to illustrate the progress that the team made during their first collaborative work session.

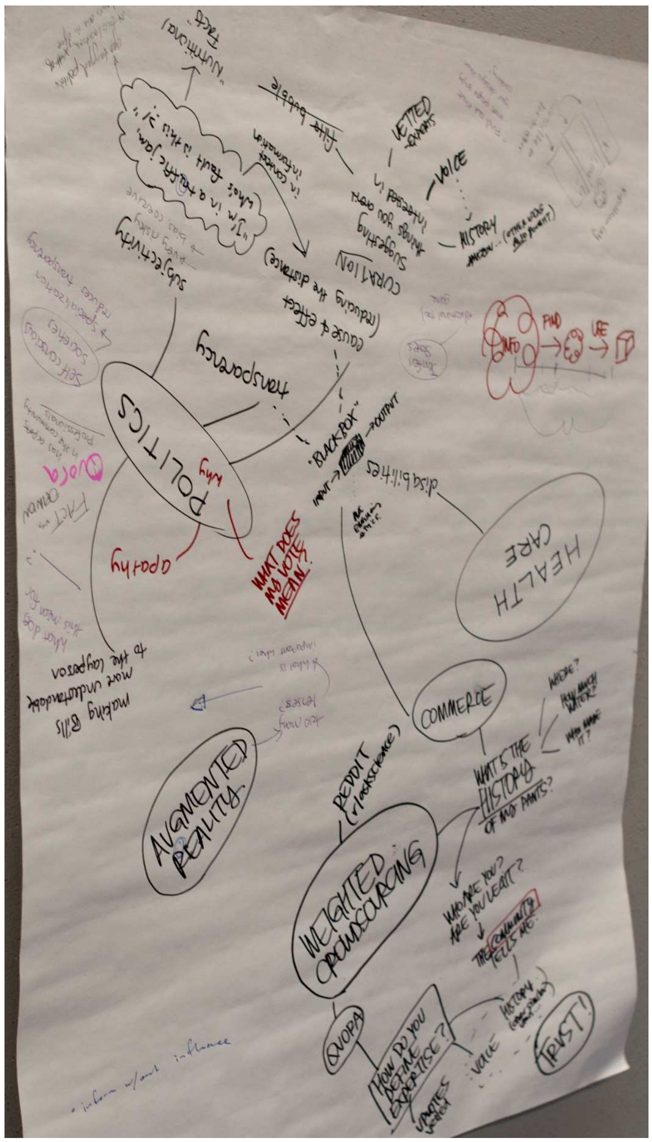

Figure 59. Team B analog design artifact that resulted from January 12 work session.

The analog design artifact in Figure 59 was the point of departure for the members of Team B with regard to developing their first team-wide deliverable (the design project description). Molly described how the team members decided to collaborate around analog tools after their first work session together, and as they settled on a process for creating their first deliverable together.

> *We…said, 'Hey. Maybe we can each independently sketch some [conceptual] models. And let's bring them together and we'll see what we have, and each person can present their model to our little group here on paper and we'll go from there.' So that was how it started and we brought paper sketches and went over that. (Molly 193)*

This quote indicates the lack of a clear boundary between research and ideation tasks as the team members tried independently to develop conceptual model ideas. Using the sketch shown above as a starting point, the members of Team B initially worked independently on their own ideas related to people's health information, and then they brought those sketches to their next work session for discussion.

Molly continued her description of how the team created their conceptual model deliverable.

> *From there we went to the whiteboarding sessions and sometimes we actually sketched on people's sketches that they had brought in or put sticky notes on them saying, 'Okay. I see what you're saying. I see where your model is going. I see it like this. I would put an arrow off this way because we have to include this piece.' (Molly 194-195)*

Here, Molly provided additional detail about the analog design artifacts that the members of Team B created for this deliverable, as well as the extent of their collaboration with and around a few different analog tools: whiteboards, sticky notes, and multiple paper form factors. They chose to use these tools as they worked through their research and ideation tasks because they felt that these analog tools most effectively encouraged rapid iteration of ideas without team members clinging to specific ideas too tightly.

Molly clarified this point later in her interview when she explained why the members of Team B decided to use analog rather than digital tools for their research and ideation tasks.

> *The cool thing about paper and whiteboarding is that you can get crazy with your idea because it's fast to render and you can erase it and you can crumple it up and you can tear off a new sheet. So when you're really in the early stages of your [design] process, paper and whiteboarding make sense. So we started out with whiteboard and paper because then we didn't ever become too precious about our initial ideas. (Molly 217-219)*

Molly explains here that analog tools such as paper and whiteboards better support collaborative performance of research- and ideation-related task work precisely because those performances result in low-fidelity design artifacts. She uses the word "*precious*" to characterize students' feelings of attachment to the digital design artifacts they create, and how hard they can be to critique because they look far more polished than analog design artifacts. It is exactly that additional layer of polish that makes digital design artifacts appropriate for the final (presenting) stage of the design process, but not for the first two stages (research and ideation).

Further, Molly claims that the unique qualities of analog tools encourage collaborative discussion around the *function* of the ideas being presented, rather than being distracted by the high-fidelity form of those ideas.

> *If we had all said, 'Let's come to class tomorrow. Let's all independently start working on a draft model. We'll all come to class tomorrow and share with each other.' If Nathaniel ended up [digitally] rendering that one, instead of coming with a paper sketch, and said, 'This is my idea,' we would all be like, 'Ooooh. That's beautiful. I don't want to actually critique it.' I mean, we can critique it, but it just doesn't encourage critique or discussion…in the same way that a medium that's obviously a draft does, I guess. So that's why I think we chose those [analog tools] for the initial stages. (Molly 219-221)*

Later in her interview, Molly lent additional context to this quote by describing how it was hard to critique digital design artifacts (as opposed to analog design artifacts) because digital design artifacts look far more polished than analog design artifacts. As a result, digital design artifacts invited different kinds of comments during critiques that focused less on the content of the ideas and more on how those ideas were presented. Molly described the perils of this false sense of completeness regarding the team's design ideas as expressed digitally.

Once we get something we're happy with, then it's time to commit to it and render it and make it beautiful. So sometimes we'd start out making an idea beautiful and then finally realize, 'Oh. We have to go back to the drawing board. It's still a half-baked idea.' (Molly 245)

According to Molly, the alternative to analog tools was software and online tools such as Adobe Illustrator, which certain members of the team (e.g., Nathaniel) knew how to use and could have worked with while performing research and ideation tasks. She claimed that if Nathaniel had produced a digital design artifact using a tool such as Illustrator, his idea would have been privileged above analog design artifacts primarily because the team would have been distracted by the relatively polished form in which he presented that idea. Instead, software and online tools were suited to the prototyping stage of the design process; again, according to Molly, once the essential design idea was settled it was time to shift from ideation to prototyping tasks. That shift also signaled a shift from analog tools to software and online tools in order to progress from "*raw ideas*" on paper to a "*really beautiful*" (Molly 243) digital design artifact.

After the January 12 work session, Molly and her teammates worked independently on paper-based sketches of design ideas, which they brought to their next work session on January 15. At that session, the team iterated their design concept using paper and whiteboard sketches to come to a common understanding of their design concept and goals. Eventually, the team decided to shift from these research and ideation tasks and prototype the specific design concept they wanted to pursue. They gave the final sketch they created to Nathaniel so he could convert that sketch into a digital design artifact. Molly explained this process in more detail.

> *We met on Sunday and our presentation was on Tuesday, so as a group we were like, 'Okay, cool. We're all pretty happy with this. What's everyone's schedule like over the next two days?' Four out of five of us were like, 'I have zero time.' And Nathaniel was like, 'Okay.*

> *Well, I can take the sketch. I have time. I can take the sketch and mock it up in Illustrator. I'll put a PDF in Dropbox so you can all look at it. Give me some feedback by Monday night and then, based on your guys' feedback, I can revise it Tuesday morning and we can get together on it right before class to make sure we're all happy with it.' (Molly 197-203)*

This quote characterizes the shift to the prototyping stage of the design process in the context of Nathaniel's explanation of the tools he would use as he engaged in prototyping tasks. Nathaniel volunteered to take the analog design artifact they created collaboratively and convert it into an Illustrator file, from which he produced a draft PDF file for team-wide feedback, as well as the final PDF.

The flow of tasks that Nathaniel undertook as he created a digital design artifact for his team clearly illustrates how Team B went about the task work associated with the activity of developing the conceptual model deliverable. As the members of the team worked through the different stages of the design process while creating that deliverable, they also performed articulation work to use the tools at hand, stay focused on their deadlines, and ensure that team members worked with the tools that best fit their skills.

For example, Team B created the design artifact in Figure 59 on paper because there were no whiteboards available that day. As with Team A, the members of Team B did not have a conversation about the tools they thought they should use for this task. Instead, after they looked around and noticed that the whiteboards were all being used, they obtained a large piece of paper from an easel pad and began working with the analog tool that was closest at hand. This is a classic example of articulation work as Strauss (1985) defined the phrase because the members of Team B responded to local circumstances, modified the structure of the task at hand, and completed that task in order to ensure the successful continuation of the rest of that activity.

Similarly, the team had set up a Facebook group page on January 10 as a repository and discussion board for their digital design artifacts and design ideas. The team relied on that group page as a repository for digital copies of analog design artifacts, as a site where they were able to hold private discussions about those artifacts, and as a communication channel through which team members provided instructions related to the task work associated with the activity at hand. During the evening of January 30 Nathaniel added two posts to his team's Facebook page that were related to their collaborative work on the conceptual model deliverable. In the first post (5:50 PM, January 31), he added the photos that he took of the paper-based design artifact that resulted from the January 15 work session. The purpose of that first post was to enable all of the members of Team B to see and reflect on the task work they had completed so far during the research and ideation stages of their design process for that activity.

The second Facebook post (5:54 PM, January 31) contained the following text:

> */Users/Nathaniel/Desktop/Conceptual Model.pdf*
>
> *Emailed this out as well. Will put slides 1 and 3 together based on Molly's rough notes & will send the drafts out when finished. Let's talk/refine tomorrow am.*

This second post served multiple purposes, all of which describe Nathaniel's interest in performing articulation work to keep the entire team aligned around the proper order of operations to be followed as they completed the task work associated with that deliverable. First, Nathaniel pointed his teammates to the specific Dropbox folder location where they could find the PDF file of that deliverable, which was too large to share through Facebook. He then noted that he also emailed everyone the same PDF file as a redundant communication method, suggesting that everyone should have access to the file so they could provide feedback. He continued by updating everyone on his progress with the deliverable, and cited teammate

Molly's notes as another source of input on which he was relying. Finally, Nathaniel promised to send out an updated draft of the conceptual model deliverable once he had it ready, and he wanted to get everyone together for a collaborative discussion the morning of January 31st. Neither of these Facebook group posts had any comments from other team members.

This detailed description of how Nathaniel used a variety of tools to complete his tasks and make the resulting artifacts available for team-wide critique raises deeper questions about how he decided to use those tools. When asked about why they decided to use particular tools, Molly explained some of the thought processes that drove those decisions.

> *I think there are a bunch of other programs out there that kind of do similar things, but Dropbox is really easy to use, extremely easy. It's just so convenient and we didn't really consider using anything else. It's just like, 'Oh. Well, Dropbox, obviously.' (Molly 051)*

This quote from Molly regarding the choice of Dropbox as a file sharing tool is interesting because she was the only team member who had not used Dropbox prior to her collaboration with the other members of Team B. Even though she did not include this tool in her personal toolbox at the start of the quarter, she concurred with her teammates that Dropbox was the best way to share files that were too large to share via Facebook because it was the easiest tool to use for that purpose. By the end of the quarter, Molly included this tool in her own personal toolbelt because of her experience with this design project.

Similarly, Peter explained that the team decided to use Facebook to enable asynchronous communication and information sharing because certain members of the team lacked knowledge of other, competing tools.

> *It made sense for us to have [Facebook] as our tool because even though [Nathaniel] was slow as hell, he knew what he was doing. You know? He'd be like, 'Okay. When I go over here, now the photo is there.' You know? It's like he knew how to use it. And so that was probably one of the main reasons we ended up using Facebook. We all knew how to use it, and we were all on it all the time. And it was just a simple, easy way of sharing pictures. And*

that's all we really needed to do. If we shared files, we either used Dropbox or email. But…again, they have all their own problems. (Peter 295-301)

Beyond situating Facebook as easy to use and popular with his teammates, Peter also explained how the team decided to use that tool as well as Dropbox for specific collaborative tasks. Specifically, he regarded Facebook as a tool for sharing photos of his team's research and ideation tasks, whereas he noted that Dropbox was one of two tools used to share the larger digital design artifact files on which the team members worked.

However, these quotes from Molly and Peter also indicate how teammates who had decided to use particular tools for specific purposes still differed with regard to why they thought they made those decisions. For example, Peter described Facebook as a tool for sharing photos of artifacts, but Molly explicitly described the same tool as more than just a way to share photos.

[We] also had a Facebook page for our group that we used and we posted all kinds of things there, not just images. (Molly 049)

Just as Molly differed from Peter with regard to her perception of the team's use of Facebook, she also differed in her characterization of Dropbox as the only tool they used to share files. Finally, she did not cite email as a tool used to transfer files among team members, even though field notes and other artifacts reveal that the team did use email extensively for that purpose.

These differences are important to point out because they indicate how the members of Team B approached the performance of articulation work in different ways. All five members wanted the team as a whole to succeed; at the same time, they had different opinions about how to structure the task work and how to mesh actors and actions in order to achieve success. They also had to mesh actors with other actors, a challenging process given that "actors" are more than just human members of a team. As established in Chapter 2, non-human actors can also participate in the actions that comprise social life. The members of Team B decided to use specific tools in order to structure their collaborative effort. In so doing, they also performed articulation work as they chose tools that were either included in all of the team members' personal toolbelts (e.g., Facebook), or that were straightforward to learn and add to a toolbelt (e.g., Dropbox). Stated differently, the team members were motivated to select non-human actors (tools) that were easily meshed with the human actors because they wanted to keep their focus on performing task work rather than continuously performing articulation work around the use of tools.

Creating the Video Prototype

The final deliverable of the course was a video prototype, which each team was required to present at the final course session on March 13, 2012, along with a presentation describing and contextualizing the design vision in more detail. At the final course session, the instructor and a few judges from Microsoft viewed the final video prototypes and corresponding presentations, and then decided which team would present at the Microsoft Design Expo that summer.

This section describes examples of the task work and articulation work that the members of Teams A and B performed as they collaborated to produce their video prototypes. Each team is discussed in turn before the chapter closes with a summary of how the students on these teams decided which tools to use in support of their collaborative project work on the conceptual model and video prototype deliverables.

Team A. The members of Team A developed a video prototype that illustrated their design concept by telling the story of a young man who was buying an engagement ring so he could propose to his girlfriend. The video includes only two main characters (the man and the woman) and no dialogue: The entire story is told through images and has a straightforward plot. In the video, the man picks up the ring at a store, returns home to prepare a cup of ramen noodles, meets up with his girlfriend on a ferry, and surprises her with the engagement ring hidden in the cup of noodles. Along the way, he struggles with traffic flow problems, so he relies on the mobile phone application that Team A designed in order to select different forms of transportation and get to his destination on time.

By the last two weeks of the quarter, the members of Team A were spending all of their time trying to complete specific prototyping tasks, such as recording video footage based on their script and scene list and then generating new edits of that footage on an almost daily basis. As with the conceptual model deliverable, Anne led the effort to create the video prototype for Team A. She enlisted Khloe and her fiancé as the two actors for their video because their availability was ensured.

The team's work session on February 28 exemplifies the context for Anne's tool-related decisions. At that work session, the field notes indicate that all five members of the team met in the classroom to watch the rough cut of their video prototype on Anne's laptop and provide verbal feedback. Anne played the video within Apple Final Cut Pro, which was the software tool she used to edit the footage that the team recorded. The following photo (taken on February 28, 2012) shows how Team A gathered around Anne's laptop to watch an early version of their video prototype and provide spoken feedback to Anne regarding the content, editing, and cinematography of the video.

Figure 60. Team A collaboratively viewing and discussing their video prototype draft. In this photo, Anne is seated at her laptop, which means she controlled what the rest of the team can see. Nancy (far left), Khloe (left), Bae (middle), and Kylie (right) all look on as Anne plays the draft of the video prototype that she has compiled from the footage they had recorded to that point.

The tools that Team A used for their video prototyping task work did not allow more than one person to work with the file at any given time. Anne's selection of tools for the video prototype deliverable did not reflect a concerted effort to limit the participation of other team members. Instead, software tools such as Adobe After Effects, Adobe Illustrator, and Apple Final Cut Pro do not facilitate the type of synchronous, collaborative work that other software tools (e.g., Google Docs, Dropbox) are designed to support. Although the team collaborated around the creation of storyboards and the video script, their work became increasingly cloistered and less collaborative as the end of the academic quarter drew nearer.

The task work was structured in this way partly because of the articulation work Anne was doing to align actors and tasks. She decided that the simplest way to get the project completed successfully was to avoid assigning any tasks to two of her teammates: Kylie and Nancy. They participated in almost none of the video recording sessions; given the time pressures of the academic quarter, Anne, Khloe, and Bae made no attempt to schedule those sessions so that Kylie and Nancy could help out.

For example, Anne described how the decision to use specific tools for video production and editing tasks was made within her team.

> *No one really knew [which tools to use], and they just went to me. They were like, 'What should we use? What should we do?' And a lot of people were sending me blog posts or just Web resources asking what we should use, and I basically took the standpoint of…like, 'Well, this is what I'm familiar with, and this is what I can use. If you think something's better, go for it.' But it was basically just what I had done in the past and what I had known. (Anne 051)*

In this quote Anne characterizes the decision to use specific tools to create their video prototype as a choice that she made for her team. Although Bae worked on video editing and production tasks as well, the observation notes from this study indicate that he acquiesced to Anne's choice of tools and task work assignment decisions. Specifically, when Bae wondered aloud what he was supposed to be working on, Anne told him to complete a specific task: creating mockups of the mobile phone interface that the team was designing. Field notes show that Bae accepted that action item and, instead of protesting, left the room to get a snack. Ultimately, he used Adobe

After Effects to make the mockups, which Anne inserted into the video footage to make it look as though the actors were actually interacting with a real mobile phone application.

This quote also describes Anne's performance of articulation work because she decided at that meeting, based in part on the skill sets that each team member possessed, to avoid assigning tasks to Kylie and Nancy that they might have struggled to complete. In their interviews, Kylie and Nancy discussed how they felt about those decisions; Kylie expressed frustration that she did not get the chance to learn more about video production and editing.

> *Anne was doing the videos mostly. Bae was doing the After Effects [work], and I was sort of hoping to sort of creep on them as they were doing them to see if I could pick anything up. It didn't work out just because of time constraints. They really needed to just sort of sit there and get it done. Those would be useful things for me to know how to do, but I guess there are other ways to learn about that. (Kylie 015)*

Although Kylie seemed annoyed that she did not get the chance to learn new tools or new techniques related to video production, she stated that her own lack of effort to engage Anne and Bae as they were working contributed to her lack of learning opportunities. She also seemed as willing as Bae to accept the way that Anne set about structuring the tasks and assigning those tasks to different actors.

Similarly, Nancy explained that she was not entirely sure which tool Anne used to edit their video prototype because she did not participate in the task work associated with that deliverable.

> *I wasn't involved with that [task work] because it was at that point where things needed to get done fast, and if you didn't know what you were doing you were going to be more of a hindrance than a help. (Nancy 191)*

Clearly, then, Kylie and Nancy both understood that because they were not as knowledgeable about video production and editing tasks as their teammates, and because their final deliverable was due in a couple of weeks, Anne and Bae simply needed to "*sit there and get it done.*" Nancy explicitly acknowledged this need to perform articulation work by assigning tasks to the team members who had the most knowledge about the tools required for those tasks, which would help the team avoid getting bogged down so close to the end of the arc of work.

> *When it's crunch time, you just give the task to whoever can get it done the best and the most quickly. (Nancy 197)*

Finally, Anne’s decision to assign tasks only to herself and Bae (with Khloe acting in a supporting role) had implications for the tools that the team decided to use for their video production and editing tasks. By removing the constraint of involving less-knowledgeable team members in that task work, they could simply use the tools they preferred and already knew how to use. Again, Anne performed articulation work to align actors with tasks, but she also worked to align (human) actors with other (non-human) actors so that the project itself would stay on track.

Team B. The members of Team B decided to produce a unique video prototype that had a richer plot structure and story than that of Team A. The characterization was more detailed in the Team B video because their design concept centered around personal health decisions and how to make better lifestyle choices. This concept necessitated a lot of backstory in a documentary style about the main character, played by team member Molly.

In the video, Molly receives ambient information about her health status throughout her day. At the midway point of the video, Molly reveals that she is dealing with a life-threatening heart problem that also runs in her family, and that requires her to pay close attention to the decisions she makes about her diet, exercise regimen, and medications. The plot culminates with a doctor visit that occurs remotely using two-way video conferencing technology, and that also features an interview with the doctor about the benefits of the ambient health design concept. The video mixes naturalistic interview footage with action footage designed to make it look as though

Molly was seamlessly encountering the team's design concept in various aspects of her life: driving to her dance studio, brushing her teeth, or playing with her sister's children.

Just as Team A primarily worked on prototyping tasks while creating their video prototype deliverable, Team B also shifted from research and ideation tasks into a variety of prototyping tasks as they worked on their video prototype. Molly and Nathaniel initiated the prototyping tasks by taking sketches made earlier in the quarter and arranging them on a wall to create a draft of their storyboard, all before they began writing the script for the video. Once they had arranged those sketches, they asked Fiona to help them create an updated set of storyboard sketches so they could film a quick proof-of-concept video before they dove into production of their actual video prototype. The proof- of-concept video consisted of one team member holding the stack of sketches that Fiona had made and flipping through them in order. Molly, Nathanial, and Fiona showed this video to Peter and Logan, as well as the instructor, in order to gather feedback about their progress before they began recording video footage of actual people acting out the scenes.

Again, this example reflects the fuzzy boundary between ideation and prototyping as discrete stages of a codified design process. Team B created the proof-of-concept video while engaging in ideation task work: The team members used analog tools to create analog design artifacts (a stack of paper sketches), which they then converted into a digital design artifact (the proof-of-concept video). Along with the instructor, they critiqued the ideas represented in that video, modified their design concept, and moved on to the next task: writing the video script.

Molly and Nathaniel decided to use Google Docs so they could work together on writing the video script. Fiona assisted Molly and Nathaniel with the script writing task; however, rather than limiting their work to a single shared document, they created and worked with multiple scripts saved as different Google Docs files. Logan helped write the script and described that collaborative process as challenging because the contents of the script were distributed across multiple shared documents.

> *We had our movie script [in Google Docs], but we had three different…movie scripts. Some of the script documents had presentation notes on it. It was getting kind of wild. (Logan 165)*

This quote is interesting because the team began using a specific tool but they did not align their understandings of how best to use that tool in support of their work. As a result, they used the same tool to generate three different source files for the same task, which caused them grief and led them to reconsider their decision to use Google Docs as they wrote their video script.

Ultimately, the team members felt compelled to perform articulation work as they struggled to complete their task work. Specifically, they decided to stop using Google Docs and switch to a combination of Microsoft Word and email when writing the final video prototype script. Logan explained that decision during his interview.

> *The one problem with Google Docs is that…there's no archive - like there's no history of previous stuff. And I remember Nathaniel was looking for something frantically, for something in the script, but we had taken that out from the script and it was lost forever. (Logan 170)*

The members of Team B found it frustrating to lose work they had created together, but they also wanted to see who had edited each part of the script and what had been changed. Based on their knowledge of Google Docs, they were unable to refer to a revision history of the work that they had already completed. Additionally, they were relying on Google Docs as the communication channel where they discussed their ideas through the revisions and comments they inserted directly into the source file. They eventually created one script using Microsoft Word so they could track their changes, identify who had made each change, and insert comments to one another regarding the changes. They shared that script via email, and again they relied on

Microsoft Word (rather than face-to-face conversations) as the site for their discussions about the script contents and their plans for who would work on the script from day to day.

As they worked on their video prototype deliverable, the members of Team B discussed the different levels of expertise they each brought to the variety of tasks required. The team members who had the most expertise with regard to video production and editing also had the most credibility when it came time to decide which tools to use. For example, because Peter worked for Adobe on the Premiere Pro team, he was the master of video recording and editing. The following image (taken on March 6, 2012) shows a tangible example of articulation work that Peter performed as he explained to his teammates how to structure the task work associated with recording video footage.

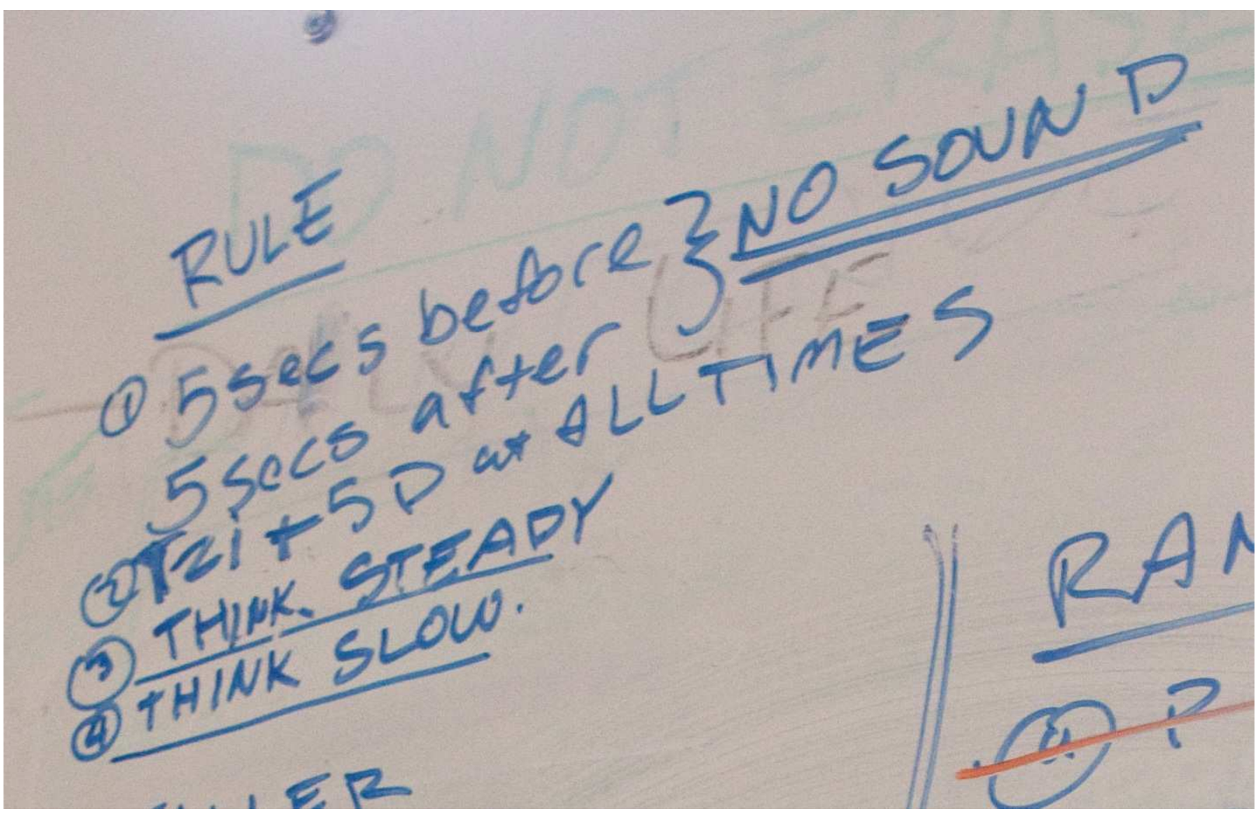

Figure 61. Example of Team B analog social artifact written on whiteboard.

This analog social artifact lists Peter's "rules" for recording footage. He wrote these rules for everyone to read so that he could explain to his teammates how he expected them to perform the tasks if he was unavailable to help out. Field notes from March 6 reveal that the other team members appreciated Peter's guidance, as they asked him to outline for them how he would go about recording video footage himself.

Finally, because Peter was the video expert given his professional background and personal interest in cinematography, he was also the team member who performed articulation work when it came time to make decisions about which specific tools to use for recording video. He insisted on using specific digital hardware tools (e.g., Canon T2i and 5D DSLR cameras) because of the superior quality video recordings they produced. He also wanted to have two DSLR cameras recording each scene, which meant that each recording session required at least three team members to be present since Molly was serving as the lead actor and could not help as much with the recording process. Nathaniel typically assisted Peter with the filming; comparatively speaking, Fiona and Logan contributed far less of their time to the recording process because they acknowledged that they were better at other tasks and activities, such as sketching (Fiona) and script writing (Logan). Again, all of these decisions describe how Peter attempted to structure the task work associated with creating the video prototype, and how all of the actors aligned themselves around the different tasks in order to set the project up for success.

Chapter Summary

This chapter contributes an understanding of how students performed task and articulation work during the study, as well as how they decided which tools to use for a specific collaborative activity. This contribution is accomplished by analyzing explores four examples of how the students in this study referenced their toolbelts and decided which tools to use as they performed task and articulation work across design stages of their collaborative design projects.

Based on the variety of data gathered for this study and discussed in this chapter, these students decided to complete their research and ideation tasks primarily by using analog tools, whereas they decided to complete their prototyping tasks primarily by using digital tools. As described in this chapter, the members of Teams A and B organized their collaborative research and ideation task work performances around whiteboards, paper, and sticky notes. For example, Nancy from Team A successfully advocated in favor of using sticky notes for her team's ideation-related task work when it became clear that whiteboards would not be regularly available for those tasks. In so doing, she was able to convince all of her teammates to incorporate sticky notes into their own toolbelts for future use on other design projects.

The members of Team B also decided to use analog tools as they worked on their research and ideation tasks. They provided clear reasons why they preferred analog tools over digital tools when they engaged in tasks during those stages of the design process. Specifically, they valued the temporary nature of the ideas that they were exploring as they performed collaborative research and ideation tasks around a whiteboard. Logan from Team B also noted that he would reference his personal notebook as he worked at the whiteboard in order to add his own notes to the broader discussion about the team's ideas.

When these teams shifted to prototyping their design ideas, they also shifted to digital tools and away from analog tools. Fiona from Team B described this parallel shift from one stage of the design process to another and from one type of tools to another.

> *I never really abandoned [one tool] for another, [instead] we transitioned to the next [design] phase, so when doing the user interface, you can draw boxes on the whiteboard as*

> *many times as you want, so you're actually making something, so then you move on to the computer. When Peter and I worked together for a UI, we would just draw on a board for a while, and then we were like, 'Okay, we both have the same idea by now. Let's go move on to the computer and actually build things.' (Fiona 171-173)*

This quote suggests that students' tool-related decisions were partly predicated on their alignment around their design ideas as they worked on their deliverables. Fiona noted that she and Peter had to agree on their vision for their user interface design before they could stop ideating and start prototyping.

Further, their prototyping task work was to take place on "*the computer*" where they would "*actually build things,*" rather than using whiteboards or some other analog tool. Anne and Khloe from Team A also indicated that they completed their prototyping tasks using their laptop computers because that was how they made their ideas more "*concrete*," to borrow a term that Khloe used in her interview. Khloe also described digital design artifacts as looking more "*polished*" than analog design artifacts, which she contrasted as "*quick and dirty*" representations of design ideas that were clearly made to invite critique and iteration. She cited the final stage of the design process (presenting) as the time when she expected to show the final version of her digital design artifact to the instructor for assessment, as well as the time when she expected to "*make [her] thought process explicit*" regarding her design concept.

This latter point is important because, although Khloe was mindful of the different design stages suggested by the instructor, the field notes for this study reflect a complete lack of students' explicit discussions about the design stages within which they were operating at any given time. In their interviews the students consistently spoke about the tool-related decisions they made as they described their processes for creating the conceptual model and video prototype deliverables, but they referred far less often to the particular *stages* of those processes.

Throughout the quarter as well, audio recordings of work sessions reveal no debates about whether team members should be engaging in ideation tasks or prototyping tasks.

Importantly, the shift from ideation to prototyping was not always obvious. The description of how Team B created their video prototype indicates the fact that the students in this study did not **always** complete their research and ideation tasks using only analog tools. However, in the context of Team B's proof-of-concept video, three team members worked very closely to produce sketches and flip through them while filming. The team collaborated around analog **and** digital tools while completing ideation tasks in a way that was simply not possible once they began using software and online tools for video editing and other prototyping tasks.

However, as the students used different tools to complete their task work, they also dealt with a great deal of frustration because of those tools. Some of the examples of frustration are basic and easily solved, as when Team B gathered around a single, large piece of paper to write their design ideas down. At the end of that task, they realized that they had all written in different directions, which made the resulting analog design artifact extremely difficult to read.

Other examples are not so easily resolved by switching tools because of the functionality tradeoffs that occur when shifting from one tool to another. Team B used a single tool (Google Docs) to work on the script for their video prototype, but they somehow wound up creating three different versions of the same script. Each of the three team members who was working on that script started a new version of the document; in so doing, they unintentionally branched off from the main document and created multiple copies of the script. Eventually, once they realized that they had no "main" document anymore but were left instead with fragments of their script across three different files, they decided to switch from Google Docs to Microsoft Word because of the limitations that Word imposed on their collaborative task work. Whereas they could all work simultaneously within the same Google Docs file, they were forced to take turns independently editing the Microsoft Word file before sending the file via email to the next team member whose turn it was to modify the content.

Finally, this chapter has intentionally framed students' collaborative work in terms of their performance of task and articulation work. The definition of articulation work applied here offers a relatively limited way of characterizing how the students collaborated with each other, however, partly because this definition only considers adjustments made within, and not across, activities. To truly understand students' collaborative work practice, it is necessary to consider how students performed metawork during their design projects.

In his 2007 article, Gerson uses the phrase "increased reach" (p. 194) to explain a variety of phenomena related to the ways in which people accomplish collaborative work. One of his essential points is that, as task work becomes "more intensively computer-supported" and "markedly more complex" (p. 195), researchers need more powerful ways to document the complexities of articulation work that occur as actors collaborate with one another. One of his suggestions is to draw a distinction between local articulation work and metawork. This chapter has described multiple examples of "local" articulation work performances by examining students' tool-related decisions in the context of how they structured and adjusted their task work on specific activities (e.g., the tasks completed for the conceptual model deliverable).

By contrast, students' metawork performances impact the structure and outcome of *multiple* activities within an arc of work, not just the local circumstances of a task within a specific activity. The next chapter explores four examples of metawork performances; each example traces how seemingly simple tool-related decisions rippled across the entire arc of work for the students' projects. The resulting discussion enhances the current understanding of metawork at a conceptual level by describing how specific metawork performances played out among the students in this study as they collaborated on their design projects.

Chapter 6. Tracing Students' Metawork Performances

This chapter extends the discussion from Chapter 5 about tool-related decisions and students' performance of work by describing how students perform metawork on collaborative design projects. The specific contribution of this chapter is to characterize how and why students performed metawork when they made tool-related decisions that impacted multiple activities within their projects. However, while the concepts of task work and articulation work are well studied and clearly understood, the concept of metawork remains undertheorized.

Therefore, this chapter begins with a deeper investigation of the differences among task work, articulation work, and metawork as the foundation for understanding how students perform different types of work as they collaborate on design projects. Next, a review of the definitions of inscription and conscription devices is presented, along with a discussion about how actors use conscription devices to enlist allies. That discussion explains how actors' use of conscription devices are useful as a way to trace their performance of metawork across activities within an arc of work. Specifically, actors who are collaborating on a design project perform metawork when they negotiate which design artifacts best represent their overall design concept, as well as which tools they should use to modify those artifacts.

After the initial discussion of relevant concepts, this chapter presents four metawork performance examples described in the context of students' use of conscription devices as well as their use of tools as allies and their use of artifacts to enlist allies. The chapter concludes by describing how metawork differed in practice from task and articulation work, as well as how the students attempted to simplify the metawork associated with their projects. Whereas Chapter 4 addressed the first research sub-question by documenting the constellation of tools and artifacts that university students use and create to support their collaborative work, the analysis presented in this chapter as well as the prior chapter addresses the other research sub-questions:

- How do they decide which tools to use to support their collaborative work?
- How does their performance of different types of work organize, facilitate, and constrain their collaborative project work?

Specifically, Chapter 5 addresses these questions in the context of students' task and articulation work performance as they accomplished specific activities within their projects. The present chapter builds on that analysis by considering how students perform metawork as they use tools and artifacts to negotiate how to align and structure multiple activities across their projects.

Distinguishing among Task Work, Articulation Work, and Metawork

Chapter 5 specifies the differences between task work and articulation work. In summary, the students in this study performed task work when they carried out the wide assortment of jobs required to complete each activity. They performed articulation work when they identified and obtained the resources they believed they needed to complete their task work, and when the local circumstances associated with an activity changed such that they had to adjust their strategies for completing the tasks associated with that activity. No matter how clearly and specifically the members of a team define a task and the resources required to complete it, local circumstances inevitably change. When that happens, the team members must realign resources or redefine the tasks as needed. As a reminder, Chapter 2 defined "resources" as the actors on a project, as well as the tools and artifacts they use in order to complete specific actions on a given project.

Importantly, task work and articulation work occur in the context of a specific activity. Gerson (2007) and Schmidt (2011) both describe articulation work as occurring in the "local" context of a specific activity within an arc of work, which comprises multiple different activities.

For the students in this study, the course assignments were the activities that described the arc of work for each team. Each assignment represented a different “class” of activity since every assignment required the completion of different tasks. However, although the arc of work might have been the same for every team of students in this study, the members of each team pursued different design concepts, approached activities differently compared to their peers, and produced unique deliverables.

The concept of metawork is primarily a topic of discussion among researchers within the computer-supported cooperative work (CSCW) community. For example, Gerson (2007) and Schmidt (2011) both contrast articulation work and metawork by describing articulation work as situational and metawork as classificational. Stated differently, for Gerson and Schmidt the concept of metawork describes the work of deciding how to coordinate and integrate classes of activity. From this perspective, when the students in this study discussed how they would structure different activities so they could rationalize the output from one activity with another, they were performing metawork because they were aligning classes of activities and not just the tasks within a particular activity.

With this background in mind, it is fair to suggest that the students in this study performed metawork when they negotiated *how project resources should be aligned across activities, as well as why those particular resources should be aligned in that way*. This definition implies that metawork efforts pervade collaborative project work, such as when two actors negotiate whether a third actor should be assigned to a particular type of action throughout the project, or how a task should be carried out with the total arc of work in mind. Further, this definition implies that students perform metawork when they attempt to mesh actors with actors, or actors with tasks, across activities.

Defining Bracketing and the Need for Rationalizing Activities

It takes a great deal of effort, however, to mesh actors and tasks across activities. The complexities of trying to align different human actors across a diversity of tasks is daunting, as is the challenge of structuring multiple task sequences such that those actors will complete each activity correctly and set up successive activities for success. As stated in Chapter 2, members of collaborative teams use brackets to simplify relationships across activities by rationalizing those relationships in different ways (Gerson, 2007, p. 198). Segregating rationalization involves separating “complex tasks…into multiple independent tasks” and “making things independent of one another, removing the connections or contingencies among them wherever possible” (p. 198). Standardizing rationalization entails making “connections and relationships among things uniform” (p. 198), where “things” can be interpreted as tasks or as actors. The goal of this form of rationalization is to simplify the activities associated with an arc of work so that “more gets done with the same resources” (p. 198).

Finally, coordinating rationalization occurs when team members continuously “[refine] relationships so that they are particularly well-suited to their situation” (p. 198). Specifically, “within a given activity, tasks are made more responsive to one another by removing everything that does not contribute directly to smooth functioning and by strengthening everything that does” (p. 198). The actors on a project accomplish coordinating rationalization partly through ongoing efforts to “fine-[tune] interacting parts so as to make them accommodate one another’s peculiarities” (p. 199).

This discussion about rationalizing the relationships among activities within an arc of work is germane to this chapter because the students in this study attempted to create brackets for the different deliverables they had to produce. Actors on collaborative projects engage in bracketing when they specify how activities within an arc of work mesh with one another by defining the characteristics of those activities such that they are complementary yet distinct. This information makes it easier to know how to specify the task work across activities in order to achieve the desired final product. Gerson also points out that bracketing reduces the complexity of the metawork that is performed when determining how parts of an information system should interact with one another (p. 197).

The students in this study did not spend their time trying to align parts of an information system, but they did have a similar job to do: They had to align actors and tasks across 10 different deliverables and decide how the output from each activity would feed into the next activity. The deliverables they created had to complement one another, yet they also had to be distinct reflections of their progress toward a final product. For these students, the arc of work was their sociotechnical system, and the actors and tasks comprised the parts.

In theory, then, metawork should be observable by carefully documenting instances from the students' projects when they made decisions about how to align or structure their task work **across multiple activities** within the arc of work for their project. Such alignment efforts involved deciding which team members would always work on specific kinds of tasks that were required for more than one activity (e.g., editing video footage), or how those tasks should always be designed regardless of the activity for which they were being completed. In practice, however, metawork performances are challenging to identify because team members did not always realize that decisions about resource alignment and task definition would impact the entire arc of work from that point on. In other words, the students in this study did not always know that they were performing metawork.

Given that the students all had personal toolbelts stocked with the tools they preferred and knew how to use, it is reasonable to assume they advocated those tools partly because they could accomplish their task work more efficiently using those tools. As discussed in Chapter 2 in the context of project-based learning, students are generally interested in simplifying the task work required across activities and want to get their tasks done as efficiently and as quickly as possible (cf., Volet & Mansfield, 2006; Yacci & Rozanski, 2011). These students engaged in bracketing when they made tool-related decisions that affected task work across multiple activities. Stated differently, when students attempted to mesh tools across activities, they performed metawork **whether they realized it or not**.

These performances can be traced by analyzing the specific artifacts that students created and used to represent their design concepts in team discussions and with actors outside the team. Four instances of these artifacts are discussed in this chapter in the context of the tool-related decisions that led to the creation of those artifacts. First, however, the actor-network theory (ANT) concepts of inscription and conscription devices, as well as the enlistment of actors as allies, are described to set the stage for that discussion.

Characterizing Artifacts as Inscription Devices

ANT scholars have attempted to characterize the ways in which human actors collaborate with and through non-human actors, such as the artifacts and tools created and used during design projects. Chapter 2 presents an initial discussion of enlistment and the social construction of knowledge through inscriptions. This discussion is expanded upon here in order to provide necessary background information about the concept of conscription devices, as well as how this concept relates to the performance of metawork on design projects.

Bucciarelli (1994) and Henderson (1991, 1999) both studied engineering design teams, and both scholars have theorized about what happens when people with different knowledge bases, different lived experiences, and different points of view form a team and work on a design project together. Given their disparate backgrounds, team members must rationalize their different design perspectives and ideas so they can successfully complete their project. That rationalization effort is “a social process of negotiation and consensus” (Bucciarelli, 1994, p. 20) whereby design team members try to “bring their stories into coherence” (p. 83).

Bucciarelli claims that the artifacts that team members create during the design process are the awkward expressions of their negotiative, consensus-building social processes. The sense of awkwardness reflects the fact that the members of a team engage in contested collaboration when they attempt to create a design product together; they bring their own unique perspectives to their collaborations and “[fix] them in the artifact” (p. 186). Similarly, according to Henderson (1999), design artifacts are the “arena in which negotiations can be held” (p. 200) about the design idea, which is developed and captured in various forms during the project.

Henderson (1991) draws upon the body of social science literature regarding the construction of knowledge and refers to engineering design artifacts as the “inscriptions” (p. 451) that design team members generate while they work together. The **inscription devices** that members produce “socially organize the workers, the work process, and the concepts workers manipulate in engineering design [projects]” (p. 452). Additionally, inscription devices are the “social glue” that team members use to describe how they intend to reach their design and project goals (Henderson, 1999, p. 133-4).

The meaning of these devices can be interpreted in different ways because team members bring different perspectives to bear on their project work. Henderson cites this potential for different interpretations as a positive quality of inscription devices. When teams engage in contested collaboration, members gradually (and sometimes painfully) try to achieve consensus about their design idea by iterating inscription devices independently and collectively until they create a final product, which includes elements of some or all of the team members' design ideas.

Identifying Conscription Devices and Enlisting Allies

Achieving consensus is a challenging process because team members must handle issues of authority and control as they iterate their inscription devices. The stakes are high when team members negotiate "the form that knowledge will take…the use or nonuse of that knowledge…control of workers and work, and access to material and labor resources" (p. 134). Authority over the team's progress is established gradually during a project, as decisions are made regarding which design directions the team will take. The team member who wields the most authority, and by extension the most power, is the one who exerts the most control over the form and function of the final design product.

Henderson suggests the term "**conscription devices**" (p. 53) to describe the specific design artifacts that team members use to represent their mutual understanding of their design concept, and through which they attempt to modify that concept by enlisting actors as allies who will support their ideas. They also enlist tools as non-human allies: Tools are a necessary component of conscription devices because they mediate team members' engagement with visual representations of their ideas, as well as assist communication among actors (e.g., other team members, the instructor). The concept of the toolbelt is important here because team members prefer to use certain tools for different design tasks and activities, and because they are more likely to enlist preferred tools as allies when working with conscription devices. Clearly, tool choice is important given the ways in which different tools enable and constrain how ideas can be represented for discussion (cf., Bardzell, 2007).

For this reason, conscription devices are best thought of as dynamic, contested sites of meaning, or as sets of practices and decisions, rather than specific objects. Team members' struggles for control over the final design product play out with, through, and around conscription devices. They negotiate which visual representations best reflect their design concept, as well as which tools they want to try and enlist as allies when modifying those representations. Henderson also notes that conscription devices act as boundary objects because team members rely on them to facilitate multiple interpretations of their contents depending on who they are trying to enlist as allies.

Tracking the Use of Conscription Devices Using Metawork Performances

The students in this study completed the task work for specific activities using specific tools, and they performed articulation work when they selected tools for those tasks. When the students decided to enlist tools as allies that they used in that capacity across multiple activities, they performed metawork because the ramifications of those decisions extended across multiple activities. However, given that the students in this study could not know how the results of their negotiations, decisions, and enlistment efforts might impact the rest of their project work, it was necessary to gather the data for this study progressively and retrospectively using a mixed-methods approach. Observations of team meetings were made on a regular basis as the quarter progressed, and detailed field notes were made during those meetings. Audio recordings, video recordings, photographs of team work sessions and artifacts, and informal interviews with individuals or entire teams rounded out the data set for this project. The semi-structured interviews that occurred after the quarter ended asked the same questions of every student about how they tracked the overall vision for their designs and products, as well as other questions about specific deliverables and their processes for selecting tools to use while working on those deliverables.

The application of these methods produced a data set that describes metawork performances within teams and across team members. Specifically, the four performances discussed in this chapter characterize how the students in this study used specific visual representations to discuss their design concepts and enlisted tools as allies across activities within their projects. These performances document how they struggled with their teammates to control how their final design products would look, and the examples provided here reflect how they worked with, through, and around conscription devices as their projects played out.

Performing Metawork Using Adobe Illustrator as an Ally

All of the teams were required to complete 10 different assignments throughout the academic quarter. The instructor designed the syllabus and the progression of those assignments such that the students could iteratively improve their design concepts by revising and improving the deliverables they created for each assignment. For example, the first team activity was the design project description presentation, which was meant to help teams externalize their first thoughts about their design ideas so that the instructor and other students could review and assess them. All of the teams presented digital design artifacts to everyone in the class as their deliverables for that first assignment.

Five of the six teams in this study used Adobe Illustrator during the academic quarter, and all five of those teams used Illustrator to create their design project description deliverables. The only team that did not use Illustrator (Team F) used Adobe InDesign instead. Nancy from Team A characterized Illustrator as the most popular tool among the interaction design students, all of whom included Illustrator in their personal toolbelts and all of whom owned a personal copy of the tool.

> *On the computer, Illustrator was…the dominant tool. And I got the sense that…the whole class was using Illustrator a lot for everything. So I think Illustrator is like the interaction design student's multi-tool. [They] use it for anything that doesn't need to move. (Nancy 187)*

This quote from Nancy highlights the flexibility of Illustrator as a tool, which she likens to a multi-tool with many blades and attachments. She also notes that the interaction design students used Illustrator for task work that did not involve animation. Field notes support Nancy's comments: The members of every team (except for Team F) used Illustrator to create presentations, storyboards, user experience walkthroughs, and other artifacts throughout the academic quarter.

The members of Team A used Illustrator in some capacity on every team-wide activity they were required to complete. The initial decision to complete task work with this tool is traceable to a specific choice that Anne made after the team's January 12 work session but before their next work session on January 16. When the members of Team A met on January 12, their discussion primarily centered around their performance of research and ideation task work. During the last 15 minutes of their work session, the members of the team realized that they needed to figure out how to create their design project description deliverable for the January 17 course session. They expressed their feelings of confusion to one another about which tool to use to create that first deliverable. The syllabus described the deliverable using the word "presentation," which the students found particularly enigmatic. They talked about how to make a formal presentation using tools with which they had some familiarity (e.g., Microsoft PowerPoint). They also discussed the idea of trying out a new tool to make their presentation (Prezi), but decided against using a tool that none of them had personally worked with in the past.

Team A concluded their January 12 work session without having decided which tool to use. When the team met again on January 16, Anne surprised her teammates with her independent work on the design project description deliverable. During the intervening four days, Anne had decided to shift from ideation to prototyping, so she had begun using Illustrator to translate the team's analog design artifacts into digital form. Her presentation of this file to her teammates at their January 16 work session reflected her performance of metawork because she used the significant progress she had already made with that deliverable as an excuse to continue using Illustrator for that assignment as well as the next assignment. Put simply, Anne had decided to enlist Illustrator as an ally, and she wanted to continue working with Illustrator in that capacity for the rest of the project. Nancy explained how they made that decision at that work session.

> *[Anne] had done some of [the work] beforehand and then basically we had a graphic…and she put some original text, like her thoughts. And then she was changing the text as we were talking, and then she was actually changing the graphic while we were talking. When you're good at Illustrator you can do things really quickly. Unfortunately, I don't know how to do that. (Nancy, informal interview, January 17, 2012)*

In this quote, Anne explained how she was able to convince her teammates that the visual representation of their design concept that she had made using Illustrator accurately reflected their design concept. Her teammates agreed to use the Illustrator source files as the visual representation of their design concept, which they showed to others as an indication of their current thinking about their project. Their use of Anne's file in this way also led them to physically configure their work around Anne and her laptop computer during future work sessions. In this way, she established a specific design artifact and the tool she decided to use to produce it as a conscription device. Anne had successfully enlisted Illustrator as an ally, and she was able to drive the team's work sessions through her use of that tool over the next several weeks of the academic quarter.

Anne's domineering approach to collaborative work was a topic of discussion in interviews with her teammates after the end of the academic quarter. Although four team members included Illustrator in their toolbelts, only Anne preferred to use that tool over similar tools (e.g., Adobe InDesign). Kylie and Khloe both indicated in their interviews that they knew how to use Illustrator, but neither preferred to use that tool because they were more proficient with other tools like InDesign. Bae had also used Illustrator before but primarily used Photoshop in support of his project work. Nancy did not know how to use Illustrator at all, although she acknowledged that she needed to learn the tool if she wanted to succeed in the design community.

> *I need to learn [Illustrator] though, people only want designers who know how to use Illustrator. I need to learn how to use it. I own it, but I need to learn how to use it. (Nancy, informal interview, January 17, 2012)*

This quote from Nancy is interesting because even though she owned a personal copy of Illustrator, she had not spent the time required to learn how to use that tool. Instead, Nancy preferred to use tools such as Keynote and Microsoft PowerPoint when developing presentations.

Because her teammates were less adept at using Illustrator, or because they preferred to use other tools, Anne was able to exert control over the design vision for the project by enlisting Illustrator as an ally and by refusing to share the source files for the team's deliverables. She maintained this practice throughout the project: Because the design project description deliverable became the foundation for all of the work that followed, Anne continued using the

Illustrator source files she made as the basis for the next activity (the conceptual model presentation) and for several other activities that built on that design project description deliverable.

Nancy described how Anne limited access to those source files by keeping them on her computer and by positioning herself as the gatekeeper for all changes to those files.

Nancy: Anne had several massive Illustrator [source] files.

Alex: Were those files that all of you were able to view?

Nancy: No. They were only on [Anne's] computer.

Alex: Oh, so did she share them with everyone or did you just look over the folder?

Nancy: She would show them to us.

Alex: So was there any kind of [file] distribution or Dropbox or that sort of thing?

Nancy: No. (Nancy 099-111)

In this exchange, Nancy described how Anne withheld access to source files, only showing the contents of those files to her teammates during work sessions. Unlike the variety of other files that team members created and shared via Dropbox or another tool, Anne kept the several Illustrator source files on her personal laptop throughout the quarter. This behavior aligns with Henderson's (1999) description of how team members guard conscription devices "from exposure to unwanted input" (p. 53).

Again, this decision can be traced back to Anne's performance of metawork at that January 16 work session when she successfully enlisted Illustrator as an ally. In so doing, she developed the authority within Team A to constrain the ways in which her teammates could collaborate, which meant that she was able to dictate how tasks would be performed across activities and how resources would be aligned to complete those tasks. Nancy explained how she was only able to help iterate her team's design ideas by working directly with Anne.

> *[Anne] took over the project and I was allowed to help, and then [Anne] started scheduling all the [meeting] times. So all the time that she was working, she would invite me too, but then we did the equivalent of pair programming. So [the file] was still on her computer, but we were talking through all the points and sketching things on pieces of paper, and then she would make [the deliverable] in the Illustrator file. (Nancy 115)*

The following photo (taken during their February 28 work session) shows a typical instance of Team A physically orienting their collaborative work around Anne and her laptop.

Figure 62. Team A orienting their collaboration around Anne (seated at laptop).

This photo reflects the fact that Anne controlled the work that Team A performed in the weeks that followed their January 16 work session. Kylie described how Anne exerted control over her teammates throughout the academic quarter.

> *[Anne], from the very beginning, had a vision. [Laughs] And you could tell because she was very adamant about her vision, and if something didn't fit it, she would yell at you. (Kylie 043)*

Similarly, Nancy explained how Anne controlled the team and their vision for the entire design concept on which they worked throughout the quarter.

> *Anne took over and then the [project] vision was inside of her, so that was easy to keep track of. As much as it is incorrect protocol for one person, [she] did take over: 'I'm doing everything. You can help if you want to and don't get in my way.' (Nancy 091)*

These quotes align with the results of observations and field notes, as well as with Anne's own description of her performance during the quarter.

> *I think I just took initiative on everything, I think. I was just like, 'I'll do it. I've got this.' I think most people were like, 'Well, when can we get together again and do this?' And I was like, 'You know what? I'll just do it.' (Anne 145)*

In summary, although the members of Team A used other tools as they worked on their tasks and activities, Anne asserted control over the team's design vision when she established and continued using Illustrator as an ally in her quest to situate herself as the center of power within her team. She was quite successful in this endeavor as she was able to limit her teammates' contributions to tasks and activities, as well as their ability to modify the overall design vision, because they did not prefer to use (or even know how to use) Illustrator. Additionally, they were typically unable to modify source files unless Anne was there to perform that work for them. Anne successfully imposed that limitation on the team because all five team members agreed at their January 16 work session to let Anne continue using Illustrator to work on their first assignment.

In retrospect, Anne's performance of metawork at that work session changed how the members of Team A collaborated with one another for the rest of their project. She established her visual representation of the team's design concept and her use of Illustrator to modify the sources files as the conscription device, around which the rest of the team had to physically collaborate if they wanted to incorporate their own ideas into the design vision.

Performing Metawork Using a Whiteboard and Markers as Allies

All six teams used a combination of various paper form factors, sticky notes, and whiteboards in support of the collaborative research and ideation tasks they performed on each deliverable. At times these kinds of tasks involved multiple team members using the same analog tool simultaneously. In these situations, multiple team members wrote and sketched around a specific topic related to their design concept. As they worked, they erased, scratched out, redrew, or added details to the inscriptions that each team member made.

As an example, the following photo shows how the members of Team E worked with the same sheet of poster paper at their February 9 work session.

Figure 63. Team E collaborating around poster paper.

In this photo, Arlene and Erica are both using markers to write notes on the poster paper, while the other three team members look on. Carl and Timothy are both referring to personal notes as Arlene and Erica write, and field notes taken during this work session reveal that other members of Team E also wrote on the poster paper throughout the session.

While this photo shows how Team E collaborated using a specific analog tool during their research and ideation task work, other teams of students in this study did not always work with analog tools in such an egalitarian way. For example, at their first work session on January 12 the members of Team D left the classroom space and went to another room so they could use a whiteboard. Although they used whiteboards in concert with other analog tools throughout the quarter, their ideation tasks throughout the quarter were always physically centered around whiteboards from that point on. Even when they used sticky notes, they placed their sticky notes on whiteboards so they could draw connections between the ideas they had written on those notes.

During the work sessions when they performed ideation tasks (e.g., brainstorming), the members of Team D preferred to let one team member write down everything that was being said rather than gathering around the whiteboard and collectively writing notes or sketching ideas as they talked. Therefore, the task work that Team D performed during the research and ideation stages of their design process involved one team member standing at a whiteboard taking notes as the team broadly discussed aspects of their design concept that they needed to explore, sketch, or refine. Delilah was the member of this team who typically took notes at the whiteboard because she was the only team member with access to the room in which the markers were kept, and because she happened to know where in that room the markers were typically stored. Field notes reveal that serviceable markers were often hard to find throughout the academic quarter, as other students used the same classroom and the "good" markers would go missing between course sessions.

From Delilah's perspective, the team member who took notes on the whiteboard wielded a lot of power over that team's design ideas partly because they created the durable record of what was being discussed as they worked through their ideation tasks. As the note taker, Delilah felt she had a responsibility to get everything down as accurately as possible, although she still "missed" some details from time to time.

> *Not everyone felt they had the right to get a marker…it was one [person's] responsibility to write down everything that was being said, and some stuff was being missed. (Delilah 051)*

Delilah expanded on this point by claiming that, aside from bearing a sense of responsibility for the content, the person taking notes possessed an implicit amount of authority as the curator of the team's discussion.

> *I feel like the person with the pen…[was] the person with authority, when really they're just trying to provide a kind of practical service of recording everything that everyone's saying. But ultimately they ended up kind of curating what actually gets put up on the board… if it's one person documenting for the group, it can end up…not reflecting the whole group's conversation. (Delilah 057)*

Delilah suggested that the person wielding the marker had a great deal of control over how the team's discussions and ideas were represented. Because she was the only team member with access to the whiteboard markers, she was usually the person who held the marker and was in control of recording the team's conversations. However, she did not simply transmit the verbatim contents of what she and her teammates said. Instead, she curated the discussion by making a number of choices about how to represent that discussion as it occurred.

For example, Delilah pointed out that whomever took notes explicitly structured those notes as the conversation proceeded.

> *As I or anyone else writes, they would organize the things they were writing on the board within sections…the organization itself is something that usually came from the person writing, rather than from the group…. Sometimes ideas came so fast, or were so unrelated…that they would just end up on the board, and other things would start to accumulate based on the person who was writing them and trying to organize it. (Delilah 067-069)*

As Delilah described her team's process, the pace of their conversations and the flow of ideas necessitated a lot of writing at the whiteboard. Rather than slowing those efforts by asking questions about how to capture the discussion, Delilah attempted to structure the ideas and concepts that were being discussed as she wrote everything down. She was indeed curating the details of her team's ideation tasks because she was in charge of producing discussion summaries rather than precise records of those discussions.

It was clear from her interview that Delilah situated herself as the team member who always recorded notes when the team performed ideation tasks because she understood the value of enlisting the whiteboard and markers as an ally. If she had not taken up that role and had instead handed the marker over to another teammate, she would have ceded control over the note-taking process and relinquished her chance to subtly imbue the team's ideas with her own perspective. The summaries that Delilah created using the whiteboard became crucially important later in the academic quarter because, according to the three members of Team D who participated in interviews (Baron, Delilah, and Isole), they did not formally track their design vision throughout the quarter.

Instead, according to Delilah, she and her teammates referred to the photos they had taken of her whiteboard notes during the last few weeks of the quarter as they worked on prototyping tasks and tried to decide whether they were still in alignment with regard to their design vision.

> *There were some critical times when we were making decisions about what the direction was of the project…where we would look back at photos we had taken of our brainstorming sessions. I would take photos of – this was something we did consistently – take photos of the whiteboard…and look back at some of the initial variations and ideas we had early on. And [we'd] use that to help us understand whether there was an alternative direction for where we were going, or if we had gone down a path, a single theme, that we realized from earlier on we had pigeon-holed ourselves into. (Delilah 083)*

By centering later design discussions around the notes that Delilah wrote earlier in the quarter, the members of Team D reified the value of that information to their overall design vision and extended its usefulness across activities. In so doing, they situated those notes as a conscription device because their negotiations around how to proceed with their design concept occurred with, through, and around the photos of the notes that Delilah had written.

In this example, the metawork performance is challenging to trace precisely. The team members collectively decided to use the whiteboard as their preferred tool for ideation tasks across all activities in their arc of work. Weeks later, once they were more focused on prototyping their design concept using software tools, they referred to the whiteboard notes that were written when they were performing ideation-related task work so they could determine how to adjust their design concept. In this way, although the team collectively (and tacitly) made the decision to use the whiteboard, Delilah found a way to enlist that tool as an ally in her quest to infuse her design ideas and perspective into the team's final product. She was the team member who typically controlled the marker as she and her teammates worked around the whiteboard. She was also the one who took photos of those notes, ensuring that her curated version of the team's ideation task results could be referenced later in the quarter. However, at the time when she authored those notes, Delilah did not necessarily know she was performing metawork, nor did she and her teammates realize how important their decision to use the whiteboard and let Delilah take notes would turn out to be later in the quarter as they shifted from ideation to prototyping task work.

This point about their lack of awareness regarding this metawork performance is important because the decisions and actions described here reflect the tacit attempts that the students in this study made to control their teams' design concepts. These students did not use terms such as "metawork," "ally," or "conscription device" during work sessions or when describing in interviews how they went about completing their project work. Instead, they engaged in behaviors reflective of these concepts without necessarily making their intentions known to their teammates. By contrast, the next two sections describe metawork performances that occurred when certain students intuitively recognized that specific artifacts and tools were being used together to create conscription devices, and they adjusted how they negotiated design-related decisions within their teams as a result.

Performing Metawork Using a Visual Representation as an Ally

Every team created and worked with conscription devices during the study. For example, during one of Team B's work sessions that occurred early in week six of the academic quarter, the team members collectively developed an analog design artifact that they felt reflected their design vision most accurately. The essential idea motivating their design concept was to help people live healthier lives, so they were working on developing a mobile app and associated Website.

Additionally, Team B used the same three whiteboard panels in the classroom throughout the entire quarter, which meant that they took notes and sketched ideas without fear of erasure between work sessions. For this reason, the members of Team B were able to reference the analog design artifact described above until they chose to erase it from the whiteboard. In this way, they used that particular artifact as a conscription device because they relied on the details presented in the artifact as a way to explain their app and Website interface design details to others outside the team.

One of the ways in which the students performed metawork was by making changes to specific design artifacts that were already being used as conscription devices. In so doing, they subtly inserted their own ideas into a broader design vision. Logan from Team B engaged in this practice: He used the phrase "anchoring artifact" to refer to the analog design artifact described above, which Team B had been using as a conscription device. The following photo shows that conscription device, as well as Logan pointing to a particular detail of the artifact.

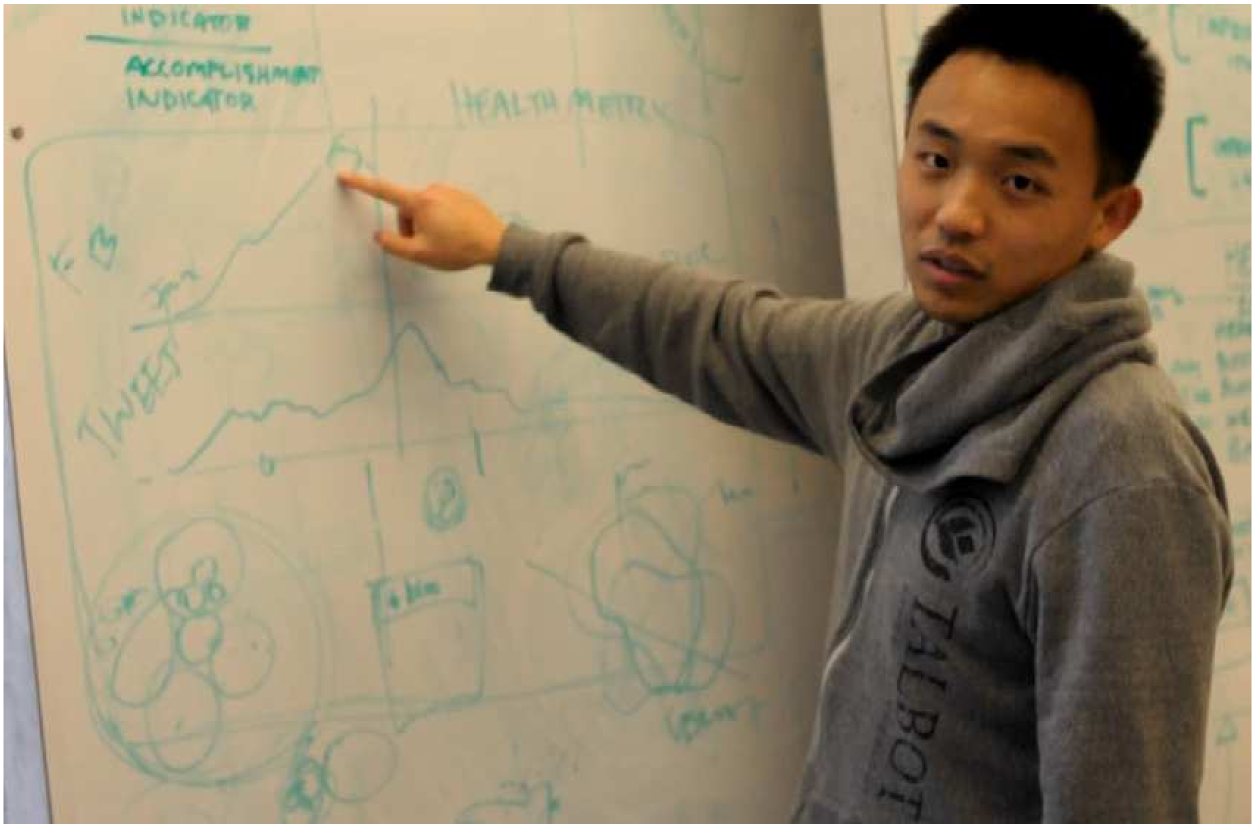

Figure 64. Logan (Team B) pointing out an “anchoring artifact.”

In this photo, Logan is pointing to a circled part of the sketch that he himself circled to emphasize a particular design idea he wanted to discuss with the team. As stated earlier in this chapter, designers create and rely on artifacts to externalize their ideas, and they use those artifacts to align their design “stories” with one another. The negotiative efforts that occur with, through, and around conscription devices are an important part of that alignment process. The members of Team D went through this alignment process by designating the visual representation shown above as critical to their understanding of their design concept. In so doing, all of the team members chose to align their design vision around that sketch, making it a conscription device around which future discussions about their design had to occur.

Logan recognized that if he wanted to incorporate his own ideas into the team's design concept, he needed to build consensus for his own idea somehow. He could have tried to create an entirely new design artifact for discussion, but he knew the team members had already gone through the process of aligning their design thinking around that existing sketch. Therefore, he chose to enlist an important visual representation as an ally and then add his own modifications to that representation.

> *I used the [anchoring artifact] phrase because we had all agreed that this [sketch] was important somehow…. We decided that this artifact that we created together was something that we all agree on and it's important.*

Logan continued by explaining why he added the circle to the sketch during the team's work session that day.

> *I was just trying to take advantage of the [anchoring artifact] so that I could introduce an idea using an already existing idea, building on something that we already agreed upon.*

Logan acknowledged in this quote that he knew the best way to get his point across to his teammates was to modify an aspect of the conscription device they had created together. In so doing, he hoped to exert control over the interface design concept that his team collectively established by embedding his idea within their agreed-upon visual representation of that concept.

Logan was quite interested in getting his design ideas integrated into the overall vision for the team's final product. During his interview, he described how that process had been challenging at the start of the academic quarter when he and his teammates worked on the conceptual model deliverable (the second team assignment).

> *Nathaniel and Molly were drawing a conceptual model on their own, and then I was drawing a conceptual model on my own on a whiteboard, and we spent like an hour and a half or maybe two hours just working separately. And then we came together, and I didn't win. (Logan 145)*

Logan described how Team B externalized their ideas by creating individual design artifacts that led to a discussion about which artifacts reflected the team's overall design vision for their conceptual model. He used the word "win" to characterize the way that his teammates selected another idea over his own as the basis for their conceptual model. A few weeks later, however, Logan chose to enlist part of a conscription device as an ally and modify it in order to win support for his design idea (rather than creating a separate, competing artifact).

Logan's use of the word "win" also reflects the appropriateness of the phrase "conscription device" with regard to describing the process of aligning disparate design stories around a single concept. Conscription devices enlist team member participation in a design concept or vision in exactly the way that Logan described above when he discussed how he modified the conscription device his team had previously created. The following photo shows an example of what it looked like when Logan spoke to the rest of his teammates (only Molly and Fiona are pictured) and tried to convince them to incorporate his modifications into their interface design concept.

Figure 65. Logan (Team B) modifying a conscription device to pitch his design idea.

At the moment when this photo was taken, Logan was sketching a red line on top of the "anchoring artifact" shown earlier. He was speaking about how the red line that he was drawing reflected his own insight into how the user interface for the team's design idea should be developed. As a result of that discussion, the rest of the team agreed with his idea, which meant that Logan's strategy of modifying the details of the conscription device was successful as it influenced his teammates' thinking about how to iterate a specific aspect of their design concept.

This example of a metawork performance is interesting because Logan decided to realign the details of a conscription device in order to get his ideas included as part of the team's overall design concept from that point on. As Logan stated in his interview, he knew that if he could get his idea incorporated into a visual representation that the team used as an "anchoring artifact," his teammates would record images of the modified sketch and refer to them at future work sessions without questioning the qualities or meaning of their content. Ultimately, that is exactly what happened: The team referenced that modified sketch to inform their design thinking across multiple activities, and because Logan modified the contents of the sketch during its useful life as a conscription device his ideas were reflected in the final design product.

Performing Metawork Using a Social Artifact to Enlist Additional Allies

The students in this study relied on Facebook for their initial recruiting efforts when teams were forming. They regarded Facebook as an unobtrusive way to approach other students whom they did not personally know, but with whom they especially wanted to work. For example, Holly described wanting to get Norbert on her team because the level of his Adobe After Effects and Adobe Flash skills were unique among the students in the course. Given Holly's intense desire to win the design competition in the course and present at the Microsoft Design Expo, she successfully recruited Norbert using Facebook before the academic quarter had even begun.

After the teams had formed during the second week of the academic quarter, three of the six teams in this course continued to use Facebook for internal communications. Team B was one of the three teams that decided to use Facebook for asynchronous communication, along with a variety of other tools (e.g., email, Pinterest, team-wide blog) that were all designed to support communication through the creation and sharing of social artifacts. Although the members of Team B did not rely exclusively on their Facebook group page for all of their internal communication throughout the academic quarter, they did come to rely on their group page as a conscription device across every design stage for multiple activities within their arc of work.

The following screenshot shows a portion of the Team B Facebook group page, along with callouts that describe the purpose of each specific entry, comment, link, and so on.

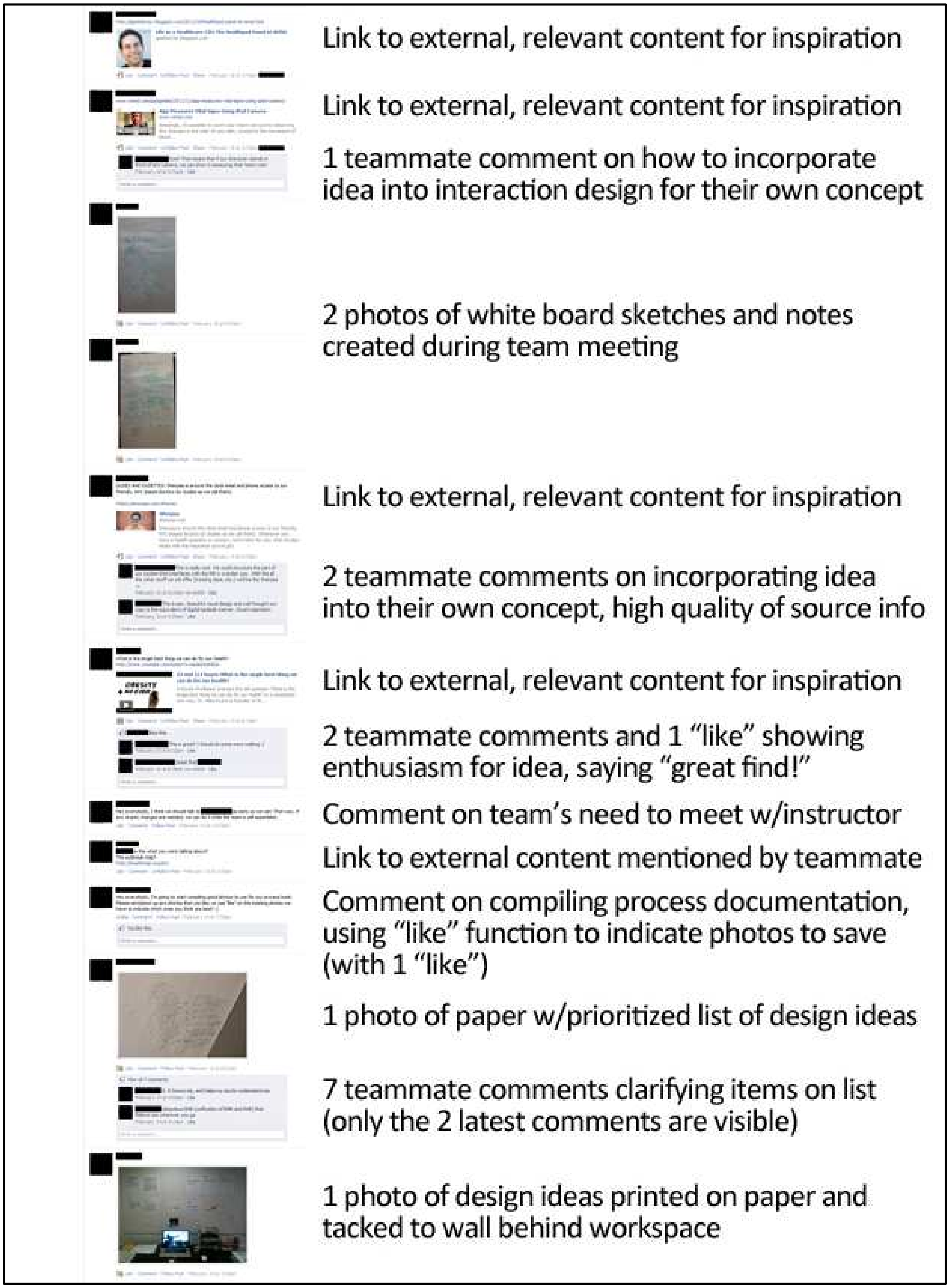

Figure 66. Segment of Team B Facebook group page.

Note that this screenshot is the same as the one shown earlier in Chapter 4, but is presented here to show a snapshot of how the members of Team B used their Facebook group page as a digital social artifact throughout the academic quarter. Statistics drawn from their group page indicate that the members of Team B referred to this page throughout the academic quarter and beyond. They posted 106 unique entries on their page between January 10 (the day when Fiona created the page) and April 4 (a few weeks after the academic quarter had ended). Additionally, there were 70 different comments added to those entries and 14 “likes” of specific entries.

This screenshot also shows some of the ways in which the members of Team B used their Facebook group page at different stages of their design process within different activities. For example, they shared their own personal design ideas, as well as sources of relevant information that existed elsewhere in the world. They published photos of the analog design artifacts they created collectively as the result of research and ideation task work, including meeting notes and design ideas; the expectation was that everyone on the team would review those photos. They talked about how to elicit feedback from their instructor as a way to strategize about their next critique. They also used the commenting feature included within Facebook to leave responses on each other’s posts, to clarify what was being said in a particular set of meeting notes, or to explain in more detail what was being shown in a photo of an analog design artifact. They engaged in those interpretive behaviors after they had begun prototyping different deliverables and they needed to return to the earlier artifacts and clarify details of how their design vision should be executed.

In one sense, the members of Team B used their Facebook group page as a conscription device through which they conducted an ongoing conversation about their design project. At the same time, however, their use of this page reflects how individual members would publish external sources of information in order to try and enlist those sources as allies. In essence, their Facebook group page was an ever-changing site for the ongoing creation and modification of meaning regarding their design concept. Their struggles for control over their final design product played out with, through, and around this particular conscription device in a number of ways.

For example, field notes indicate that the members of Team B referenced this page at the start of several work sessions. They would kick off design discussions by recalling what they had previously discussed or decided, and by reviewing the potential applicability and usefulness of information that team members had posted. Fiona spoke during her interview about how she and her teammates relied on their Facebook group page as a conscription device around which they organized their work sessions and thoughts about their design vision.

> *I posted…a lot of pictures of the [whiteboards] so that we could all refer to those images when we went to a meeting because some of them would be a task list or a calendar or just important notes for the meeting, so I put them on Facebook so we'd all see them. (Fiona 137)*

Fiona also cited her team's use of their group page as a crucial part of their "*process for research*" (Fiona 165) because they posted relevant sources of information (e.g., news articles, blog entries) so that the team members would review those bits of information between work sessions. Again, if one team member could successfully instill the contents of an external information source into the team's design concept, he or she would have successfully enlisted that source as an ally.

In his interview, Peter provided additional context about how the team used their Facebook group page as a conscription device. Speaking about the team's second assignment (the conceptual model presentation), Peter described how the act of publishing photos of important design artifacts to their Facebook group page was an important reason why they chose to use that tool.

> *This [conceptual model] started on a whiteboard. Then it moved to a piece of paper, and then it moved back to a whiteboard again. So this model was built and rebuilt a hundred times over. At some point, it was finalized…. At some point, someone took a picture of it…and that image went to Facebook…and then Nathaniel accessed it and built the [final] conceptual model based on the conceptual model that we had sketched in the photograph uploaded to Facebook. (Peter 189-197)*

In this quote, Peter described the broader process for creating a particular deliverable while also indicating the important role that the team's Facebook group page played in that process. He and his teammates used that page as a conscription device by agreeing that important information would be posted there (e.g., photos of analog design artifacts that also served as conscription devices) and could be referenced across tasks within an activity. According to other interview comments and field notes, the expectations was that the members of the team would review information posted to the Facebook group page between work sessions so they could come prepared to discuss it all. In so doing, the members of Team B essentially specified rules for enlisting the artifacts they created as allies: Discussions held during work sessions provided the opportunity for team members to suggest how specific artifacts should impact the broader design vision for the team.

This choice to use a digital social artifact as a conscription device through which other allies could be enlisted reflects a specific example of the team's performance of metawork. Although the members of Team B used a variety of tools to communicate with one another, they consistently returned to their Facebook group page throughout the academic quarter as the hub for discussing their project and reminding themselves what they had previously discussed and decided when they started new work sessions.

Peter provided three reasons why the team made the collective decision to use Facebook as one of their communication tools. First, Facebook facilitated the private discussions that the five team members wanted to have about their design ideas. According to Peter and Fiona, they expressly wanted to avoid letting other people who were not taking their advanced interaction design course see their ideas and thought processes.

Second, Peter and Nathaniel used their smartphones to upload photos of design artifacts directly to their Facebook group page as they engaged in work sessions. This functionality streamlined their process for sharing photos of important design artifacts with the entire team because they did not have to use any other tools to save photos of analog design artifacts on their group page. This process was also helpful because they could add captions and other contextual information when they uploaded the photos, a task they typically performed when the details of their artifact-related discussions were still fresh.

Third, and most important to Peter, Facebook was preferable to other tools that offered similar sharing and discussion capabilities because everyone on the team already knew how to use Facebook. They came to rely on their group page as a conscription device not just because it acted as a repository for information, but because it was the lowest common denominator for the team members with regard to the technical knowledge required to use it as a tool for sharing and discussing information.

> *[You need] that common ground, right? Here's the body of tools I know how to use. And here's the body of tools that Nathaniel knows how to use. And in that overlap is Facebook and Twitter and Dropbox and whatever else. And that's how it worked for all of us: We all knew how to use these [tools]…so we decided to use them. (Peter 321-323)*

Here, Peter suggested that he and his teammates "*decided*" to use tools such as Facebook at the start of the academic quarter. Had they used Facebook for a specific task within a particular activity, that decision would have been an example of articulation work. Instead, because the team members ultimately oriented their project work around their Facebook group page across activities throughout the entire quarter, they used that page as a conscription device and the decision they made early on became an example of the performance of metawork.

Finally, Peter cited the information management issues that arose within the team as they generated more and more email as a counterpoint to the ease with which they could all reference a single, threaded view of their comments, photos, and links on their Facebook group page. Therefore, the team established their Facebook group page as a conscription device because they chose to align their collaborative work around that page across the entire arc of work for their project. However, other team members did make attempts to erode the Facebook group page as a center of power within the team.

For example, during the sixth week of the quarter Logan suggested that the team use Pinterest rather than Facebook for sharing ideas and sources of inspiration about their project. Pinterest was similar to Facebook in that the team members set up two private “pin boards” where they could publish links to images and other online information. However, they did not publish photos of their artifacts to the pin boards that Logan set up.

After trying to use the tool for about a week, everyone on Team B quit using the Pinterest pin boards. Logan explained that he and his teammates decided to stop using their pin boards because their Facebook group page already served as a content and idea repository. Furthermore, the team’s only attempt at using Pinterest to inform the design of one of their deliverables led to a disastrous critique.

> *We made an interface with a lot of triangles, and that came from Pinterest. Like we used Pinterest to build that [deliverable], and we were like, 'This isn't working.' [laughter]. Pinterest got us in trouble….Pinterest was actually not that helpful. But either way, we have Facebook as a repository of ideas, and also [for] visual identity and video [prototype] style. Those were decisions that had already been made. (Logan 206-208)*

This quote is reminiscent of Peter's earlier quote about the collective decision to use Facebook. Logan explained that the team had already made the decision to use Facebook both as a "*repository for ideas*" and as a guide for their "*visual identity and video [prototype] style*."

Taken together, these quotes from Peter and Logan reflect how the members of Team B performed metawork when they chose to continue using their Facebook group page to structure their design thinking across activities. As they produced a deliverable for each assignment, they individually updated and consulted their Facebook group page, using that page as a conscription device through which they brought coherence to their disparate design ideas and attempted to enlist allies in the form of external sources of information. This is not to suggest that their group page was the only conscription device in use during the quarter; as stated earlier, they also used certain analog design artifacts as conscription devices. Instead, this section has described how Team B decided to use their Facebook group page as a conscription device across multiple activities within their arc of work, a decision that reflected their performance of metawork.

Chapter Summary

Whereas the previous chapter traced examples of students' task and articulation work, as well as how they decided which tools to use for a specific collaborative activity, the contribution of this chapter is to document how students performed metawork when they made tool-related and design-related decisions that impacted multiple activities within their projects. Specifically, the four examples presented in this chapter illustrate how students used specific tools as allies, as well as specific artifacts as conscription devices within and beyond their teams in order to enlist other actors as allies. Those actors included other people (e.g., the instructor, professional designers who advised the students) who served as arbitrators regarding the design direction that the team should take, tools (e.g., Adobe Illustrator, whiteboards and markers) that determined how and by whom those artifacts could be designed and iterated, and external sources of information (e.g., design blogs) that influenced how team members thought about their projects.

As the examples presented here demonstrate, the students performed metawork in an effort to complete their projects as efficiently as possible. They attempted to make the activities they had to complete manageable within the constraints of the course, which included the different deliverables to complete during the brief duration of the academic quarter, the limits of team members' skills with regard to certain types of tasks and tools, and the availability of preferred tools. Importantly, the students were performing metawork **even when they did not realize it while they were performing it**. Instead, they were focused on successfully finishing their projects and achieving their personal goals for the course in the process.

The students defined success in different ways, however, and were motivated by multiple factors to perform metawork as their projects proceeded. When asked during their interviews about the personal goals they had for this project, 10 of the 16 students indicated that they wanted to develop a high-quality portfolio piece or product prototype that would represent them well as designers. Furthermore, three other students said they wanted to win the competition and present their design ideas at the Microsoft Design Expo. The remaining three students were less concerned with developing their personal portfolios or winning the competition, and were more interested in enriching their personal skills with specific tools or gaining experience working with students from other programs and departments.

This context is important because, in essence, 13 of the 16 students interviewed for this study began their projects with the goal of externalizing their design ideas such that others (e.g., the instructor, professional designers, Microsoft Design Expo judges) would assess those ideas favorably. Therefore, the students created and relied on conscription devices partly to simplify the processual effort required to achieve consensus around a team-wide design vision, and partly to drive their own ideas and opinions into that vision during that consensus-building process. In that aspect of their use among these students, conscription devices are similar to Gerson's (2007) concept of the bracket, which actors use when they attempt to rationalize the relationships among activities within an arc of work. As stated earlier, Gerson (2007) defines three kinds of rationalization: segregating, standardizing, and coordinating. The examples of metawork presented in this chapter are each discussed below in the context of these different kinds of rationalization efforts.

Segregating rationalization involves separating "complex tasks…into multiple independent tasks" and "making things independent of one another, removing the connections or contingencies among them wherever possible" (p. 198). The students in this study engaged in segregating rationalization whenever they divided up task work *such that the students who were the most adept with the tools required to complete given tasks performed that work*. For example, Anne from Team A consistently strove to avoid any dependency on other members of her team, particularly when those members were uninterested or unable to assist her with specific tasks or activities, as when she explicitly refrained from assigning Kylie and Nancy any video production and editing task work to complete. Whereas that decision was specific to that activity, Anne made multiple tool-related decisions that limited the ways in which Kylie and Nancy could contribute across multiple activities within the entire arc of work for their project. Her enlistment of Adobe Illustrator as an ally simplified her performance of metawork because she was able to limit future discussions about how to align actors and tasks. Only the actors who knew how to use Illustrator could participate equally, which meant in practice that Kylie and Nancy were never assigned tasks that required knowledge of Illustrator.

Standardizing rationalization entails making “connections and relationships among things uniform” (p. 198), where “things” can be interpreted as tasks or as actors. The goal of this form of rationalization is to simplify the activities associated with an arc of work so that “more gets done with the same resources” (p. 198). The members of Team B engaged in standardizing rationalization when they decided to create and use a Facebook group page as a communication channel during, and even after, the academic quarter. Although they did not discuss their use of Facebook in these terms, the members of Team B selected this tool precisely because it helped them standardize the myriad ways they *could* communicate about their design project.

Everyone on Team B included Facebook in their personal toolbelts, and because some members of the team were perceived as less technically savvy than others, they considered it logical to rely on their group page as a conscription device. In so doing, they engaged in team-wide discussions whereby they negotiated which design artifacts best reflected their collective vision for their project, for example. The members of Team B considered Facebook “more convenient…and more reliable” (Gerson, 2007, p. 198) than their interactions with similar tools that competed for their attention (e.g., Pinterest). By settling on a specific tool, they simplified their metawork because they did not need to renegotiate where they would store and discuss the artifacts they produced each time they met.

However, their efforts at standardizing rationalization were imperfect as they did use other tools in concert with their Facebook group page (e.g., email, Dropbox). The Facebook group page persisted as a conscription device precisely because the team members' process for communicating about their project through Facebook was well-defined and repetitive. Again, the team kept using their Facebook group page because the decision to use another tool would have required Nathaniel to learn that tool. That requirement would have meant more time spent on metawork: negotiating which tool to use, determining how to align all of the activities around that tool, and so on. Instead, the members of Team B defaulted to the well-defined, repetitive process of letting Nathaniel upload his photos to the group page for discussion and clarification.

Finally, coordinating rationalization occurs when team members continuously "[refine] relationships so that they are particularly well-suited to their situation" (p. 198). Specifically, "within a given activity, tasks are made more responsive to one another by removing everything that does not contribute directly to smooth functioning and by strengthening everything that does" (p. 198). The actors on a project accomplish coordinating rationalization partly through ongoing efforts to "fine-[tune] interacting parts so as to make them accommodate one another's peculiarities" (p. 199). This process includes significant articulation work to pair actors with one another based on how well they work together.

As stated earlier, actors and tasks are the "parts" being described in this quote. Actors can be human and non-human, and both kinds of actors can be regarded as "interacting parts" of a project. Delilah from Team D engaged in coordinating rationalization when she actively curated her team's discussions by writing notes from specific work sessions on a whiteboard. Because she was in charge of translating conversations into written records of what the team had discussed, she was also able to prune and reshape those records in ways that could influence future design decisions. Stated differently, she conveyed her own ideas about the team's design vision through her note-taking process by excluding or restating the parts of the discussions that did not align with her way of thinking. This metawork example indicates how Delilah knew from the start of her collaborative project work that the notes she took would become the reference point later as the team reflected on the basis for their evolving design vision. Therefore, she situated herself as the note taker so she could be most directly responsible for shaping that vision.

Finally, Logan's modification of his team's conscription device demonstrates how, as Gerson puts it, coordinating rationalization often involves "taking advantage of specialized local circumstances or knowledge in order to create specialized local short-cuts" (p. 198). In that example of Logan's performance of metawork, he knew that if he could convince his teammates to add his idea into an extant conscription device, that idea would become a part of the conscription device as the team moved forward with their task work. Stated differently, he took a shortcut: Rather than proposing an entirely new design idea (as he had unsuccessfully done earlier in the quarter), he suggested what seemed to his teammates like a local modification to a sketch on a whiteboard. Logan explained in one of his interviews that he wanted to "*take advantage*" of the conscription device, which he did by successfully incorporating his design idea into the broader vision for the team's project.

Importantly, Logan acknowledged in his interview that he knew this simple, local change to a conscription device would become absorbed into the team's overall design from that point on. In practice, that is exactly what happened: After Logan modified the conscription device and convinced the team to let his modification stand, they took photos of the updated whiteboard sketch and later referenced those photos as the canonical representation of their design concept. An action on Logan's part that seemed like an articulation work performance or a local shortcut turned out to be a metawork performance, one that helped Logan drive his own idea into his team's design vision.

In summary, the students performed task work as they organized, facilitated, and constrained the effort required to develop tangible representations of their design ideas. They performed articulation work as they reorganized and realigned actors and tasks within specific activities in order to keep their projects on track. By contrast, they performed metawork when they negotiated how and why to align actors and tasks across multiple activities. In so doing, they relied on specific tools as allies, and they attempted to use specific artifacts as conscription devices in order to enlist other actors as allies who would concur with their design ideas and help move projects forward. Given the challenges associated with performing metawork, they attempted to rationalize details of their projects in order to simplify their metawork performance. In that way, they also attempted to ease the always difficult process inherent in collaborative projects of meshing human actors (and their diverse backgrounds and abilities) with one another, with different tools, and with the tasks that must be completed.

Chapter 7. Conclusion and Implications

The overarching research question for this study is as follows: **How do university students use different tools and artifacts for their collaborative design project work?** Three research sub-questions are included to help address the overarching question:

- What is the constellation of tools and artifacts that university students use and create to support their collaborative work?
- How do they decide which tools to use to support their collaborative work?
- How does their performance of task work, articulation work, and metawork organize, facilitate, and constrain their collaborative project work?

The three prior chapters have provided findings and analyses that answer these questions. This chapter summarizes those answers in the context of the research questions for this project. The sub-questions are answered first, while the overarching question is addressed at the end of the chapter as a way to summarize the overall research contribution of this dissertation.

Summarizing the Tools and Artifacts That Students Used and Created

The analytic details presented in this section address part of the first research question for this project. Specifically, this summary describes how the university students studied for this research project used analog tools, digital hardware tools, and software and online tools to create four types of artifacts: analog design artifacts, analog social artifacts, digital design artifacts, and digital social artifacts. Examples of each type of artifact include the sketches that students made on white boards (analog design artifacts), the notes they wrote to themselves in their paper notebooks (analog social artifacts), the scenes they recorded for their video prototypes (digital design artifacts), and the Vimeo and YouTube pages they used to publish drafts of those videos (digital social artifacts).

The students in this study used and created specific types of tools and artifacts at particular points throughout their projects. The task work that all of the students performed as they completed the 10 required course assignments was structured around a basic design process comprised of four stages: research, ideation, prototyping, and assessment. The students also iterated their design concepts and ideas during the first three stages leading to assessment of their deliverables, and they used previously-submitted deliverables as the basis for the creation of new artifacts and deliverables.

The students consulted their personal toolbelts as they progressed through these design stages during each assignment. The toolbelt concept was defined here as *the aggregation of all the tools from which designers select preferred tools to perform task work within and across activities*. Rather than creating rigid categorizations of all artifacts and tools that the students in this study created and used, this research project reintroduces the toolbelt concept as a way to characterize and understand the constellation of tools that the students decided to use for their project work.

For example, all of the teams used the same set of analog tools (collective and individual paper form factors, sticky notes, and whiteboards) at some point during the academic quarter. However, while each team eventually settled on a set of tools based on students' preferences for certain tools, as well as the resources that were available during collaborative activities, team members rarely kicked off their collaborative work sessions by discussing which tools to use. Instead, if a whiteboard was available, one team member would simply pick up a whiteboard pen and start writing, and then the rest of the team would begin discussing ideas or progress on specific tasks. Alternatively, they used different paper form factors and sticky notes for their research and ideation tasks depending on what they were trying to accomplish during specific work sessions. These work practices occurred not because the students collaboratively discussed which tools to use, but because students already felt comfortable using specific tools and so they defaulted to those particular tools when faced with specific tasks.

Specifically, whenever the students collaborated with and around analog tools, they did so in support of research and ideation tasks. The members of Team B described quite clearly why they preferred to use a whiteboard for those types of tasks, although large pieces of paper fulfilled these same requirements of use:

- Whiteboards give **physicality** to ideas
- Whiteboards lend a **temporary** nature to the ideas being explored; content is clearly only a draft and is easily modifiable so nobody gets too attached to any of the ideas being presented
- Whiteboards are a **highly visual, easily focused on, and immediately modifiable** tool
- Whiteboards serve as an **orienting device** with regard to team collaboration

By contrast, the students relied on sticky notes when they wanted to focus their design discussions and jot down very specific ideas or small amounts of text describing a specific topic or idea. The resulting notes were easier for the students to categorize and discuss compared to the expansive, sometimes overly broad ideas that they sketched on whiteboards or large pieces of paper.

Overall, the students used only a few different analog tools because there are far fewer such tools available compared to the software and online tools they used as they created digital design and social artifacts. Given the lack of choice, it was a rare occurrence during field observations to overhear or notice teams of students discussing which *analog* tool to use. Instead, they worked on and around a whiteboard if one was available, otherwise they obtained large pieces of paper, adhered it to a wall or a table, and conducted their collaborative task work around it.

The students in this study also relied on a comparatively greater diversity of digital hardware tools as well as software and online tools because they came from seven different academic disciplines and departments, each of which emphasized the use of different tools. Further, certain students had more real-world experience than others with different digital tools. For example, Peter worked at Adobe on the Premiere Pro team, which meant that he had significant experience using that tool. Those differences in academic and professional emphasis on specific tools impacted the contents of each student’s personal toolbelt.

With regard to artifacts, students created analog design artifacts around which the teams collaborated as they performed task work during the research and ideation stages of their design process. Those stages represent the crucial time within the process of developing each deliverable when team members throw all kinds of ideas out for discussion, and they rely on analog tools to help them externalize, discuss, and modify the key aspects of those ideas. Whiteboard sketches, sticky notes covered with design ideas, large pieces of paper covered with thoughts from brainstorming sessions, and personal notebooks with students’ individual ideas drawn out are all representative of the analog design artifacts that these students created during the academic quarter.

The students used those analog design artifacts as the raw materials from which they created digital design artifacts. As they shifted from research and ideation to prototyping, they also began working with software and online tools to facilitate their prototyping task work. As a result, they created thousands of drafts of their digital design artifacts leading up to specific deliverables that they submitted to the instructor for assessment. Those deliverables were invariably produced using specific tools and were submitted using specific file types.

For example, the students spent much of their time using Adobe Illustrator while prototyping their ideas, but they formatted their deliverables as Adobe PDF files to ensure readability across computing platforms and accessibility for the instructor and other students who could not necessarily open and read Illustrator source files. Similarly, the digital design artifacts that students created as they developed their video prototypes resulted in a host of supporting files, none of which were submitted as part of the deliverable for the final assignment. Instead, students submitted finished video files using specific file formats that software tools such as Apple Quick Time could play back successfully.

Finally, the students created and relied on a combination of analog and digital social artifacts throughout the academic quarter in order to track their progress within and across assignments. Whereas the correspondence between design stage and tool type was clear, there was far less rigidity with regard to the type of social artifacts that students used during the research, ideation, and prototyping stages of their design process. Students individually tracked action items and task work completion in their personal paper notebooks, on whiteboards during work session, on Facebook group pages, through email conversations, within team-wide blogs created and maintained specifically for this design project, and so on.

Summarizing Students' Tool-Related Decisions

Given the constellation of tools and artifacts that students used and created, it is important to understand how they made decisions about which tools to use as they collaborated on their design projects. Those decisions led to the creation of specific design and social artifacts, the design and content of which would differ depending on the tool selected for their creation.

The students in this study consulted their personal toolbelts as they structured their task work within specific activities. For example, Chapter 4 charts how Norbert from Team C constructed his own stylized flow of task work in order to produce the video prototype he wanted to create. He created animated interface elements using Adobe Flash and static interface elements using Adobe After Effects, and then he used Adobe Premiere Pro to merge both sets of elements with the video footage that the team had produced. Norbert paired these three tools together in this manner partly because he made his decisions about which tools to use based on his personal toolbelt, even though his work process required painstaking manual labor and took hours just to render a few seconds of completed video footage. Although it required a lot of effort, Norbert considered the end result worth the time. His approach was justified when Team C ultimately won the competition within the course and presented at the Microsoft Design Expo.

However, students' tool-related decisions based on their personal toolbelts were not always final because they had to perform articulation work when the details of their tasks within an activity required adjustment or redefinition. The example above in which Norbert worked across three software tools simultaneously describes how he meshed different tools in a specific way to facilitate the completion of a particular activity within the arc of work for his team's project.

Unfortunately for the students in this study, their meshing efforts were not always so simple. They did not always agree on which tool was best suited to a specific task, or which tools should be used in parallel for the task work associated with a specific activity. As described in Chapter 4, the members of Team B struggled to align team members around a particular tool (Adobe Illustrator) because Logan did not own a copy of that tool and could not view Illustrator-formatted files unless they were saved as Adobe PDF files instead. As Molly from Team B pointed out, the team had to realign their task work when sharing Illustrator files in order to accommodate Logan's lack of access to Illustrator. Therefore, while students' toolbelts did influence their choices about which tools to advocate or use in specific situations, and their personal preferences for particular tools predisposed them to favor certain tools over others, their tool-related decisions also required them to perform articulation work and mesh actors with tasks when necessary to keep their projects on track.

Another factor that affected students' tool-related decisions was the frustration that certain students felt about the decisions that other team members made. Chapter 5 presents the example of Team A and team member Nancy's insistence on using sticky notes during one of the team's first collaborative work sessions. The quote from Kylie bears repeating here as it concisely captures the frustration that the other team members felt with Nancy and her desire to use sticky notes rather than whiteboards or large pieces of paper at that meeting.

> *[It's] not that we didn't want to [use sticky notes]. I think we were a little bit frustrated with each other at that point, and we were in the middle of doing whiteboard stuff and writing stuff down on paper, and she sort of just wanted to stop us where we were and change tracks. It was like, 'No.' But yeah, it worked out well in the end. (Kylie 109-113)*

Nancy's goal in advocating for sticky notes was to help her teammates focus their energy on writing down specific ideas rather than continuing to think too broadly about their design vision. In a separate interview, Nancy explained that she tried to channel the team's tool-related decision toward sticky notes and away from whiteboards as a strategy for getting everyone to specify details of their design concept. In essence, her decision to try and convince everyone else to use sticky notes sprang from her frustration with her teammates, who then became frustrated with her attempt to cajole them into using a different tool that none of them (aside from Nancy) included in their personal toolbelts.

The shift from research and ideation to prototyping tasks, and the concomitant shift from analog to digital tools that occurred, had the effect of encouraging the students to divide their labor such that they focused on completing tasks for which they already had the requisite skills. For example, Chapter 4 traces how the members of Team A created each of their deliverables leading up to their final design product. Bae from Team A did nearly all of the digital sketching as the team worked on use cases and user experience walkthroughs for their design concept.

When asked in her interview how the members of the team decided which student would perform each task, Anne explained that she and her teammates regarded Bae as the best sketch artist, so much so that they did not even consider assigning sketching tasks to anyone else.

As far as sketching…it was Bae automatically because he's an awesome sketcher. (Anne 055)

At the same time, the shift from analog to digital tools also had the effect of discouraging equal task work participation among team members. When asked about the artifacts that she personally created for her team project, Nancy said that she personally made none of them. She elaborated on this point by talking about the inequity of task work across team members as a function of the tool-related decisions they had made.

> *I did a lot of the talking…and some of the sketching on paper or whiteboards, but very little of the creating digital [artifacts]. While I was working on digital artifacts, it was in tandem with somebody else so it was usually on their computer…. I guess I just deferred to other people because they seemed to be a lot more attached to using their computer, doing it with their own hands than I was. So since they cared a lot and I didn't really care, I just kind of went with what they wanted to do. Like when I was working with Anne on stuff in Illustrator, it was like, 'Yeah. You can do this much faster than me so it makes sense to let you do it.' (Nancy 279-283)*

Because Nancy did not know how to use Adobe Illustrator, she was unable to contribute equally when her other teammates who knew that software tool were busily creating digital design artifacts. Field notes support Nancy's story: Although she was an integral part of the project, largely as a project manager by her own admission, she was not able to directly modify the source files for the digital design artifacts and deliverables that her team created.

The unequal division of labor among students on a team is important given the research questions that ask how university students use tools and artifacts in the service of their collaborative project work, as well as how their work practices inform the process of collaboration within and across design teams. Returning to the ideas of contested and adversarial collaboration, it seems that the members of Team A engaged in adversarial collaboration most often based on how they typically worked together. Contested collaboration is defined as *two or more actors working together on the same project who are attempting to address the interpersonal differences and different work styles that make project work more challenging*. By contrast, adversarial collaboration is defined as actors who must collaborate but who each have different goals in mind. As stated in Chapter 2, it may not be possible for these actors who are attempting to complete specific tasks together to resolve their differences with one another. Friendly, ongoing cooperation is not a condition of this type of collaborative work; instead, the point for the actors is to complete the project according to their goals and move on with their lives.

As students work together, they engage in cooperative and adversarial behaviors; in the case of Team A, the balance seems to tip toward adversarial behavior most often. This finding is unsurprising given the stated, personal goals of each member of Team A. Nancy took the course and engaged on this project hoping to develop a nice-looking portfolio piece. Anne had taken the junior-level version of the same course the year before, so for this course she wanted to be more involved with the process of running everything, especially the video creation and production elements required for the course. Kylie wanted to win the competition and present at the Microsoft Design Expo. Khloe had a variety of goals that included a desire to get a good grade in the course and hopefully win the competition, an interest in proving her skills and value to her teammates throughout the quarter, a need for a good portfolio piece, and an aspiration to learn more about specific tools such as Adobe Premiere Pro. Bae was not interviewed, so no specific data about his personal goals for the course were collected.

These stated goals came from the interviews with each student; as a team, these students never discussed their personal goals for the course. At their first work session on January 12, they talked about their backgrounds, interests, and skills, but they did not explain what they hoped to get from their experience working as a team. As a result, the members of Team A never reconciled their goals or aligned them closely enough to avoid engaging in adversarial collaboration and consistently achieving the more constructive form of contested collaboration. This adversarial approach to collaboration occurred precisely because these team members did not necessarily realize how misaligned their goals were; none of them prioritized their grade in the course as their most important personal goal, but instead focused on several other outcomes that mattered more to them. For example, it is not surprising that Anne’s stated goal was to run the team and learn how to do that across all aspects of the design process.

One of the ways in which Anne achieved her goal was to make tool-related decisions for her teammates, and then enforce those decisions in a variety of ways that reflected her performance of metawork. The next section focuses specifically on the different kinds of work that the students performed throughout the academic quarter.

Summarizing Students' Performance of Task, Articulation, and Metawork

This dissertation has traced specific examples of students' tool-related decisions in the context of their decisions to shift from ideation tasks to prototyping tasks. Chapter 5 concluded that students decided to work on research and ideation tasks primarily using analog tools, whereas they decided to complete their prototyping tasks primarily using digital tools. This decision was reflected in the consistent shift in tool use that occurred when team members switched from researching and ideating around a design concept to prototyping their design ideas. When they made that shift, they also changed the focus of their work from analog to digital tools in order to support their prototyping tasks. Their prototyping task work took place within digital tools because that was how students made their ideas less abstract and more concrete and polished.

However, the shift from ideation tasks to prototyping tasks was not always obvious from a research perspective, nor was it obvious to the students themselves as to when they should stop ideating and start prototyping. For this reason, it is quite difficult to specify which tools *should* be used during specific stages in the design process because the space between stages is poorly understood. It is challenging to characterize how the shift from ideation to prototyping occurred judging solely by the tools that students used for their tasks and activities.

One way that this dissertation research addresses this challenge is by developing a richer understanding of what it means when students perform task work, articulation work, and metawork on their team projects. The students in this study needed to work together in teams and complete 10 assignments for their advanced interaction design course. Because every team had the same assignments to complete and the same deadlines for completion, the arc of work was the same for each team. Those 10 assignments that characterized the arc of work were the “activities” on which the teams of students worked, and their deliverables were the products of each activity. Although the arc of work might have been the same for every team, the students pursued different design concepts, approached activities differently from team to team, and produced unique deliverables.

These differences are evident in the kinds of work that the students performed as they completed each activity, and can be characterized by describing how they worked on each deliverable. Activities are “made up of many tasks done over time” (Strauss, 1985, p. 2), and each task within an activity is a discrete unit of work that must be completed. Rather than trying to define additional terms that separate tasks into even more atomized and contorted units of work (e.g., “sub-tasks”), the notion of the “task” is presented here as the smallest unit of measurement for the performance of work.

The students in this study performed *task work when they carried out the wide assortment of jobs required to complete each activity*. Tasks are not homogeneous units but are entirely dependent on how the students decided to scope the effort required to complete each activity and deliverable. For the students in this study, task work included recording video prototype footage, sketching panels of a storyboard, or writing design ideas on sticky notes. The six teams of students all developed different methods for tracking their task work; some teams (e.g., Team D) did not bother tracking this information formally but instead “*played it by ear*” (Baron, 229). Other teams (e.g., Team B) outlined their entire arc of work and the most critical tasks to complete as a project schedule at the start of the quarter.

The students performed *articulation work when they identified and obtained the resources they believed they needed to complete their task work, and when the local circumstances* *associated with an activity changed such that they had to adjust their strategies for completing the tasks associated with that activity*. The contextual details of a project plan specify an example of the performance of articulation work: defining which team member will work on each task, the sequence in which tasks must be completed, prerequisites for starting the next task, and so on. However, no matter how clearly and specifically the members of a team define a task and the resources required to complete it, local circumstances inevitably change. When that happens, the team members must realign resources or redefine the tasks as needed. All of these articulation work performances are traceable through team members' discussions about how to complete specific activities, as well as through the artifacts and deliverables they produce while working on those activities.

For example, Chapter 5 described a typical situation that impacted each team more than once throughout the academic quarter: changes in resource availability led to the need to perform articulation work. Team B created a specific analog design artifact on a large piece of paper because there were no whiteboards available for their work session on a particular day. After they looked around and noticed that the whiteboards were all being used, they obtained a large piece of paper from an easel pad and began working with the analog tool that was closest at hand. This is a classic example of articulation work as Strauss (1985) defined the phrase because the members of Team B responded to local circumstances, modified the structure of the task at hand, and completed that task in order to ensure the successful continuation of the specific activity that task was a part of.

As a result of that experience, the members of Team B were much more aggressive about using the available whiteboard space in the classroom. Specifically, they took over the three whiteboard panels in the back of the room and they used those whiteboards for the rest of the quarter. They wrote “DO NOT ERASE” on the whiteboard panels to explicitly request that other students refrain from modifying or erasing the contents of those panels.

This response from Team B represents the difference between an articulation work performance (which is specific to a certain activity) and a metawork performance (which extends across multiple activities). The students in this study performed *metawork when they negotiated how project resources should be aligned across activities, as well as why those particular resources should be aligned in that way*. With regard to the way that Team B dominated the whiteboard panels in the classroom, they performed metawork because they attempted to align their work *across all future activities around those whiteboards*. Whereas other teams often shifted among different analog tools depending on what was available, Team B refused to settle for other tools and negotiated the alignment of their activities with and around that particular tool.

Metawork performances can be challenging to identify because team members do not always realize that decisions about resource alignment and task definition will impact the entire arc of work from that point on. For this reason, instances of metawork are most clearly identifiable in retrospect through careful analysis of multiple sources of data. Chapter 6 outlined and analyzed four examples of students’ performance of metawork that, taken together, explain how they relied on specific tools as allies, as well as how they attempted to use specific artifacts as conscription devices in order to enlist other actors as allies who would concur with their design ideas. They also attempted to rationalize details of their projects in order to simplify their metawork performance.

Specifically, students engaged in three kinds of rationalization: segregating, standardizing, and coordinating (Gerson, 2007, p. 198). The students in this study engaged in segregating rationalization whenever they divided up task work such that the students who were the most adept with the tools required to complete given tasks performed that work. This form of rationalization harkens back to the ways in which the members of Team A collaborated with one another as they developed their deliverables throughout the academic quarter.

By contrast, the members of Team B engaged in standardizing rationalization when they decided to create and use a Facebook group page as a communication channel during, and even after, the academic quarter. Although they did not discuss their use of Facebook in these terms, the members of Team B selected this online tool precisely because their creation and use of a group page as a digital social artifact helped them standardize the myriad ways they *could* communicate about their design project. They defaulted to the use of Facebook as a tool, and the use of their private group page as a digital social artifact, for team-wide communication from the start through the end of the quarter.

Finally, coordinating rationalization occurs when team members continuously "[refine] relationships so that they are particularly well-suited to their situation" (p. 198). Delilah from Team D engaged in coordinating rationalization when she actively curated her team's discussions by writing notes from specific work sessions on a whiteboard. She situated herself as the note taker so she could embed her own ideas about the team's design vision into the notes that she took by excluding or restating the parts of the discussions that did not align with her way of thinking.

Summarizing the Research Contribution of the Dissertation

As stated at the outset of this chapter, the overarching research question for this study was as follows: **How do university students use different tools and artifacts for their collaborative design project work?** This dissertation addresses this question by describing how the students in this study performed task work, articulation work, and metawork as they consulted their personal toolbelts, decided which tools to use, and then developed artifacts using those tools, all in order to create the necessary deliverables and final design products for the course they were taking. Their personal goals for the course and their projects also affected the variety of project-related decisions they made, as did the issues of authority and control with which they grappled as they worked with one another on their design projects.

Therefore, the central research contribution of this dissertation is to establish a representation of collaborative project work that comprises the following parts:

- **Different types of work –** task work, articulation work, and metawork
- **Different types of tools –** analog, digital hardware, and software and online
- **Different types of artifacts –** analog design, digital design, analog social, and digital social
- **Different stages of the design process –** research, ideation, prototyping, and presentation/assessment, as well as iteration throughout the stages

Specifically, this dissertation describes the variegated relationships among different types of work, the different types of tools that students chose to use as they created different types of artifacts, and how those decisions and types of work played out differently depending on the stage of the design process. Additionally, the students' decisions about how to structure their task work influenced their choice of tools; those choices in turn influenced the students' processes of artifact creation as well as their performance of articulation work and metawork. This dissertation documents the reflexive nature of that relationship among students' tool-related decisions, artifact-related creative processes, and collaborative practice.

Furthermore, the students' decisions, processes, and practice change as a function of their shifts among stages in the design process. When students shift from ideation to prototyping, for example, they also shift from analog tools to software and online tools. This decision to change tools also impact their artifact creation processes and their collaborative practice partly because the students physically orient their task work around digital hardware tools rather than analog tools. Another contribution of this dissertation, then, is to describe how students' use of tools, their decisions to use specific tools, their creation of artifacts, and their collaborative practice co-evolved as they completed their design projects.

However, the students did not always reflect on the characteristics of that evolutionary process as they completed their projects. For example, students made some of their tool-related decisions without regard for future activities, particularly when they just needed to get specific tasks done. In those cases, they made snap decisions about which tools to use without discussing the decisions and without considering the consequences with regard to how the tool would format the artifact or constrain their creativity. At other times, as with Anne and her use of Adobe Illustrator, the choice of tools was quite intentional as a limiting factor with regard to how other team members could even participate in the task work being done.

Finally, this dissertation further develops the previously undertheorized concept of metawork, as well as its application to understanding how the students in this study collaborated on their design projects. In particular, the findings presented in the prior chapters surface students’ metawork performance throughout their projects and at different times during different stages of their design process, as well as the ramifications of the fact that they were not always aware that they were performing metawork.

Study Limitations

This study had a number of limitations that shaped the analysis and findings presented here. For example, the setting for this course was an advanced interaction design course with a mix of senior undergraduate and graduate students from seven academic programs. This study population is relatively heterogeneous; it might have been preferable to have had students who were from the same academic program (e.g., Interaction Design) and who also had approximately the same levels of professional and academic experience.

The reason why a more homogeneous population might have been preferable is because of the focus in this study on tool use and artifact creation in the context of a collaborative design project. It would be worthwhile to study students with similar backgrounds and knowledge bases to see how they approach their project work in ways that are both similar and different depending on local and project-wide circumstances. Given that this project was qualitative and was informed by ethnographic methods, however, the relatively heterogeneous backgrounds that students brought to their projects exposed a variety of work practices worth reporting.

Another limitation is the fact that this study had only one researcher working on it. There were six teams of students, and these teams met during and outside of course hours, making it challenging for the researcher to be present at all meetings in all locations. The solution was to focus on two teams (Teams A and B, as described in Chapter 5) and gather rich information about those teams’ members through more focused observations. One of the ways in which the researcher dealt with this limitation was to lend audio recording devices to the members of

Teams A and B so they could record their offsite meetings and so the researcher could review those recordings later.

A third limitation relates to the structure of the course that the students took, and how many of the students had actually taken a similar course the year before that was designed for junior-level (rather than senior-level) design students. This study would have benefitted from a comparative analysis of how students went about their project work as they worked on multiple design projects across two different courses. Again, however, because study resources were extremely limited, it was not possible to take a more longitudinal approach to this research.

One way to address this limitation would have been to study two different courses concurrently and answer the same research questions using both subject populations. This study was initially designed to do just that: The research setting initially included an advanced interaction design course and a human-computer interaction (HCI) course. The researcher sat in on course sessions for both of these courses during the first four weeks of the academic quarter before the decision was made to stop observing the HCI course and focus on the design course. The reason was, again, related to the limited resources for this study.

Directions for Future Research

The concepts that have been developed in this dissertation suggest a number of directions for future research. For example, the concept of the toolbelt deserves further exploration and should be accounted for when study materials are being developed. Future studies of students' use of tools should be designed to capture their tool preferences, habits and practices of use, and reasons why they would be willing to consider using new tools. All of these data would be best aligned around a standard typology of tools such as the one presented in Chapter 4 so that the concept of the toolbelt could be formalized or operationalized for future studies. Such studies could make use of an elaborated version of this concept as a way to characterize the power dynamics, as well as issues of authority and control, that play out when members of design teams attempt to collaborate with one another.

This point about collaboration suggests another direction for future study: exploring and characterizing different forms of collaboration (e.g., contested, cooperative, adversarial). The CSCW community would benefit greatly from a return to theorizing about the nature of cooperation and collaboration, along with a reconsideration of whether the phrase “collaborative work” should replace “cooperative work.” As discussed in Chapter 2, it is possible to regard cooperation as a quality of collaboration; future studies should gather empirical data that can be used to probe these differences and establish clearer distinctions between forms of collaboration.

Further research into metawork would also help CSCW scholars better understand when and how students negotiate authority, control, and power as they struggle to collaborate with one another. For example, instructors who develop their courses around project-based learning methodologies of instruction should explore alternative ways to engender learning behaviors among their students. The results of this study validate the conclusions of Volet and Mansfield (2006), who suggest that students who collaborate on team projects try to avoid an equitable division of labor. Instead, they parcel out tasks based on which student has the most relevant skills and is most adept with the required tools.

As they made clear during their interviews, the students in this study were motivated primarily by their desire to generate portfolio pieces or win the competition, and secondarily by their desire to learn new tools (if they mentioned that at all). Stated differently, they operated in the mode of students who needed to pass a course rather than learners who wanted to understand how certain aspects of their design process and academic practice could be improved. Rather than spending their precious time trying to add tools to their personal toolbelts, they were instead focused on completing the specific tasks for the next deliverable, week in and week out. When they did try to learn new tools, they expressed disappointment because other team members actively realigned actors and tasks in order to reduce learning opportunities and keep their projects running as efficiently as possible.

Again, an opportunity for future research exists at the intersection of project-based learning pedagogy and the ways in which different pedagogical approaches can convert students into learners. In particular, given that the students **were** performing articulation work and metawork, an opportunity exists to formalize their practice around those types of work so that students can become aware of their performance of types of work other than task work. Specifically, it would be valuable for educators to teach these skills in a formalized way to design students.

Similarly, developers of software and online tools meant to facilitate collaboration can help students become better designers by surfacing their performance of articulation work and metawork *as it happens*. By helping students understand the downstream ramifications of their decisions to enlist specific tools as allies or to use specific artifacts as representations of their design concept, they can make those students aware that they are potentially engaging in the performance of metawork. By interpreting specific tool-related decisions as the performance of metawork, for example, groupware developers gain a powerful analytical concept that can lead to novel design interventions and approaches that assist students as they learn how to collaborate with one another. Although future research is needed to explore the application of metawork in this context, the possibilities are certainly exciting.

Finally, for members of the CSCW research community, this dissertation is a call to action regarding the need to continue exploring the concept of metawork, particularly how and why members of teams perform metawork when they collaborate. Gerson (2007) suggested this term several years ago, but the term has not gained currency within the CSCW research community. Given the importance of metawork to the present research project, it seems appropriate to continue theorization about this concept based, again, on empirical research. It is presently unclear whether it is even possible to operationalize and study performances of task work, articulation work, and metawork in a quantitative way. Future research should strive to make that possible.

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Appendix A – Final Survey Instrument

Question 1.
Please enter your first name

Question 2.
Please enter your email address:

Question 3.
Please enter your gender:

Question 4.
Please enter your age:

Question 5.
Which country are you a citizen of (e.g., US, China, Germany)?

Question 6.
Please enter your ethnicity

Question 7.
What are your current school/college and departmental affiliation? (School of Art – Industrial Design, School of Art - Interaction Design, College of Engineering - Computer Science and Engineering, College of Engineering - Human Centered Design & Engineering, iSchool – Informatics, iSchool – other, Other)

Question 8.
What is your current grade level? (1st-year, 2nd-year, 3rd-year, 4th-year, 5th-year, 6th-year or higher)

Question 9.
What is your current degree program? (Bachelor of Arts, Bachelor of Science, BFA, MFA, Master of Science, PhD, Other)

Question 10.
List the information technologies that you use regularly for school-related work (e.g., pad of paper or paper notebook, laptop, iPad)

Question 11.
List the software applications that you use regularly for school-related work (e.g., Dropbox, Google Docs, Adobe Photoshop):

Question 12.
List the information sources that you use regularly for school-related work (e.g., course Web sites, ACM Digital Library, specific blogs, textbooks, Wikipedia)

Question 13.

Please explain how you decided which other students you wanted to work with in a group for this class

Appendix B – Final Interview Protocol

Let's talk about the group project you recently completed in your advanced interaction design class. Your real name will never be published and I will not share your answers with other group members or classmates.

1. What were your personal goals for this project?
    a. How did the possibility to learn new skills factor into your goals for this class?
2. How did your group determine which activities each member would perform?
3. Tell me the story of how your group decided which concept to explore for the project.
    a. (follow up on any tools or artifacts that the interviewee mentions when answering)
4. How did your group keep track of the overall vision for your final design and product?
5. How did your group track the progress you all made while working on different activities?

Let's talk about the tools and artifacts you and the other group members used and created. Your group was asked to turn in several deliverables leading up to the final video prototype, process book, and presentation slides. Aside from these deliverables, you and your group created a number of "artifacts" while working on this project, such as paper sketches, whiteboard drawings, photos, and so on. You probably used a variety of tools to make these artifacts, where a "tool" could be any type of technology, like a sketch pad, or a laptop, or a Pinterest pinboard, or Adobe Acrobat, or anything else that comes to mind. Let's take a look at a specific deliverable, the conceptual model presentation, that your group created and talk about the tools and artifacts that got you there (bring up on screen).

6. Tell me the story of how your group created this conceptual model presentation.
7. What tools did you and the other group members use to create this conceptual model?
    a. How did your group decide to use these tools?
    b. Describe all of the tools you used to keep in touch with your other group members.
    c. How often did you abandon a specific tool in favor of another one?
8. What artifacts did your group make in the process of creating this deliverable? For example, a whiteboard sketch might have led to an idea that you eventually added into the deliverable.
    a. What tools did you use to make these other artifacts?
9. What artifacts did you personally create in the process of making this deliverable?
    a. What tools did you use to make these other artifacts?

Wrapping up.

10. How do you feel about the project that was selected to be shown at the design expo?
11. Is there anything you would like to add? An interesting experience we haven't talked about?
12. Can I contact you via email later if I need to clarify any of the information we discussed today?