Characterizing the application of design ethnography techniques to improve novice human-centered design processes

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Mechanical Engineering)
in the University of Michigan
2016

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Acknowledgments

I would like to thank my advisors Kathleen Sienko and Shanna Daly for their support over the past five years and for making my journey to a PhD fun and exciting. They allowed me to carve out my own path and were trusting and supportive throughout the process. I am truly grateful for the opportunity to have worked with them. I would also like to thank my committee members Steven Skerlos and James Holloway. Their feedback, guidance, and enthusiasm for my research has been an invaluable asset and crucial to the work in this dissertation.

I would also like to thank all the members of the Laboratory for Innovation in Global Health Technologies who made going to lab enjoyable and stimulating. Special thanks to Amir Sabet Sarvestani for the great discussions, games of squash, and exciting fieldwork in Ethiopia and Ghana.

I particularly want to thank my collaborators in Ghana and Ethiopia for their vital support in both my research and design work. I am especially grateful to Zerihun Abebe whose enthusiasm and support for our project is unmatched.

Thank you to all those who I have worked with over the past five years on the research in this dissertation: Linh Huynh, Grace Cravens, Joseph Adomako, Carrie Bell, Senait Fisseha, Kristin Ydoate, Elsie Kaufman, Frank Anderson, Timothy Johnson, Kevin Jiang, Dilayehu Bekele, Corey Bertch, Anthony Franklin, Adam Joyce, Jacob McCormick, and Michael Shoemaker. I would also like to thank all the design students I have worked with while at the University of Michigan.

I would like to thank my parents Sergio and Teresa Mohedas. Everything I have achieved has been made possible by their hard work and unwavering support. Thanks to my sister Jimena and brother Agustin for keeping things from getting too serious.

Finally, I could not have done any of this without the support and love of Jeseth Delgado Vela.

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Abstract

Design is a central, distinguishing feature of engineering requiring the development of technical solutions to well-defined societal problems. Successful design solutions must not only be technically sound, but also well-adapted to the context and culture in which they will be deployed. However, common strategies for understanding customers' preferences (e.g., surveys, customer complaints, etc.) typically only uncover surface-level information and may not reveal critical contextual information. Through the studies represented in this dissertation, I explored the use of design ethnography during front-end engineering design phases to capture stakeholder preferences and deep contextual understanding allowing engineering designers to make high quality design decisions.

Design ethnography is a collection of primarily qualitative data collection and analysis techniques that have been adapted from the field of anthropology to support design decisions during the engineering design process. Studies in the fields of computer-supported cooperative work and product development have demonstrated that design ethnography techniques lead to more successful products and are cost-effective. However, major gaps exist in design ethnography literature including 1) a lack of understanding with respect to the major barriers to and factors that influence success, 2) no research on the information processing required to implement design ethnography, 3) no synthesis of the best practices during design ethnography interviewing, 4) no developmental trajectory of novice to expert skill acquisition in design ethnography, and 5) the existence of few case studies to provide design practitioners with examples of how design ethnography should be implemented in diverse settings.

My collection of studies sought to address these gaps in the literature by employing a mixture of qualitative and quantitative research methodologies. The studies included a case study where design ethnography was used during front-end design, two longitudinal studies where design teams were followed over a capstone semester, two studies based on an interactive design task where designers were closely observed in a controlled setting as they employed design ethnography techniques, and a synthesis study where the results of the previous research were interpreted through an established theoretical framework. These studies have resulted in 1) the

development of a descriptive example of how design ethnography can be used in low-resource settings, 2) evidence supporting the use of specific coding methods during front-end design ethnography use, 3) an understanding of how novices currently implement design ethnography and identified the barriers to their success, 4) knowledge of the critical internal and external factors that affect the utility of stakeholder engagement for novice designers, 5) the identification of a specific relationship between the level of information processing conducted and the quality of product requirements developed, 6) an evaluation methodology to determine the quality of stakeholder interviews during requirements elicitation, and 7) the development of a preliminary model of design ethnography skill acquisition from novice to expert.

As a result of my dissertation studies, we have gained an understanding of what knowledge and ability is required to effectively implement design ethnography, specific insight into how design ethnography can be more effectively taught and supported within human-centered design curriculum, defined the developmental trajectory for design ethnography, and detailed an example of how design ethnography should be implemented during front-end design phases. This work provides critical knowledge at the intersection of mechanical engineering, design science, and engineering education. The results benefit design practice by providing contextual examples of design ethnography use in emerging markets and provide specific details about strategies that improve the efficiency of design ethnography. Additionally, beneficial to both engineering education and practice, the work describes design ethnography sophistication from novice to expert, elucidates the type of support structures that increase the utility of design ethnography use by novices, and suggests design ethnography pedagogy for curricula in education or training in industry. If implemented, these contributions would allow design ethnography to be implemented more effectively by both novices and practitioners, benefitting the engineering design process by producing products and services that are well-adapted to the context and culture in which they will be deployed.

Chapter 1 Overview, motivation, and background

1.1 Introduction

A central feature of engineering is the design of artifacts via the application of mathematics and science (Simon 1996). Therefore, the study of design processes and how they are taught to future engineers is of significant importance (C. Dym et al. 2005). However, only over the past thirty years has design begun to be studied methodically in an effort to improve its processes (Cross 2001).

To solve the major challenges of the 21st century, engineers must be prepared to use design principles that lead to innovative solutions (Clough 2004). Innovative design solutions must not only be creative, but should be well-adapted to the context and culture in which they will be deployed (Prahalad and Ramaswamy 2004). Development of a product that is well-suited to a specific context and culture, however, is challenging because it requires a deep understanding of both the stakeholders who will interact with the product and the environment in which it will be used. Design ethnography is a collection of activities used to obtain this deep level of stakeholder and contextual understanding and apply it to design. Design ethnography techniques evolved from research methodologies in anthropology where researchers sought to develop deep, rich understandings of unfamiliar cultures or environments (Wasson 2000). The tools of design ethnography include observing stakeholders while they interact with products of interest or as they go about their daily activities, interviewing stakeholders about their priorities, experiences, and preferences, observing the environment in which a product will reside, developing genealogies and social maps, performing demographic research, photographing and videotaping, researching archives, "deep hanging out", and others (Powdermaker 1966; Salvador, Bell, and Anderson 1999; Wax 1986; Werner, Schoepfle, and Ahern 1987). These tools are employed in an effort to better understand stakeholders' daily lives and preferences, their culture, and the environment in which a product will function in order to make well-inform design decisions (Blomberg et al. 1993; Bucciarelli 1988; Salvador, Bell, and Anderson 1999).

The first documented use of design ethnography use during product development occurred at Xerox Palo Alto Research Center (PARC). During the 1980s Xerox PARC hired an anthropologist (Lucy Suchman) to study how office workers used (and struggled with) Xerox copying machines (Sanders 2002). This work led to machine interfaces that were vastly more usable and spurred other large corporations such as Microsoft, Intel, and Motorola to employ design ethnography techniques as well.

As globalization has pushed companies to develop products for emerging markets there has been increased appreciation and use of design ethnography. Within a globalized context, design ethnography allows designers to gain a deep understanding of stakeholders and contexts of use even when the designers and stakeholders do not have a shared cultural background. Within universities, there has also been a push to expose design students to design ethnography techniques as design programs targeted to particular end-users/contexts have become more common (e.g., resource-limited design, community-based design). Designers, in turn, have recognized the relevance of design ethnography for product development within one's own culture because it brings to light the assumptions that are sometimes made about stakeholders or the context that, in turn, lead to poor product design.

1.2 Objectives

While the use and appreciation of design ethnography techniques have grown, empirical studies of design ethnography have remained confined to the business and human-computer interaction communities. Within the business community, research has focused on assessing the costs and benefits of design ethnography during the product development process; attempting to determine whether investment in design ethnography leads to more successful products (Rosenthal and Capper 2006; Sanders 2002; Wasson 2000). In software communities, ethnography has been employed as a method of developing better human-computer interfaces and to better understand computer-supported cooperative work (Anderson 1994; J. Hughes et al. 1994). These studies have focused on developing more usable computer interfaces and a better understanding of how work is accomplished within collaborative groups when technology is involved (Jordan 1996). Furthermore, while appreciation and use of design ethnography is growing (in both industry and academia), discussion and development of techniques has been largely focused in the area of data collection with little attention to how data should be synthesized/analyzed and then applied to design processes. This has left large gaps in our understanding of design ethnography (noted in Figure 1.1).

Aspects of Ethnography	Social Science Use began during 1920s	Design Use began during 1980s Use in Practice	 Novice to Informed
Data Collection	Various methodologies have been developed and used in many studies	Thoroughly described in business & design literature; studied within HCI community	Few studies have looked into this area and few descriptions of skill development process
Synthesis & Analysis	Various methods developed and is considered key to research process	Few methods or detailed descriptions available in literature; formal use is not well-documented	No studies looking specifically at this area with respect to novice development
Application	Applied anthropology is well-established and has increased in use over time	Outcomes of design ethnography are described in general but not in particular	No studies looking specifically at this area with respect to novice development

Dissertation focus

Figure 1.1: Knowledge gaps related to design ethnography

The gaps in the literature described in Figure 1.1 indicate that design ethnography is only described and studied in broad strokes within the literature (or in the very specific field of human-computer interaction). The complexities of design ethnography data collection, synthesis, analysis, and application to informing design decisions have remained largely unstudied and inadequately described. This dissertation addresses these gaps by accomplishing the following research objectives:

I) Determine how and to what effect design ethnography techniques can be applied to the design of medical devices for low-resource settings.

II) Characterize how novice to more informed designers implement design ethnography techniques (including data collection, synthesis/analysis, and application) throughout design with an emphasis on front-end design phases.

III) Characterize how novice designers collect and synthesize data while developing product requirements and translating requirements to engineering specifications.

IV) Determine the differentiating factors between novice to more informed designers when conducting stakeholder interviews during front-end design.

V) Develop a model that describes the developmental trajectory of novice to more informed practitioners of design ethnography during front-end design phases.

Figure 1.2 shows how the work in this dissertation is situated within the context of engineering design. It shows that within this dissertation I have specifically focused on the initial phases of front-end design (e.g., needs finding through requirements development). Additionally, per human-centered design, I do not assume the traditional dichotomy between engineering and marketing within the design process; wherein engineers are focused on performance and technical requirements/constraints while marketers focus on providing the human behavior and contextual product requirements/constraints. Instead, engineers are concerned with all aspects of problem definition and product requirements development. In this role, engineering designers must be prepared to employ techniques such as design ethnography that allow one to understand their stakeholder and context of use at a deep level and apply this understanding to design decision making. Within this area, I focus on 1) the practice of how these techniques should be executed and 2) how design ethnography skill development is achieved.

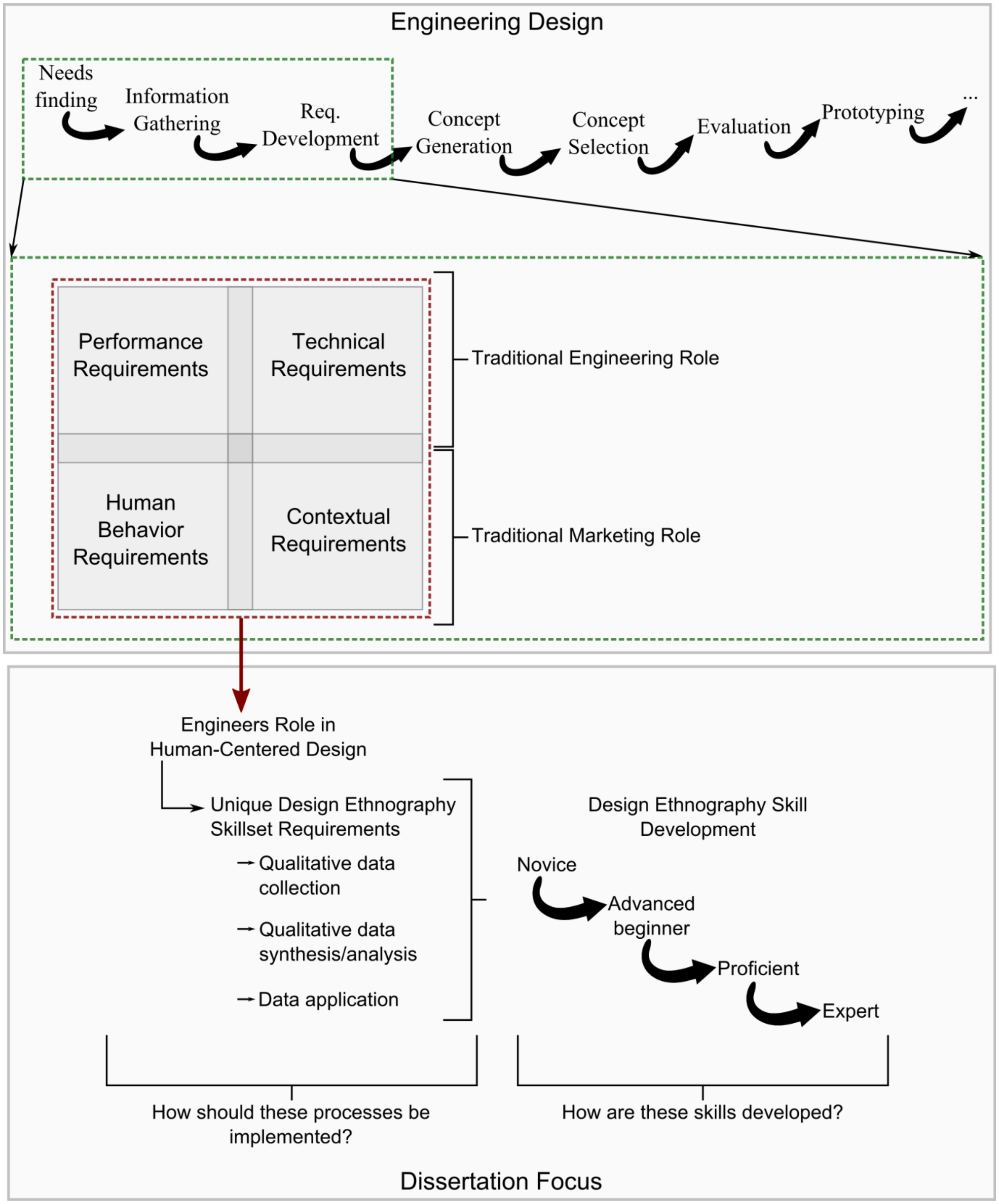

Figure 1.2: How this dissertation is situated within the context of engineering design

1.3 Chapter overviews

Below, I discuss the various chapters within this dissertation and the objectives they accomplish:

Chapter 2: In Chapter 2, I provide a case study wherein design ethnography is used to evaluate a medical device designed for rural Ethiopia. This case study demonstrates how design ethnography can be systematically implemented during device design and will help to introduce high quality use of design ethnography techniques (Objective I).

Chapter 3: In Chapter 3, I describe a study of student use of design ethnography techniques within a capstone design course. This study provides an understanding of what challenges/benefits student design teams face/gain from using design ethnography within the context of a design course (Objective II).

Chapter 4: In Chapter 4, I provide a deeper look at how novice designers engage with stakeholders during a design course. This study revealed the internal and external factors that affect the utility novice designers gain from stakeholder interaction. Additionally, the study uncovered aspects of design projects that could be adjusted by course instructors to improve stakeholder interaction (Objective II).

Chapter 5: In Chapter 5, I describe an interactive design task study that sought to better understand how novice designers use information during front-end design phases of requirements and specifications development. By employing a controlled design task study methodology, this study was able to better understand the information processing challenges associated with front-end design ethnography use (Objective III).

Chapter 6: In Chapter 6, the data collected from the same interactive design task (from Chapter 5) is assessed in order to understand how effectively novice designers interview stakeholders during requirements development. A methodology of evaluating interview transcripts is developed and the relationship between interview quality and information elicited is shown (Objective IV).

Chapter 7: In Chapter 7, I propose that the Dreyfus and Dreyfus model of skill acquisition accurately describes the learning trajectory of novice designers as they gain the skills of design ethnography and stakeholder engagement more generally (Objective V).

Chapter 8: In Chapter 8, I provide a summary of this dissertation, discuss the contributions and implications of the work, and describe the limitations and future work that should be undertaken.

Taken together, the studies in this dissertation and the synthesis of results provide significant knowledge within design ethnography literature where major gaps existed. These results directly contribute to our understanding of how novices currently employ design ethnography, provide evidence for interventions (in the form of design tools and pedagogy) that would increase the utility of design ethnography to novice designers, specifically consider the role of data analysis/synthesis in the implementation of design ethnography, and provide a more thorough understanding of skill development with respect to design ethnography.

1.4 Research methods

The objectives mentioned in Section 1.2 have been achieved through a series of studies employing a mix of quantitative and qualitative research methods. Qualitative methods allowed for an emergent approach to data collection and analysis, as opposed to being hypothesis driven (Creswell 2013). This was particularly well-suited to my dissertation research because the lack of prior research on design ethnography precluded the development of well-founded hypotheses and may have been a barrier to discovering concepts and theories that are not evident prior to commencement of data collection. Quantitative methods were also used as way to investigate relationships among behaviors identified using qualitative methods.

In engineering research, quantitative methods are often considered the normal approach and thus used extensively A case can be made, however, that qualitative methods are essential to developing a better understanding of the engineering design process because it is a process largely built upon social interactions and complex processes (Daly, McGowan, and Papalambros 2013). Qualitative methods are infrequently seen and, therefore, I provide a thorough description of qualitative methods below.

1.4.1 Qualitative research methods

Qualitative research methods have several inherent advantages that make them suitable for work in design research (in general) and for this dissertation (in particular). Qualitative methods allow for an emergent approach to data collection and analysis, as opposed to requiring hypotheses a priori (Creswell 2013; Patton 1990). This is particularly well-suited to the study of design ethnography because the lack of prior research means that hypotheses would not be well-informed and may be a barrier to discovering concepts and theories that are not evident prior to commencement of data collection. Qualitative methods are also well-suited to the study of complex phenomena involving humans and social interactions. Design is a social process during which multiple people work and communicate together to develop an artifact (Alexiou and

Zamenopoulos 2008; Bucciarelli 1988). This multi-faceted complex process cannot be adequately described with a small set of variables (as would be necessary with quantitative methods) and attempting to do so may lead to the loss of insightful results. Qualitative methods also allow the flexibility needed to identify emergent themes and theories, thus allowing the data collected to guide the research process (Starks and Trinidad 2007; Stern 1980)

1.4.1.1 Data collection

Qualitative research results in "thick descriptions" of the situations or subjects being studied (Lincoln and Guba 1985). Developing a detailed and thorough understanding of the study subject is key to being able to develop theory that explains (or predicts) behavior. One must perform extensive data collection to ensure the perceptions of study subjects and the environments/phenomena being studied are accurately represented with the data. Data collection methods can include (but are not limited to) interviews (structured, unstructured, and semi-structured), observations (direct, discrete, participant), document/archival data, questionnaires/surveys, and focus groups (Chism, Douglas, and Hilson 2008; Marshall and Rossman 1999). Described below are the three data collection methods that will feature prominently in this dissertation.

Interviews: Interviews are one of the most common methods of qualitative data collection (DiCicco-Bloom and Crabtree 2006). They allow the researcher to guide the study subject through a discussion of particular topics and provides the researcher with freedom to ask follow-up questions whenever responses or ideas are vague or present interesting points to further discuss (Chism, Douglas, and Hilson 2008). Semi-structured interviews have and will be used extensively in this dissertation to better understand students' use of design ethnography during their design projects. During a semi-structured interview the research begins with a template for the types of topics he/she would like to cover and questions he/she may ask. Once the interview has begun, however, the interviewer has the freedom to deviate from the protocol whenever he/she determines that it is appropriate (Patton 1990).

Observations: Observations are a distinct example of how the researcher is the instrument of data collection during a qualitative research study. By studying subjects in their natural environment (just as in design ethnography) observations allow the researcher to explore aspects of the subjects' daily lives that would not be as easily done through interviews. Observations can be performed in two ways, direct observation and participant observation (Punch 1998). In direct observation, the researcher is an "outsider," attempting to not influence the subjects or situation he/she is studying. In participant observation, the observer is also an actor in the situation/context which he/she is observing. For example, within the context of this dissertation I will conduct participant observation since I will at one be designing medical devices for low-resource settings and studying they ways in which design ethnography is used in this context.

Documents: Documentation by study subjects can be a fruitful data source during a qualitative study. Documents analyzed in qualitative work are usually not produced as a result of researcher suggestion, so one has access to an 'unbiased' information source (Chism, Douglas, and Hilson 2008). Throughout this dissertation, various documents will be used as data sources including design reports (as are produced during capstone design courses) in addition to product requirements and engineering specifications. These documents provide a thorough history of how the design of a device evolves over time.

1.4.1.2 Data analysis

As mentioned previously, qualitative research involves both inductive and deductive approaches to data analysis. An inductive approach begins from a specific example or piece of data and then attempts to generalize from this data (bottom-up approach). A deductive approach begins with a general theory of a particular phenomenon and then generates a hypothesis about how this would apply to a specific situation; from there one can test one's theory within data collected. While one often finds deductive approaches associated with quantitative methods and inductive approaches associated with qualitative methods, this is not always the case. One can use qualitative methods to test a theory/hypothesis and one can use quantitative methods to inductively generate theory.

Qualitative research is also a highly iterative methodology. This means that data analysis actually starts with data collection and not after data collection has finished (Burnard 1991; Maxwell 2013). As data is collected, a researcher will begin his/her analysis and this will inform crucial data collection decisions such as what questions should be asked, who should be interviewed, and whether enough data been collected. This is an important aspect of qualitative research because it is difficult to predict what data will reveal prior to collection and thus the researcher needs to be able to adjust to new or different aspects of the data he/she collects. There are a vast number of qualitative data analysis strategies; Leech and Onwuegbuzie cover seven unique strategies in a review of methods (Leech and Onwuegbuzie 2007). Below I describe the constant comparative method of data analysis that will be used extensively throughout this dissertation.

Constant Comparison: Constant comparison is one of the most common data analysis methods used in qualitative research (Leech and Onwuegbuzie 2007). This approach is used in order to identify themes in the data. Themes are “conceptual labels placed on discrete happenings, events, and other instances of phenomena” (Strauss and Corbin 1998). Themes serve to link various ‘chunks’ of data into more abstract categories which, when put together, help a researcher better understand the phenomena or situation of interest (Ryan and Bernard 2003). The constant comparison method of identifying themes grew out of work with grounded theory during the 1960s (Glaser and Strauss 1967). Within the context of grounded theory, a researcher is attempting to build theory from data collected and is thus searching for themes that tie his/her data together logically. To perform the constant comparative method one must iteratively read through the collection of data. One must then break up the data into logical fragments (these can vary in size from a single word to a complete thought to one or more paragraphs). Once the data is separated in logical fragments, the researcher then begins to label each fragment with a code that describes it in some way. One then proceeds to do this for all fragments, being sure to ‘constantly compare’ new fragments to old fragments to determine when the same labels should be applied. This process is iterated until changes cease to be made. Afterwards, the codes can then be compared on their own to determine whether they can be combined or separated and whether themes can be inductively generated. This process can be seen visually in Figure 1.3. Iterating this final procedure eventually leads to the development of theory that can help to explain aspects of the phenomena being studied.

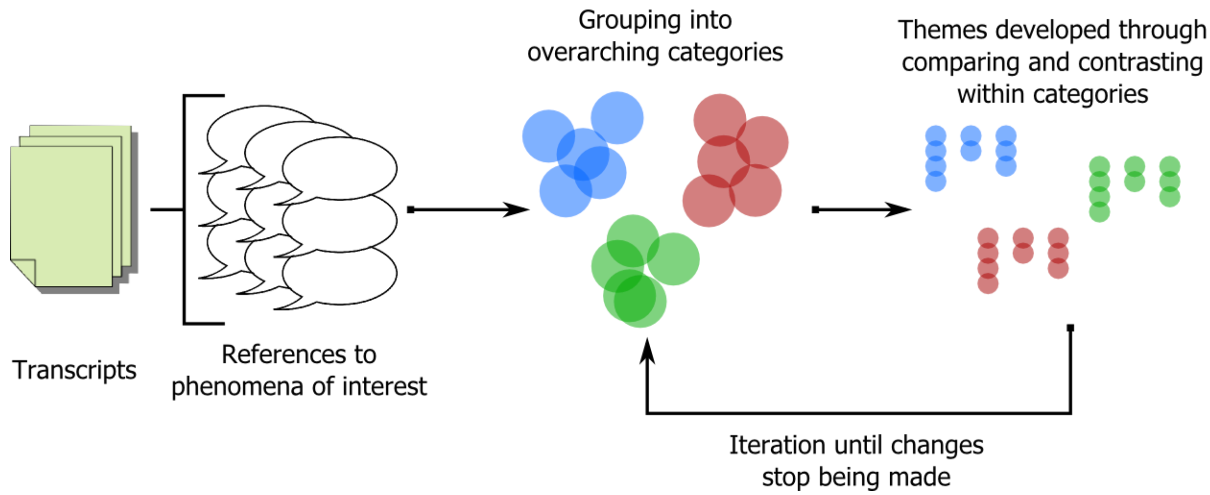

Figure 1.3: Graphical representation of the constant comparison method

1.4.1.3 Reliability & Validity

Within quantitative research, the concept of reliability is closely tied to the replicability and/or repeatability of experimental results or observations (Joppe 2000). Within qualitative research, however, replicability and repeatability are not necessarily possible. This is because qualitative research generally focusses on developing a deep and detailed description of one particular situation (at one point in time) and then attempting to theorize from this point. This type of study cannot be replicated or repeated with any degree of confidence. A similar issue arises when considering a study's validity, which in quantitative research is defined as "whether the research truly measure that which it was intended to measure or how truthful the research results are" (Joppe 2000). In qualitative research, however, many times researchers are concerned with the perceptions subjects have of a particular issue or phenomena and thus the idea of 'truthful' results becomes complicated or unattainable (Golafshani 2003). Due to these issues, other terms have been developed to assess the quality of qualitative research that are more in line with the processes and results of this research methodology.

Credibility: Credibility refers to whether the researcher is accurately representing what is occurring in a given situation. The level of credibility depends upon the 'thick descriptions' developed and the ability of the researcher to analyze the data (because the researcher is the instrument of data collection and analysis) (Patton 1990). Strategies for increasing a studies credibility include prolonged engagement with the study subjects (or situation), peer debriefing, analysis of negative cases, and member checking (Westbrook 1994).

Transferability: Transferability refers to how the findings from a particular study can be applied to other situations (Malterud 2001). Transferability is an essential component of research as the goal of almost all research is to contribute to broader knowledge. A major driver of the level of transferability of a study is its similarity to the situation in which a reader would want to apply the findings. Therefore, a key component to producing a quality, qualitative study is to provide enough detail about the situation and participants in order for readers to be able to determine whether the results are transferable (Hoepfl 1997). The transferability of the study can also be increased through purposeful sampling where the researcher attempts to sample from a diverse set of respondents in order to ensure that one's results are not biased to a certain subset of the population.

Dependability: Dependability refers to the fact that the findings and research process are consistent and could be repeated (although in a different context) (Lincoln and Guba 1985). A dependable study will have approached the research process in a systematic way and will have documented all procedures and decisions in a way where an outsider could easily follow similar procedures. One method to increase the dependability of a study is to develop an extensive audit trail that captures all facets of the study and decisions made so that one can return to it at a later time to determine whether there exist any contradictions (Lincoln and Guba 1985).

Confirmability: Confirmability is equivalent in qualitative research to the concept of objectivity in quantitative research (Patton 1990). Objectivity, however is not feasible because the researcher is the instrument of data collection, therefore, confirmability refers to the idea that the results of the study are an accurate portrayal of the subjects and situation being studied and not simply a projection of the researchers personal characteristics or preferences (Shenton 2004). Triangulation plays a major role in demonstrating confirmability by ensuring that multiple data sources point to similar study results.

1.5 Contribution

The studies in this dissertation have resulted in a deeper understanding of design ethnography use during front-end design and the processes by which novice designers learn and implement design ethnography. In Chapter 2, I have shown that design ethnography, when deployed in the complex field of medical device design for low-resource settings, can identify tacit requirements from a variety of stakeholders and be effectively employed to evaluate early phase prototypes (Mohedas, Sabet Sarvestani, et al. 2015). Additionally, it was shown that specific data analysis structures (developed prior to implementation) can noticeably increase the efficiency of data analysis and lead to more concrete design changes (Mohedas, Sabet Sarvestani, et al. 2015). In Chapter 3, I have shown that that novices struggle to gain the benefits described in the literature from stakeholder engagement. Novices gained only superficial benefits from use of design ethnography techniques (e.g., using stakeholder interaction to directly make design decisions or gain technical expertise in a specific area) and were frustrated by the information processing requirements needed to gain larger benefits (e.g., synthesizing inconsistent information, dealing with indecisive stakeholders, and determining which stakeholders to engage with) (Mohedas, Daly, and Sienko 2014a). In Chapter 4, I sought to determine what factors (internal or external to design teams) influenced whether or not design team's perceived interactions with stakeholders as useful to decision making (Mohedas et al. 2016). Five key influential factors were identified: goal specificity (referring to the level at which students pre-developed clear and explicit goals for a stakeholder interaction), stakeholder expertise (referring to the level of alignment between a stakeholder's expertise and the project topic students were pursuing), information variability (referring to the level of variation in the information students receive from stakeholder interactions), information applicability (referring to the level of directness with which design teams could apply the information obtain to a design decision), and decision making responsibility (referring to the level of responsibility design teams would take when engaged in design decisions) (Mohedas et al. 2016). The results of Chapters 2 through 4 elucidated the importance of information processing during the use of design ethnography techniques and stakeholder interaction more broadly; Chapter 5 sought to better understand how information processing influenced front-end design. In this chapter, I demonstrated a strong correlation between the diversity of information sources novices employ (i.e., their ability to synthesize information) and the quality of the requirements they develop (Mohedas, Daly, and Sienko 2015b). Additionally, designers developing high quality requirements performed more well-balanced interviews with stakeholders, took a broader approach to information gathering, displayed more iterative behavior with respect to requirements development and were less reliant on specific information sources (Mohedas, Daly, and Sienko 2015b). In Chapter 6, I focused on the ability of designers to conduct quality stakeholder interviews and apply the information generated to the development of product requirements and engineering specifications (Mohedas et al. n.d.). This study demonstrated that a coding system (based on best practices for stakeholder interviews found in the literature) could differentiate between designers performing high- versus low-quality interviews. Additionally, I was able to show that participants conducting higher quality requirements elicited more information from stakeholders that more directly influenced the product requirements they developed (Mohedas et al. n.d.). Based on the results of Chapters 2 through 6, I was able to develop a better understanding of the developmental trajectory of novice designers as they learn to use design ethnography techniques and applied this understanding to the model of skill acquisition described in Chapter 7 (S. E. Dreyfus 2004). The developmental trajectory model was based on the Dreyfus and Dreyfus model of skill acquisition and helps elucidate why novices struggle with specific aspects of design ethnography and identifies key milestones that engineering instructors can look for in order to identify progression in a students' design ethnography ability.

As globalization requires industry to develop products for culturally diverse markets, design ethnography will increase in importance as it entails a systematic methodology for producing products that are uniquely tailored to ones stakeholders and context of use. This dissertation has specifically filled gaps in the literature, as defined in Figure 1.1: adding a detailed case study of design ethnography in a new context (Chapter 2), bolstering our understanding of how novices collect, synthesize/analyze and apply design ethnography data (Chapters 3 and 4), determining the effect that information synthesis has on the quality of front-end design outcomes (Chapter 5), developing metrics for how the quality of stakeholder engagement can be quantified and its relationship to the applicability of information elicited (Chapter 6), and finally synthesizing these results into a cohesive developmental model of novice to expert behavior when implementing/learning design ethnography (Chapter 7). In doing so, this dissertation has contributed to the fields of design research, engineering education research and pedagogy, and medical device design. An understanding of the complexities which make-up design ethnography is crucial to allowing it to expand to new fields where it could be employed to develop devices or services that are better suited to the stakeholders for whom they are developed and the contexts in which they must function. While special effort was taken to study design ethnography within the context of medical devices in low-resource settings, the results of how novices approach and implement design ethnography during design has led to transferable results benefitting both universities (as they expose more students to these techniques) and companies (as they introduce design ethnography formally into their design processes). Lastly, the studies undertaken to understand a design process/skill as complex as design ethnography have employed novel research methodologies that have added to the body of techniques currently available for the study of design processes.

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Chapter 2 A case study of design ethnography use during the development of a medical device for rural Ethiopia

2.1 Introduction

Design ethnography has been observed to lead to more successful products that are more usable and better fit the context in which they must function. However, few case studies are available in the literature that demonstrate how design ethnography use in diverse contexts (particularly outside of human-computer interaction) or that provide the detail necessary with respect to data analysis to be used as a guiding template by novice designers. In this chapter, the use of design ethnography during the evaluation of a medical device prototype designed for the rural Ethiopian healthcare system is presented. The rural Ethiopian healthcare system is an ideal context in which to study design ethnography because it represents a dramatically different context for medical device design (i.e., healthcare delivery in rural Ethiopian is vastly different than in the United States) and the end-users for this device (Community Health Extension Workers) are not found outside of low- and middle-income countries. These unique characteristics increases the utility of using a research based approach (i.e., design ethnography) to understand the context of use and the stakeholders involved, allowing the benefits of design ethnography to be more clearly elucidated.

2.2 Background

2.2.1 Design ethnography

2.2.1.1 Definition & use in industry

Ethnography is the “study and systematic recording of human cultures” (“Ethnography” 2014). Ethnography and the use of naturalistic observation was popularized by anthropologists such as Malinowski while attempting to study “faraway places” (Randall, Harper, and Rouncefield 2007). Design ethnography evolved from these ethnographic research methods developed by anthropologists; during design, it allows one to gain a deep understanding of the stakeholders who will ultimately interact with a product and the environment where it will be used (Blomberg et al. 1993; Bucciarelli 1988; Wasson 2000). Within the field of product design, ethnographic principles were first discussed by designers such as Henry Dreyfus (H. Dreyfus 2003; Salvador, Bell, and Anderson 1999). Dreyfus advocated ethnographic methods such as field research as the main method of truly understanding the context for which one is designing (H. Dreyfus 2003).

Xerox Palo Alto Research Center (PAR) was one of the first companies to formally introduce the idea of using ethnography in the design process during the 1980s leading to its use in other large corporations (such as Microsoft, Intel, and Motorola) (Sanders 2002). Design ethnography can be defined as "a portfolio of methods that have been developed to understand the perspectives of people by observing and participating in activities of everyday life" (Salvador, Bell, and Anderson 1999). "Design ethnography focuses on the broad patterns of everyday life that are important and relevant for the conception, design, and development of new products and services…[design ethnographers] do not ask consumers what they want; instead, we strive to understand how they live" (Salvador, Bell, and Anderson 1999).

Design ethnography does not consist of a single tool or method, but a large toolset that can be adapted for use in one's specific design context. Tools can include (but are not limited to): interviewing (structured and informal), genealogies, social mapping, demography, photography, documentary film making and videotaping, observation, archival research, and "deep hanging out" (Powdermaker 1966; Salvador, Bell, and Anderson 1999; Wax 1986; Werner, Schoepfle, and Ahern 1987). As compared to traditional ethnography, design ethnography is "quicker, it is less expensive, and it can be less intrusive into the lives of those being studies" (Sanders 2002). Some studies have attempted to identify the key characteristics or feature of design ethnography (Arnould and Wallendorf 1994). Arnould and Wallendorf describe the following characteristics of ethnography, 1) ethnography involves systematic data collection of customers in their natural setting, 2) ethnography involves extensive time spent by the researcher in the context of interest (this is key to bringing to light the moments of ordinary life that can have significant effect on product design), 3) ethnography produces interpretations of events that those being studied would validate, and 4) ethnography involves synthesis of multiple data sources (Arnould and Wallendorf 1994).

Despite growing interest in this design toolset, the use of design ethnography is not prevalent. A study of 160 US companies found that only 12.9% claimed to use design ethnography, despite being ranked as the most effective method for understanding one's customer (R. Cooper and Edgett 2008).

2.2.2 Design process models

Design ethnography is a set of tools and a process by which the designer can come to deeply understand the end-users for whom they are designing and the context in which their product will be used. This methodology can therefore be incorporated into any number of design process models or philosophies which place emphasis on truly understanding one's users and environment. Below I review human-centered design, the design philosophy most commonly associated with the use of design ethnography methods.

2.2.2.1 Human-centered design

Recently, both industry and academia have emphasized a human-centered design philosophy, in which designers deeply integrate needs and wants of end-users and stakeholders into design decisions (Zhang and Dong 2009). Human-centered design contrasts to more traditional "technology centered" design processes that can inadvertently produce products that users do not want or cannot use (Steen 2012). Instead of focusing on the technological aspect of a product, the designer focuses on the end-users or stakeholders who will be interacting with the final product. A review of human-centered (or sometimes referred to as user-centered) design found various definitions which can be seen in Table 2.1. This review found that the following characteristics were all shared among the definitions of human-centered design (Zhang and Dong 2009):

- One must place human beings in a central place in the design process
- One must understand people holistically
- One must employ a multi-disciplinary team
- One must involve users during the entire design process
- One must make products which are useful, usable, and desirable

These definitions of human-centered design place more emphasis on the various stakeholders which are affected by the design and the broader context in which a design is used than traditional technology-centric design processes (Steen, Koning, and Pikaart 2004; Walters 2005). An ISO standard (13407) has even been developed to define human-centered design referring to it as "a systematic approach to interactive systems development that focuses specially on making systems usable" (Jokela 2003). Extensive stakeholder engagement is critical to performing human-centered design (Steen, Koning, and Pikaart 2004; Walters 2005); engagement methods include interviews, focus groups, surveys, observations, participatory design workshops, and co-creative partnerships (Grudin and Grinter 1995). Regardless of the methodology chosen, the objective is to acquire a thorough understanding of end-users and stakeholders so that a team makes informed design decisions.

Table 2.1: Definitions of human- and user-centered design within academic and industry literature (Zhang and Dong 2009)

Citation:	Term	Definition
Norman (1988)	User-centered design	A philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable.
Jordan (2000)	Person-centered design	To take a wider view of person-centered design and look, in a more holistic context, both at product use and at those using and experiencing products.
McDonagh-Philip and Lebbon (2002)	User-centered design	A design methodology utilizing users as a designing resource, to increase the involvement of the user.
Brusberg (2003)	User-centered design	User centered design aims to expand the designers' knowledge, understanding and empathy of users.
Walters (2005)	Human-centered design	A creative exploration of human needs, knowledge and experience which aims to extend human capabilities and improve quality of life.
Alison Black (2006)	User-centered design	User-centered designers engage actively with end-users to gather insights that drive design from the earliest stages of product and service development, right through the design process.
IDEO	Human factors	Applying human factors techniques to people across the ecosystem, not just end users / consumers. Putting people at the heart of the process. Making things "useful, usable, and desirable" for people.
HCDI, Brunel University	Human-centered design	Human centered design is all about putting the human user at the heart of a product, system, or process. Human centered designers use knowledge of human capabilities and limitations across a variety of methods, combining biomechanics, psychology and engineering, to produce a solution which is safe, efficient, and satisfying to use.

2.2.3 Benefits of design ethnography

Traditional methodologies (such as focus groups and surveys) of requirements elicitation or need identification have been shown to lead to only minor improvements in current products and not the truly innovative products that companies strive to develop (Dahlsten 2003; Harari

1994). These traditional methods are conducted outside the customer's natural environment making it difficult for the customer to articulate their needs and wants. Customers are not conscience of the limitations of current products or cannot imagine how a new product will function (Deszca, Munro, and Noori 1999; Mariampolski 1999). Market research conducted outside the respondents natural environment is in jeopardy of two major effects: respondents behaving differently than they would normally and researchers not being able to notice key context clues that may provide valuable impetus for questioning (Goffin et al. 2012). These deficiencies can lead to market research that produces only incremental improvements in products and unable to achieve true 'blue sky' innovations (Ulwick 2002).

Design ethnography, however, is based on research performed within the end user's daily environment. Observation of customers in their natural environment as they use existing products can lead to insights with respect to technology gaps or innovative product ideas (Leonard and Rayport 1997). These techniques are also well-suited to the elicitation of product requirements after a technology gap or product opportunity has been identified (Abbir Griffin 2013; B. Johnson and Masten 1998; Wilcox 1996).

An experienced design ethnographer can learn to identify 'contradictions' in users' responses to direct questions and how they actually use products or conduct activities. These contradictions can lead to more radical innovations that would be impossible to detect using traditional market research methods (which would rely on the 'glossed' explanations provided by users) (Arnould and Wallendorf 1994). Studies with undergraduate industrial design students have also shown that ethnographic observations can have a significant positive impact on the creativity of the students' designs (Christensen 2006).

Case studies from industry have also shown the benefits of the use of design ethnography. Miele, a German household products company, has developed many successful products through the use of design ethnography and has moved past the view that design ethnography is primarily the domain of market researchers and says "that it is essential for not only marketing but also engineers to actually see the issues first-hand. Only if you are present do you really understand the issues" (Goffin et al. 2012).

2.2.3.1 Design Ethnography Best Practices

There are no 'one size fits all' best practices for conducting ethnographic investigations during product design (Rosenthal and Capper 2006). Instead, designers must determine which techniques are most appropriate to the situation they are investigating. Most case studies have focused on determining how businesses can most efficiently implement ethnographic processes during new product development. One case study found several key principles that should be followed when conducting ethnographic investigations during new product development (Rosenthal and Capper 2006). These principles can be seen in Table 2.2.

Table 2.2: Principles for planning and executing design ethnography investigations (Rosenthal and Capper 2006)

Planning:	Start with an open mind
	Screen for diversity in respondents
	Select a suitable ethnography team and provide needed advance training
	Plan explicitly to gain access to the desired range of respondents
Execution:	Use multiple observation and inquiry techniques in the field
	Modify the ethnographic guide as needed during the study
	Be flexible enough to probe for insights when surprises arise
	Act like a team in the field
	Capture relevant visual accounts

More limited literature is available that looks at actual practices or strategies for implementing design ethnography in the field. Some practitioners have focused on developing reliable methodologies for interacting with customer’s and end-users in order to extract requirements that will translate to true innovative products. One example of this is the use of outcome-based customer interviews (Ulwick 2002). During these interviews, customers are pushed away from answers containing solutions or vague language. Instead, the interviewer looks to obtain requirements by determining the results that the user would like to see when using the product. This can involve rephrasing customer’s original answers in terms of outcomes (and then asking them to verify or validate that the wording is correct) as well as asking questions in a manner that results in the customer describing the outcome they would like to see (instead of the solution they believe is correct).

2.2.3.2 Challenges of employing design ethnography

Design ethnography takes significant investment of time and resources. A typical study could involve 30 customers and may lead to over 30 hours of video data that needs to be carefully analyzed to draw conclusions (Goffin et al. 2012). Furthermore, literature on design ethnography has shown that implementing these techniques can lead to many challenges that, if not properly approached, can compromise the validity of the results and work against a product's success.

One challenge associated with performing design ethnography is the shear amount of data that can quickly be collected during observations and interviews. A design ethnographer can generate hours of recordings and large amounts of field notes from a single day of data collection (M. Hughes and Sharrock 2003). True insights, however, are the results of quality data analysis. Collection and analysis by untrained practitioners may lead to superficial findings that don't truly represent the intentions, needs, or wants of the stakeholders being studied (Forsythe 1999; Nyce and Lowgren 1995). Many times, only the design ethnography data collection methodologies are adopted by non-anthropologists without also adopting the data analysis methods and the theoretical frameworks that social scientists use to draw conclusions from fieldwork (Nyce and Lowgren 1995). Ensuring quality when one plans and implements a design ethnography investigation, can mitigate some of these negative outcomes (Forsythe 1999).

2.2.4 Design ethnography in the design of medical devices

The case study presented in this chapter involves the design and development of a medical device for a low-income setting. The development of intuitive, easy to use medical devices is crucial to high quality healthcare delivery. Intuitive designs help assure safe and effective operation, maintenance, and installation of healthcare technologies (Sawyer n.d.). Additionally, low usability of medical devices leads to higher risk of human error during use and thus higher likelihood of poor patient outcomes (Hyman 1994; Obradovich and Woods 1996).

One aspect of developing easy to use medical devices is developing high quality product requirements which leads to many benefits in the final product, including (Martin et al. 2006):

- Improves safety of devices
- Improves usability of devices
- Reduces device recalls
- Limits the need for ad hoc modifications
- Improves efficiency of users
- Improves patient outcomes and satisfaction

The importance of stakeholder engagement during design and the potential for design ethnography to be effectively employed in the context of medical device development have been discussed within the literature (Martin et al. 2006; Privitera and Murray 2009). Literature on the design process for medical devices has described the importance of engaging with stakeholders and properly defining product requirements and engineering specifications (Yock et al. 2015). A study of focus group use during the development of assistive devices for wheelchair users found that this form of stakeholder interaction effectively identified unmet needs (Batavia and Hammer 1990). Similarly, usability studies have allowed for the identification of end-user issues with devices that were only made apparent by observing end-users' interactions with products (Garmer, Ylven, and Karlsson 2004).

While the benefits of extensive user engagement in medical devices are substantial, literature on ethnography and other user engagement techniques within the design of medical devices is limited. A literature review of requirements elicitation methodologies for medical devices found no examples of ethnography being used to elicit requirements for a medical device (Martin et al. 2006). While most studies of design ethnography have occurred within the fields of HCI and CSCW, design ethnography shows great potential as a design tool for medical devices and particularly in low-resource settings, and thus warrants additional study.

To address this gap in the literature, I systematically used design ethnography techniques during the design of a medical device targeted at rural areas of low- and middle-income countries. In doing so, I was able to generate a detailed case study that could act as a template for designers seeking to use design ethnography techniques in settings outside of HCI and CSCW. Below I present this case study and discuss the implications the findings have on design ethnography practice and design ethnography use by novices.

2.3 Methods

The goal of this study was to perform a case analysis on how design ethnography could be used in the context of medical device design in low-resource settings. Through a richly detailed case, I demonstrate the relevance of design ethnography based on the significance of the data elicited. In this section, I introduce the design of the prototype being evaluated and present the design ethnography data collection and analysis methods used to evaluate the prototype.

2.3.1 Device background

This case study focused on the design of a medical device created to assist healthcare workers in the insertion of subcutaneous underarm contraceptive implants, Figure 2.1. Subcutaneous contraceptive implants, one of the most effective forms of reversible long-term contraception, must be administered by mid- to high-level healthcare workers. This training barrier prevents their widespread adoption in rural areas of low- and middle-income countries. The contraceptive implants, which are inserted underneath the skin of a woman’s non-dominant arm, must be placed accurately within the subcutaneous tissue. Inserted too deeply, the implant enters the muscle, causing significant problems during removal. The procedure involves first wrapping the device body against the patient's arm with a blood pressure cuff and then evenly applying pressure (by inflating the cuff). This pressure pushes the patient's skin and subcutaneous tissue into a cavity in the device body. Once the arm is pressurized, adapters slide along a guiding track inserting the implant at 1.7mm below the surface of the skin. The concept solution overcomes the problem of inaccurate insertions and could potentially reduce the training requirements necessary to insert contraceptive implants (a major barrier to access in rural areas).

Design ethnography methods were first used during the needs identification and requirements development design phases. Two graduate students (Amir Sabet and I) conducted fieldwork over the course of three weeks during August 2013. Observations and interviews were performed at St. Paul's Hospital in Addis Ababa, Ethiopia. The need to reduce training requirements for the insertion of subcutaneous contraceptive implants was identified from these observations and interviews, and confirmed through discussions with Ministry of Health officials. After the need was identified, a mechanical engineering capstone design team, using input from clinicians at the University of Michigan and St. Paul's Hospital in Ethiopia, developed product requirements, engineering specifications, and designed the prototype shown in Figure 2.1.

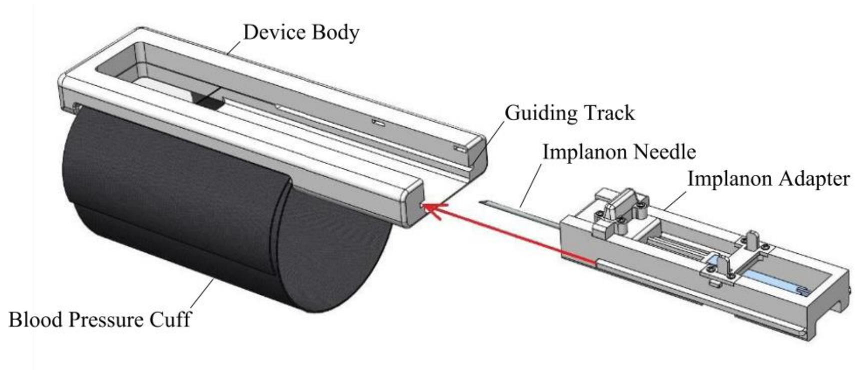

Figure 2.1: Assistive implant device prototype and its components

2.3.2 Design ethnography evaluation

We returned to Addis Ababa during May 2014 to evaluate the prototype design and gather input from stakeholders to inform future design iterations. Below I detail the use of design ethnography techniques during the evaluation of the prototype. We established two objectives for the use of design ethnography in prototype evaluation: gather feedback on the prototype that would inform modifications and/or additions to product requirements and engineering specifications, and to gain an understanding of the healthcare system (particularly in rural areas) and medical device development, manufacturing, and procurement processes in Ethiopia.

2.3.2.1 Data collection

Fieldwork took place in and around Addis Ababa. A snowball sampling methodology was used to identify as many relevant stakeholders as possible and to use local stakeholder knowledge during sampling. Participants in the healthcare field included community health extension workers (CHEWs), physicians, nurses, and midwives. Participants in other fields included key policy stakeholders from the Ministry of Health, the Food, Medicine and Healthcare Administration and Control Authority (FM-HACA), and the Pharmaceutical Fund and Supply Agency (PFSA). Peripheral stakeholders with non-medical perspectives, such as biomedical engineers and biomedical technicians in charge of equipment maintenance were also included as participants. This study was reviewed by the Institutional Review Board of the University of Michigan and was determined to be exempt (exemption #2, 45 CFR 46.101(b)(2)). All participants provided consent prior to interviews.

Data collection took place through observations and semi-structured and unstructured interviews during May 2014. Observations were conducted in the family planning office of a referral level hospital in Addis Ababa, which receives many cases from surrounding smaller hospitals and health clinics. The goal was to understand how the implant procedure is performed and how the prototype can be incorporated into healthcare settings. Observations also guided the development of interview protocols for healthcare providers.

Semi-structured and unstructured interviews with more than 50 stakeholders took place at various locations and offices in and around the city. Interviews with healthcare providers focused on identifying the pros and cons of the concept solution as it related to implantation accuracy and ease of use. Interviews sought to generate actionable feedback that would have direct impact on the product requirements and engineering specifications. Interviews with government officials were used to better understand how community healthcare extension workers are trained and how the concept solution might be implemented within the Ethiopian healthcare system. Interviews with biomedical engineers and technicians focused on current medical technologies, maintenance practices, and how the prototype design might be modified to allow for ease of maintenance and repair. Interviews were also conducted with personnel at a small Ethiopian/American start-up attempting to manufacture medical devices within Ethiopia. Healthcare clinics in a small town outside of Addis Ababa were visited to assess the rural environment where the concept solution would be deployed.

Semi-structured interview protocols were developed for all interviews. Questions attempted to identify the positive aspects of the current concept solution (where the stakeholders saw value in the current design) and the negative aspects of the concept. Questions concerning the training of CHEWs and the context of use were asked in order to understand the environment in which the device would be used and adapting it for best fit. All interviews began with an overview of the interviewee's background and general questions (if applicable) about access to family planning in Ethiopia. We then demonstrated the prototype using a low-fidelity arm simulator and the interview focused on eliciting the positive and negative aspects of the prototype. Table 2.3 provides example questions asked of clinical and manufacturing experts as well as follow-up questions that were not formulated beforehand.

Table 2.3: Example interview questions for clinical and manufacturing experts and examples of follow-up questions not formulated prior to interviews

Example questions for clinicians:
Is this medical device filling a current need? Do other products already exist that accomplish the same functions?
Does this medical device facilitate task-shifting (is it appropriate for a CHEW)?
Is this medical device appropriate for use by a mobile health unit?
Example questions for manufacturers**:**
Are there any medical devices being produced locally?
Can this medical device be produced using a production line already in place for other devices/products?
What are the current challenges to manufacturing medical devices in country?
Example follow-up questions:
If you were to be the project manager, how would you move forward with this?
Is the Ministry of Health looking for a device that could help with the entire implant [insertion and removal] process? What kind of ideas do you have to overcome insertion and/or removal challenges?
Do you have a sense of what types of sterilizing methods the CHEWs have access to?

Observations and interviews were conducted in teams of two (or more). Observation notebooks were maintained by all researchers, and all notes were compared during and after observations. During interviews, one researcher asked the majority of the questions while the other researcher(s) took notes. The team format also allowed one of the researchers to consult interview protocols and ensure that no critical questions were missed while the principal interviewer was free to ask follow-up questions. Observational field notes and interviews field notes were compiled each night into digital format later analysis. Additionally, key interviews were recorded and transcribed for data analysis.

2.3.2.2 Data analysis

Transcripts from all recorded interviews, observational field notes, and interview field notes from the three researchers were loaded into Nvivo 10 (Q.S.R.International Pty Ltd. 2012). A deductive coding scheme was developed to facilitate data organization and analysis (Creswell 2013). The coding scheme was derived from the original product requirements and engineering specifications, Table 2.4. The coding scheme allowed the compilation of all references made to each requirement and/or specification in the data. The final category, “Other,” in Table 2.4, was used to recognize data collected that did not fit into a previously defined code (i.e., it was not associated with a current product requirement or engineering specification). Originally, two additional coding schemes were used based upon 1) the various components of the device, and 2) a task analysis of the insertion procedure. However, the coding scheme in Table 2.4 allowed for more efficient organization of data and for insights to be gained more easily. After deductive coding was completed, an inductive constant comparative method was used within each code to identify patterns and discrepancies that elucidated if requirements and/or specifications needed to be modified or added (Creswell 2013).

Table 2.4: Coding scheme structured around the original user requirements and engineering specifications for the assistive device

Code Category	Code	Code Description
Accurate Implant Insertion	Depth	References to accuracy with respect to depth of implant in subcutaneous tissue.
	Min	References to how the device must ensure a minimally invasive procedure.
	Lateral	References to accuracy with respect to lateral implant location.
	Angle	References to accuracy with respect to angular implant orientation.
Safety	Cross	References to cross-contamination or sterility concerns.
	Accident	References to issues concerned with device sharps or accidental pricks.
	Biomat	References to biocompatibility of materials used in the device.
Ease of Use	Learnable	References to the learnability of the device by end-users.
	Train	References to the level of training needed by healthcare providers to operate the device.
	LowFail	References to the failure rate of the implant procedure.
	Time	References to the amount of time needed to perform the implant procedure.
Device Features	Accommodates	References to the need to accommodate multiple types of implants.
	Cost	References to the cost of the device.
	Power	References to the type/quantity of power needed to operate the device.
	Aesthetics	References to the aesthetics of the device.
Other	Other	References to the device or procedure that did not fit into any of the above codes.

2.4 Findings

The synthesis and analysis of the design ethnography data led to major modifications and additions to the original product requirements and engineering specifications. Some of these modifications and additions would not have been evident without the use of a field-based inquiry method (design ethnography) and thorough analysis. Below I discuss three specific modifications and/or additions to product requirements that were either unexpected or contradicted our prior assumptions. The following modifications/additions, which are significant deviations from our original requirements, dramatically affected the current prototype design:

1. The device must accommodate delivery of anesthesia (addition)

2. The device must address cross-contamination in a different manner (change)
3. The device must reduce patient fear of the procedure (addition)

2.4.1 Device must accommodate delivery of anesthesia

The initial concept solution neglected to consider anesthesia delivery within the product requirements, instead assuming that because CHEWs provide vaccinations, they would not have difficulty delivering the local anesthesia necessary for the implant insertion. During our original design ethnography work, clinicians did not refer to any challenges associated with anesthesia delivery, influencing our decision to not incorporate this procedure into our design.

During prototype evaluation, however, analysis of the collected data revealed that healthcare providers viewed the anesthetic injection associated with implant insertion as a more complex process than traditional injections (such as a vaccination), contrary to our original understanding. Through interviews with healthcare providers, we learned that the anesthetic must be injected first at the insertion site and then subcutaneously throughout the path taken by the implant needle. In other words, a healthcare provider must ensure that enough anesthetic is applied to the entire area and that the anesthesia needle follows the insertion path of the implant needle. Stakeholders reported that a vaccination is a simple injection requiring minimal accuracy and, thus, not a sound comparison.

We also learned that delivering the anesthetic correctly created what they termed a pilot hole, which they used to guide their implant insertion to the location where the anesthetic concentrated. The prototype only allowed for approximate alignment of the anesthetic delivery with the path of the implant needle. These reasons were not clear during the first design iteration, which is why we did not include a requirement related to anesthesia delivery in our initial design.

2.4.2 Device must address cross-contamination in a different manner

During the original formulation of the product requirements and engineering specifications, we consulted physicians and healthcare providers to determine the accessibility of sterilization equipment (namely, access to autoclaves). Based upon these conversations, we decided that CHEWs would have access to autoclaves at their corresponding health center (each health center oversees five health posts run by CHEWs). However, during interviews with healthcare providers and Ministry of Health officials during prototype evaluation, concerns about the reusable nature of the device (which would be autoclaved after each use) were raised. One physician stated, "[community health extension workers] have no reason to go to the health center and autoclave anything. But, my point is the health center should have an autoclave." It was a clear example of why we previously assumed that autoclaving after each use was viable, and why it would not work in practice. The physician mentioned that health centers do in fact have autoclaves where our device could be sterilized (as we had previously designed for); however, CHEWs do not currently have any need for traveling to the health center regularly. Providing them a device that required autoclaving (and, therefore, required them to make regular visits to the health center) would increase the likelihood that CHEWs would abandon the use of the device altogether. Physicians also told us that CHEWs only use disposable equipment (which have a reduced risk for cross-contamination), e.g., "they don't use anything that is going to need sterilization." This statement exemplifies the fact that as currently designed (requiring an autoclave) our prototype was likely to be resisted by end-users.

Some healthcare providers also thought that the safety and cleanliness of a reusable medical device for use in rural areas would be an issue for patients. After being told that the device was reusable and needed to be autoclaved after each use, a physician stated, "[patients] should be reassured that…[if the device] is going to be used in many patients, then at the same time, it is safe." Many physicians were concerned with the reusable nature of the device, that autoclaving may not guarantee sterility, and that the sterilization procedures required would add to the heavy workload of CHEWs.

The issue of cross-contamination appeared frequently in the form of suggested design changes. For example, while many stakeholders thought that certain components of the device could be reused, they also thought that the specific components directly around the insertion site should be disposable. One physician mentioned that to ensure minimize "cross contamination, you could provide 10 to 15 caps that would be thrown away after each patient." The caps would cover the insertion site and prevent bodily fluids from being transmitted between patients. Another healthcare worker mentioned providing "a new [end piece] for each patient…the end that could become contaminated." The critiques of the reusable nature of the device coupled with the repeated indications that some components should be disposable provided enough evidence to dictate a major redesign to address cross-contamination concerns.

2.4.3 Device must reduce patient fear of the procedure

A key piece of feedback obtained from stakeholders was that the device needed to be redesigned to allay patient fears of the procedure. Inserting the implant requires using a large bore needle, which often leads to so much apprehension that many women choose short-term contraceptive methods because they are more familiar with simple injections or once-a-day pills. The large size of the original device was discussed by one physician, who stated that it needed to be as small as possible in order to "not terrorize the client." Another healthcare provider said, "when you see this thing, I think it's maybe big and huge." Similarly, physicians mentioned that the device needed to be shorter, lighter, and smaller so that it would not intimidate patients and would comfortably fit the arm.

Some feedback from stakeholders related to the theme of reducing patient fear during the discussion of other features. For example, speaking about the need for anesthesia delivery to be incorporated into the design of the device, one physician stated "what patients fear is pain, so anesthesia delivery remains necessary." He talked about how the device, in its current form, would not be seen as an improvement by patients, because the design would not reduce their fear of the procedure. Nurses who worked in the family planning office spoke about the challenges of counselling women about long-term contraceptive options when they were fearful of the procedures (e.g., the large bore implant needle). These discussions made clear that future device iterations would need to account for patient concerns of the entire procedure and not focus solely on the technical requirements of the procedure.

2.5 Discussion

The findings from the use of design ethnography guided significant modifications and additions to the product requirements and engineering specifications of the assistive device. Some of the changes would not have become evident through evaluations performed outside the field (e.g., in a laboratory setting). For example, during the original needs assessment (August 2014), healthcare workers repeatedly made clear that a reusable device would help keep costs low and would be a positive feature of the device. However, during evaluation of the prototype through design ethnography, healthcare providers expressed concerns that a reusable device was less likely to remain sterile and could lead to cross-contamination issues. By showing the physical prototype to stakeholders, we learned of several issues that had not been raised previously and, as shown in previous work, which greatly improved our ability to obtain feedback about requirements and specifications (Martin et al. 2012; Yock et al. 2015).

While prior work on design ethnography has focused mainly on data collection, my goal was to demonstrate the complete process and provide detail about the methods used during data analysis (Wasson 2000). The deductive coding scheme used to organize and analyze the data collected was critical to informing modifications and additions to product requirements. Use of this coding scheme was easily employed because design ethnography was being used in the evaluation of an already-developed prototype; thus, the requirements and specifications were already fully developed. While prior literature has emphasized the role of inductive methods to analyze data collected through design ethnography, we believe that the combination of inductive and deductive methods might be opportune during later design phases as it focuses data analysis on product requirements and/or engineering specifications, highlighting necessary changes and modifications (Blomberg and Burrell 2009).

Another key realization that emerged from use of design ethnography was that assumptions were made during the original requirements and specifications formulation. During the original design process, we assumed that CHEWs were the primary end-users/stakeholders and therefore we designed to their known and perceived needs and wants. We failed to give adequate consideration to patients, because we assumed that women would make contraceptive choices based purely on the merits of the contraceptives themselves and not on the method of delivery or equipment involved. Only during the prototype evaluation phase did the use of design ethnography make it clear that the original design would negatively affect uptake of contraceptive implants, because it may add to women's fears of the procedure. Challenging designers' assumptions of stakeholders or the context of use is an important benefit of design ethnography use (Bidwell et al. 2010; Skaggs 2010).

In addition to the goal of modifying product requirements and engineering specifications to better reflect the true needs and wants of stakeholders, we also sought to understand medical device development, manufacturing, and procurement processes within Ethiopia to ensure that the approach would be synergistic with processes currently in place. While the information gained as part of this goal did not directly lead to modifications/additions to product requirements or engineering specifications, it will be important when evaluating future iterations of the design. Interviews with the operator of a small start-up attempting to develop medical devices in Ethiopia provided valuable information. For example, producing medical devices in country is advantageous when seeking to win government contracts (e.g., devices manufactured at least 35% locally receive a 30% bidding advantage over imported devices). This information, which was not directly added to the product requirements or engineering specifications, will be considered during future concept evaluation (e.g., a design that could be produced within Ethiopia might be favored over a design that would prove difficult to manufacture in a low-resource setting).

The design ethnography conducted to evaluate the prototype (Figure 2.1) led to significant changes in the product requirements and engineering specifications of the device. These changes, in turn, led to a dramatic redesign of the device as shown in Figure 2.2 (Mohedas, Sarvestani, et al. 2015). The significant changes emphasize the actionable nature of the feedback generated through data collection and the conclusions drawn from data analysis.

Figure 2.2: Device redesign based on design ethnography findings

Despite the large benefits gained by using design ethnography to evaluate the concept discussed above, several issues presented barriers to the implementation and utility of design ethnography. Data collection presented several such challenges. For example, our access to CHEWs (the primary end-user) was difficult because they were spread throughout rural areas. This made visiting CHEWs challenging and we were unable to speak with the number we had targeted. Preparation for interviews also proved challenging due to the diversity of stakeholders involved and our lack of information about particular interviewees beforehand. We found it necessary to create separate interview protocols for physicians, nurses, biomedical engineers, Ministry of Health officials, FM-HACA officials, PMFSA officials, etc. Prior to our interviews, we did not always know a stakeholder's area of expertise (e.g., some officials from the Ministry of Health specialized in training CHEWs, while others dealt with biomedical equipment issues). Thus, we had to prepare ourselves to talk about a range of topics for any one interview. Creating an interview binder containing all interview protocols was necessary to ensure proper preparation for all interviews. Data analysis also presented a challenge, specifically finding an appropriate coding scheme that facilitated the identification of necessary modifications and additions to product requirements and engineering specifications. While the coding scheme used in this study might not be as easily implemented during earlier design phases (e.g., prior to the development of product requirements and engineering specifications), a modified version could prove equally beneficial. For example, use of Garvin's eight dimensions of quality (performance, reliability, durability, serviceability, conformance, perceived quality, aesthetics, and features) could provide a foundation for data analysis during earlier design phases (Garvin 1987). Future work could focus on developing more versatile coding schemes when implementing design ethnography during other design phases.

2.6 Conclusion

Within this chapter, I detailed the use of design ethnography when evaluating a medical device prototype in a low-resource setting. In doing so, I concluded that design ethnography is particularly applicable to the design of medical devices in low-resource settings, because: 1) appropriate consideration of stakeholder needs and wants is critical to medical device design, 2) the technique helps to close the cultural gap that can exist between designers and stakeholders and 3) design ethnography allows one to deeply understand the healthcare context in which the device must function. This case study provides a critical example of design ethnography use in a context outside of human-computer interaction and provides methodological details not currently found within the design ethnography literature. This case study revealed the benefits of a structured data analysis approach (e.g., using product requirements as the coding structure for the qualitative data collected); revealing that this structured approach could more efficiently lead to required design changes (given an initial set of requirements had been developed). A structured data analysis approach could also be incorporated during earlier phases by using Garvin’s eight dimensions of quality as a formal structure.

The results of this case study also suggested the specific areas in which novice designers may encounter the most challenges when using design ethnography. For example, data analysis required extensive time, effort, and qualitative analysis experience to perform effectively. Novice designers, particularly within engineering, are not typically exposed to this type of data analysis during their academic career. Requiring novices to first perform this advanced data analysis within the context of a design course may be an unrealistic expectation and lead to novices underutilizing design ethnography techniques. Additionally, the benefits of design ethnography within the context of this case study were quickly elucidated due to the unique setting I was designing in (a healthcare and low-income context), allowing me to recognize the tacit requirements (not found through other information sources) and the inadvertent assumptions made about the context and stakeholders. In Chapters Three and Four I investigate what benefits student designers are able to obtain from the use of design ethnography techniques.

2.7 Acknowledgments

I would like to thank Dr. Fisseha and my clinical collaborators in Ethiopia, Dr. Dilayehu, Dr. Lia, Dr. Malede, and Dr. Balkachew. Additionally, I'd like to thank the original device design team, Corey Bertch, Tony Franklin, Adam Joyce, Jacob McCormick, and Michael Shoemaker. I also thank Dr. Prashant, Dr. Adhvaryu, and Dr. Johnson for their support and Colin Delaney for help with data collection. This work was supported by the National Science Foundation's Graduate Research Fellowship Program, the Ethiopia-Michigan Platform for Advancing Collaborative Engagement, and the University of Michigan Global Challenges for Third Century Team Development Grant.

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Chapter 3 Benefits and frustrations experienced by students using design ethnography techniques during capstone design

3.1 Introduction

In Chapter 2 I provided a case study detailing how design ethnography could be effectively used during the design of a medical device for low- and middle-income countries. Design ethnography allowed tacit requirements to be uncovered and elucidated assumptions inadvertently made during the original design process; adding more evidence to the benefits of using design ethnography methods that are well-documented within the innovation and human-computer interaction literature. Reviewing this literature, one sees that design ethnography leads to the elicitation of tacit needs and product requirements, removes the biases and pitfalls of self-reporting, allows a designer to obtain critical environmental and contextual information relevant to design, leads to a cultural understanding that may affect product success, and other benefits (Craig, Greene, and Douglas 2005; Evers and Day 1997; Rogers 1995; Subramaniam, Rosenthal, and Hatten 1998). While these benefits have been observed within the context of companies and experienced designers, we have a very limited understanding of how novice designers use design ethnography techniques, if they are able to achieve the benefits found in the literature, and if/how their use of design ethnography could be supported during the design process. In this and the following chapters, I investigate novice use of design ethnography to fill this gap in the literature and create a foundation for design tools and pedagogy for design students within academia as well as novice designers practicing in industry.

3.2 Background

3.2.1 Design ethnography pedagogy

The largest gap in academic literature with respect to design ethnography is in the teaching and learning of design ethnography. The limited research that has been done in this area has suggested that students struggle greatly with implementing design ethnography techniques and are not completely successful with its use. One study followed graduate students in a software design course (Sugar 2001). Students conducted usability sessions with stakeholders in order to identify issues with their software designs. However, the study found that students made little to no changes to their designs as a result of the usability sessions. Instead, students made cosmetic or superficial changes such as adding a better help file or a manual instead of changing the actual software design to be more usable (Sugar 2001). Another study where students were involved in service-learning projects where interaction with end-users and stakeholders was a key component to success found that the students encountered ‘tensions’ between the benefits of stakeholder interaction and the practical difficulties of implementing this interaction (Scott 2008). The students in this study were speaking about the benefits of user engagement and interaction, but also engaging in these interactions less and less due to the difficulties of its use.

In a study characterizing students’ understanding of human-centered design, Zoltowski developed a framework that described how student designers experienced human-centered design work, representing less comprehensive understanding, i.e., complete lack of appreciation for stakeholders, to more comprehensive understanding, i.e., developing significant relationships with stakeholders (Zoltowski, Oakes, and Cardella 2012). While these studies provide valuable insight into students as design ethnographers, there are still many unknowns in the process of moving students from novices to more informed design ethnographers. This study was motivated by this lack of research on the learning process as well as by industry’s increasing use of design ethnography.

3.3 Research design

3.3.1 Study purpose

A thorough understanding of how engineering students currently perform design ethnography and how they subsequently incorporate the information gained into their design processes is needed if engineering programs are to develop effective pedagogy in this field.

This study was guided by the following research questions:

> What design ethnography methods do students use to help them make design decisions?
>
> What perceptions do students have on the values and challenges in using design ethnography techniques?

To address these research questions, I used a small number of design teams and a qualitative approach (Case and Light 2011; Creswell 2013; Flyvbjerg 2011; Gerring 2005; Patton

1990). Qualitative approaches provide important insights into engineering education and gathering rich and detailed data is particularly appropriate for an exploratory study (Case and Light 2011). The study was approved by the Institutional Review Board of the University of Michigan.

3.3.2 Participants

Three different student design teams, which I term Teams A, B, and C, participated in the study. Table 3.1 describes their composition. All participants were senior undergraduate engineering (mechanical or biomedical) students. The mechanical engineering students had a minimum of two previous design/manufacturing courses, while the biomedical engineering students had not necessarily taken a specific design course. During the course, Teams A, B, and C worked in groups of four to design a medical device for use in a low- or middle-income country using a divergent-convergent design process that included the development of user requirements and engineering specifications, concept generation, concept selection, engineering analysis, prototyping, and validation.

During the summer prior to their capstone design course, Teams A and B participated in an eight-week immersion program in one of two low- or middle-income countries, where they conducted clinical observations and interviews in hospitals and/or clinics. Their goal was to develop at least 100 need statements, one of which became the basis for their capstone design course. Upon deciding on a need statement, the students proceeded to develop user requirements using observations, interviews, and surveys during the remainder of their immersion experience. This experience forced Teams A and B to employ design ethnography extensively during the front-end design phases (prior to the beginning of their capstone design course). Further details of this immersion experience can be found in previous publications (Perosky et al. 2012; Sienko, Huang-Saad, and Lee 2011; Sienko and Huang-Saad 2008). Team C did not participate in an immersion experience prior to the capstone design course. Inclusion of three teams with different levels of exposure to design ethnography provided diversity with respect to their experiences during the capstone design course. For example, students on Teams A and B interacted with significantly more stakeholders (on the order of hundreds) than the students on Team C (on the order of tens).

Table 3.1: Team composition and capstone design course projects

Team	Demographics	Immersion Program Experience	Capstone Design Project
Team A	4 male, mechanical engineering	Yes	Surgical device for middle-income country
Team B	1 male, mechanical engineering 1 female, mechanical engineering 1 male, biomedical engineering 1 female, biomedical engineering	Yes	Diagnostic device for low-income country
Team C	3 male, mechanical engineering	No	Surgical device for middle-income country

3.3.3 Data collection

The primary data were collected through two semi-structured interviews with each of the three design teams. Team interviews were conducted at the midpoint and endpoint of the teams' design processes; each interview lasted approximately one hour. Figure 3.1 shows the timeline of design interviews with respect to the course.

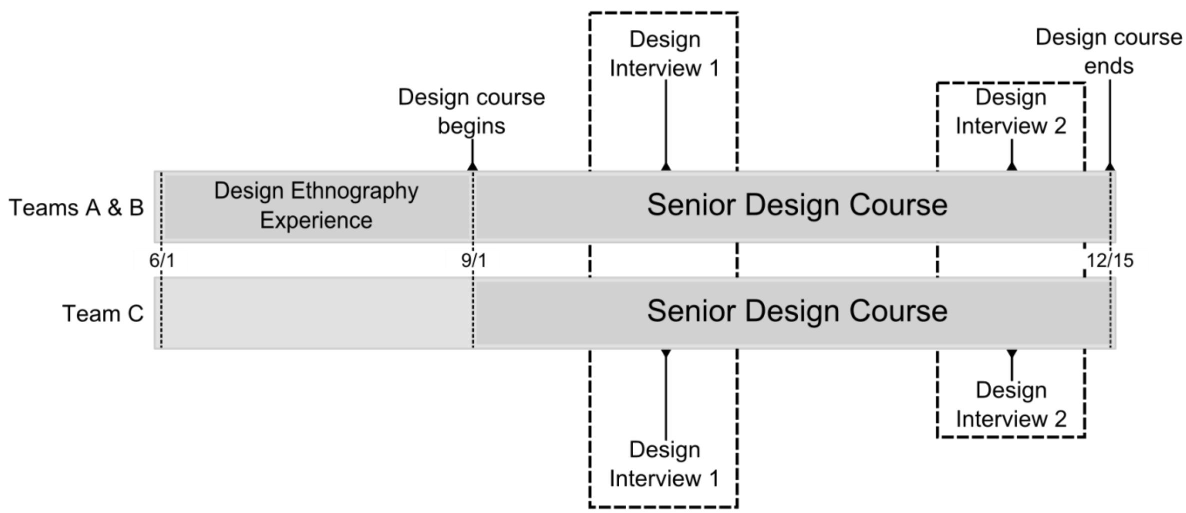

Figure 3.1: Timeline depicting semi-structured interview schedule

As part of the course requirements, Teams A, B, and C delivered four reports throughout the semester detailing the work accomplished. The study team analyzed the reports in order to characterize student use of design ethnography and extract the major decision points encountered during the design process. Decision points were defined as junctures during the design process when design teams considered multiple options or when a single option was presented with some form of justification. These decision points became the major topics of discussion during interviews. For example, the major decision points discussed during the first interview were related to user requirements and engineering specifications developed by the design teams. The major decision points discussed during the second interview included design concept iterations, changes to user requirements and/or engineering specifications, and modifications to their design plan as a result of validation testing. During both interviews, decision points were used to guide students to discuss how they used design ethnography to make decisions. When a student mentioned the use of design ethnography in making a decision, extensive follow-up questions were asked to determine what methods were used, how the methods specifically led (or did not lead) to a decision, and how effective or useful the students thought the methods were. This interview protocol allowed the study team to probe students' use of design ethnography to avoid leading questions that might imply the utility of design ethnography at decision points.

Table 3.2 lists example questions that formed the starting point for longer discussions of each team's design process. These questions were based upon the decision points identified during the design report analysis and developed to determine the inputs and outputs of students' decisions. Interview questions were discussed among the research team in order to ensure clarity, suitability, and to ensure that questions were not leading. Table 3.3 lists example follow-up questions that allowed the study team to gain a deep understanding of each design team's use of ethnographic methodologies. All interviews were audio recorded and transcribed for analysis using Nvivo 10 (Q.S.R.International Pty Ltd. 2012).

Table 3.2: Example questions asked of design students during interviews

After having developed the long list of need statements, how did you decide which would be your top choice?
How did you decide which user requirements you would include? What led you to these requirements being the most important?
It seems you had difficulty developing engineering specifications from user requirements, what aspect of this task was difficult? What resources were most helpful in overcoming this challenge?
Which user requirements provided the biggest challenge to develop? How did you overcome this challenge and what resources did you use?
Which engineering specifications were the most difficult to quantify? How did you overcome this challenge and what resources did you use?
What information sources did you use during the course of making this decision? Which one was most helpful? How did you know you were making the right decision?
How has your design changed during the course of the semester from its original conception? What prompted these changes?
What caused you to decide on this course of action?

Table 3.3: Example follow-up questions used to explore students' use of design ethnography

What information did you gain from this interview? How did you use it? Was it different from information you had previously obtained?
How did you conduct the interviews? How did you prepare for the interview?
How important was the information that you obtained during the interviews? How did it influence your decision?
What was most difficult about incorporating stakeholder information into your design process?

3.3.4 Data analysis

I used an iterative inductive coding procedure during data analysis. Theme identification followed guidelines established for analysis of semi-structured interview data (Creswell 2013). The inductive approach requires that themes emerge from the data and therefore, preconceived themes were not specifically identified, consistent with how Strauss and Corbin describe emergent theory (Strauss and Corbin 1998). The analysis sought to identify the students' perceptions of design ethnography, as opposed to the study team's perceptions of the students' use of design ethnography. The first round of coding consisted of identifying all references about or related to collecting, synthesizing, or applying ethnographic information. The specific design ethnography methods used and the types of decision points to which they were applied were noted and used to characterize student practices. Additionally, the exploration of similarities and differences among the coded segments revealed two overarching categories: student-perceived benefits of and frustrations with design ethnography. Within the two overarching categories, I explored similarities and differences among the data in order to identify themes, labeled each theme with a description, re-read each data group related to the themes, and made changes where necessary. The procedure was repeated until changes ceased to be made.

3.4 Findings

The results of the qualitative analysis are presented below in two sections. First, the design ethnography methods students used and the design scenarios in which they were applied are presented. Second, students' perceptions about their use of design ethnography are presented.

3.4.1 Student uses of design ethnography

Students used a variety of design ethnography techniques in order to inform a host of different design processes during the capstone design course. Table 3.4 provides a summary of the design ethnography techniques used by design teams and the scenarios in which they were used. Students identified several design ethnography methods that helped them to make decisions including both structured and semi-structured interviews (with various stakeholders), informal conversations, observations, and surveys. Observations were used almost exclusively during the immersion experience (Teams A & B) for problem definition while interviews were used throughout the entire design process. While all these methods were used at some point during the design process, teams relied more heavily upon interviews (especially with experts) during the capstone design course. Identifying why this preference materialized was outside the scope of this study; however, preliminary results from the semi-structured interviews with the student teams indicated that availability, ease of communication, efficiency of gaining information, and confidence with the information gained from experts may have played a significant role in this preference.

Design ethnography played a role in decision making during a variety of different design scenarios during the capstone course (Table 3.4). It was used extensively during the front-end design phases (i.e., problem definition, understanding product environment and usage, identifying user requirements, and developing engineering specifications). While the collection of data using design ethnography decreased after the front-end design phases, students continued to use the data previously collected and collect more data (to a lesser extent).

Table 3.4: Design ethnography techniques used by students during the capstone course and the scenarios in which they were used.

Design ethnography techniques used	Scenarios in which design ethnography was used
-Interviews (structured and semi-structured): -with experts -with stakeholders -with end-users -with proxy end-users -Informal communication / conversations -Observations -Surveys	-Identifying/understanding/defining the problem -Understanding the environment/product usage -Gaining background technical knowledge -Identifying user requirements -Developing/refining engineering specifications -Ranking user requirements -Understanding an unfamiliar field -Developing testing/validation methods -Confirming information/decisions -Understanding ergonomics -Guiding design decisions -Guiding design principles (i.e., simpler is better) -Evaluating concepts and approving final designs -Conducting usability testing/validation

3.4.2 Student perceptions of using design ethnography

While the results above provide preliminary findings as to the design ethnography methods students chose to employ and the situations in which they were employed, this study also sought to determine how students perceived their use of design ethnography. These student perceptions are displayed in Table 3.5 and the themes identified were placed into two overarching categories: student-perceived benefits and student-perceived frustrations with using design ethnography. An in-depth discussion is presented below.

Table 3.5: Themes found after analysis of interview data

Overarching Categories	Student-perceived benefits of using design ethnography	Student-perceived frustrations with using design ethnography
Themes	- Gaining information from stakeholders led directly to making design decisions - Receiving clear explanations for complicated and technical information quickly from stakeholders	- Receiving inconsistent information from stakeholders - Stakeholders failed to provide user requirement - Finding the “right” stakeholder to interview

3.4.2.1 Student-perceived benefits of design ethnography

Themes representing student-perceived benefits of design ethnography included gaining information from stakeholders that led directly to design decisions and receiving explanations from stakeholders on technical issues. Students consistently cited stakeholder interaction as the source of the most useful information during design decisions as well as a source of clarification during difficult and technically complicated portions of the design projects. The two primary themes in this category and excerpts from team interviews are presented below.

Theme: Gaining information from stakeholders led directly to making design decisions.

Teams A, B, and C consistently voiced the belief that interacting with experts and stakeholders throughout their projects was a very useful source of information for design decisions. Decisions affected by expert and stakeholder interaction included determining which user requirements and engineering specifications should be included, rank ordering these requirements, evaluating concepts, and developing validation procedures. When design teams faced critical decision points, they frequently found the answers during their interviews with stakeholders.

During a discussion on obtaining user requirements and engineering specifications, Team B was asked which sources of information were the most useful and relevant when obtaining the requirements and specifications:

> "People... Interviews. That's where we got the best [information]" (Team B, 1st Interview).

Team A's project involved assessing environmental hazards; this is how they described their interaction with an expert in this area:

> "[The expert] was extremely helpful to us…From OSHA [Occupational Safety and Health Administration]…She taught us about the dragger tubes. We had no idea dragger tubes even existed…And I think we figured out that sometimes online research is kind of hard for some knowledge, like the dragger tube. We would never know the dragger tube if we didn't talk to anybody" (Team A, 2nd Interview).

Team A continued to emphasize the importance of interacting with experts when seeking to understand key engineering issues. They mentioned experts who helped them through difficult aspects of the design process:

> "I feel like it was a lot more helpful to actually talk to people who are specialists in the field…once we started talking to [the manufacturing engineers]…they were able to answer a lot of questions we just couldn't find online" (Team A, 2nd Interview).

Team A considered their interaction with manufacturing experts essential as they tried to develop a successful design.

Team C spoke about the usefulness of both viewing an actual procedure in which their device would be used and speaking to stakeholders having the most knowledge about the current devices in use:

> "We actually went into the open heart procedure and [the surgeons] … showed us how all of the equipment works together, so we got a better feel for what they are expecting in terms of like the size and …the shape…how it could fit in [and] especially be held." (Team C, 1st Interview).

During interviews, all three teams commented that they gained valuable information from stakeholders that led directly to design decision answers.

While students pointed to interaction with stakeholders as a key source of decision-making information, the students did not speak to any examples where they gained tacit knowledge from stakeholders. Instead students focused on using interviews with stakeholders to solve problems outside their domain of expertise.

Theme: Receiving explanations for complicated and technical information quickly and easily from stakeholders.

The second theme in student-perceived benefits was that stakeholders articulated issues and technical jargon in ways that were both tangible and useful. For example, during the early stages of their project, Team C discovered that the specifications provided by their company sponsor did not align with the interviews they had conducted with doctors. They discussed how a single interview was able to clear up the confusion:

> "[The company] was very specific too and it took just one good interview with the [doctor] at the hospital [to obtain the correct specification]" (Team C, 1st Interview).

Team B described multiple times when experts or stakeholders helped steer the team in the correct direction:

> "It was [the electrical engineering professor who said] 'maybe you want to cascade two [filters] in line'…so that planted the seed and I found a Butterworth [filter]" (Team B, 2nd Interview).

The same team summed up this trend during the project:

> "It's a general theme of how we have done everything with this project. People point us in the right direction and we try to research it as much as we can" (Team B, 2nd Interview).

Team A had no experience in the medical field, which led to the challenge of understanding what was happening in the operating room and how the stakeholders helped them to understand:

> Student 1: "We also talked to other medical personnel, such as setup people and nurses."
>
> Student 2: "They weren't…interviews. More like quick talks. They helped explain to us what was going on because one of the challenges was we're all mechanical engineers, we're in an operating room, and we don't know what they're doing" (Team A, 1st Interview).

At various points in their design process all three teams made reference to the theme that experts were able to explain highly technical information to them in a way that enabled them to easily incorporate the information into their design process.

When interviewing stakeholders on technical topics, students appeared to be able to extract information more easily from stakeholders and explore ideas more thoroughly. We believe that this could be due to the very specific topics around which these interviews were based. For example, when interviewing professors who were experts in signal processing, Team B was able to gain valuable information with respect to how they should approach this problem. The interview was specific and students were attempting to answer a single signal processing question. In this respect, students were gaining only limited benefits of design ethnography; using the interviews to circumvent the task of reading and learning about a field as broad as signal processing.

3.4.2.2 Student-perceived frustrations with design ethnography

The students cited many frustrations related to the use of design ethnography while collecting, synthesizing, and applying stakeholder information. Frustrations were defined as issues and challenges that the students identified as barriers to using design ethnography in making design decisions. The analysis elucidated three themes discussed below.

Theme: Receiving inconsistent information from stakeholders.

The three design teams reported receiving inconsistent or incorrect information from stakeholders. Some stakeholders gave opposing viewpoints on a specific subject, some experts contradicted the literature, and some stakeholders provided conflicting information based upon how students elicited the information, e.g., via surveys versus interviews. The teams had not anticipated the possibility of having to reconcile inconsistent or incorrect information, which led to difficulties in their decision-making process.

Team A described their interviews with physicians to elicit the importance of cost for their proposed design:

> "Yeah, sometimes they would give us a little bit of mixed views, or mixed opinions. Sometimes the doctors would say that cost is super important and at other times on surveys [cost] would end up being one of the [least important requirements] on the list when we asked them to rank them" (Team A, 1st Interview).

The conflicting information between interviews and surveys was not expected by the design team and the team was forced to reconcile the conflicting information without a particular strategy.

Teams A and B ran into difficulties when quantifying information that was not uniform across stakeholder interviews. Team A described their attempt to define the accuracy of their device in order to establish validation criteria:

> "Because what does accuracy mean? Different people will interpret it different ways." (Team A, 1st Interview)

Team B described a similar issue when developing an engineering specification after interviewing doctors who held different views:

> "…except that a lot of doctors can interpret variations [in the signal] differently." (Team B, 2nd Interview)

Teams A and B both found difficulty in attempting to quantify stakeholder information which was not uniform among various interviewees.

The theme of receiving inconsistent or incorrect information from stakeholders was evident during the study team's interviews with all three design teams. This inconsistent or incorrect information often led the teams to become temporarily "stuck" at a particular decision point. However, the root of the problem may have been that students were unable to synthesize the complex information they were receiving. When considering physician opinions on topics, it is natural to expect differing views on how to interpret physiological signals; however, the students believed that there should be only one correct answer to their question and were thus frustrated when presented with varying responses. Students struggled with the open-ended nature of the problem and lacked strategies to synthesize data to inform specific design decisions.

Theme: Stakeholders could not specify user requirements.

Students were also frustrated because they encountered difficulties when gathering user requirements from stakeholders. This created downstream challenges when they attempted to design a product based upon these requirements.

This theme is exemplified when Team A reported what occurred when they asked physicians about an engineering specification for the user requirement related to the maximum allowable size of their device:

> "…they didn't even know what our solution would look like, [the doctor said], 'well I guess if it is some handheld device, maybe a 50% increase [in size over the current solution]'...they were just kind of guessing…they just ballparked…which might not have been a good thing for us to aim for, in hindsight" (Team A, 2nd Interview).

The high allowance for size specified by the physicians turned out to be erroneous, and Team A had to adjust their design after prototyping had been performed.

Often, stakeholders could not visualize the design solution; Team A described the difficulty of attempting to gather user requirements from stakeholders without preconceived solutions:

> “Well [the doctors] kept telling us to do a specific solution so … it was difficult to explain that we needed solution-independent user requirements” (Team A, 1st Interview).

During a discussion with Team A related to their development of the user requirement of patient safety, Team A was asked what the surgeons specifically meant by the term “patient safety”:

> “I don’t think we specifically asked. [The doctors] just said [safety] was the first, the most important.” (Team A, 1st Interview).

Because Team A failed to follow up, they understood only that “patient safety” was an important user requirement, without understanding how it might be translated into engineering specifications. This led to frustration when students attempted to develop engineering specifications based upon this vague user requirement.

Team B described the difficulty in explaining the user requirements to physicians without influencing their answers:

> “The biggest problem I had is if you didn’t give them an example of what a user requirement was they wouldn’t know what to tell you, but if you did give them an example of what a user requirement was, they would say ‘oh, yeah…that’s what I want’” (Team B, 1st Interview).

Another member of Team B discussed the difficulty in getting doctors to develop user requirements creatively during interviews:

> “I found that if you put [options] in front of them when interviewing…it would stump the creativity of the interview…they would do it more of like a task than critically thinking.” (Team B, 1st Interview)

This theme was largely found during interviews with Teams A and B, likely due to the fact that Teams A and B developed user requirements in the field during their international immersion experience. The international and clinical setting in which students were working may have exacerbated the difficulties of developing user requirements through stakeholder interaction.

Within this theme students pointed to the difficulties they faced when attempting to gather user requirements directly from stakeholders: students sometimes elicited user requirements from stakeholders that they later discovered were not appropriate for the design, stakeholders provided vague user requirements, and students struggled to extract user requirements without biasing stakeholders via examples or question structure. While students reported these as flaws in design ethnography, my analysis was that students' lack of extensive experience and skill with interviewing techniques limited the quality of the ethnographic data they obtained. For example, the students faced difficulty with developing engineering specifications for the "patient safety" user requirement that they gathered from physicians. However, during the interview they failed to ask follow-up questions related to precisely defining what patient safety meant and were thus frustrated when they attempted to quantify this user requirement.

Theme: Finding the "right" stakeholder to interview.

Within this theme, students spoke of being unable to interview the correct stakeholder. Teams mentioned several reasons as described below.

Team B faced the issue of no longer being able to find the experts needed to answer the questions they had about their project:

> "…so the problem with [this physiological] signal now is that there is no such thing as an expert in monitoring [it]…so we're at a cross roads where all of the external input that we get, there is not much value in it" (Team B, 2nd Interview).

Due to the specificity of their project, the team believed that they would not be able to find a stakeholder who could answer their questions towards the end of their project.

Team A wanted to solicit a price point for their medical device from surgeons, despite the fact that the surgeons were not formally involved in the procurement process:

> "I don't think the surgeons are the ones deciding to buy it, they're just the ones who use it, and so they have a pretty good

> understanding of what [the current products] cost…but there is no saying that from our interviews with them… [if] that's 100% true" (Team A, 1st Interview).

Team C described a situation whereby the information given by US surgeons did not apply to the middle-income country setting they were designing for:

> "I think [the American surgeons] are just kind of biased towards smaller devices…we understand…their point of view…but we have been designing for cost, low cost for this [middle-income] market" (Team C, 2nd Interview).

Team C recognized the differences between designing for a middle-income country and the US, but was unable to pose their concerns to US surgeons in a way that would elicit information useful to a middle-income country.

Students reported that the stakeholder they wanted to interview was not accessible or did not exist; however, the student teams were too focused on finding a single stakeholder to answer a specific question. Generally, the teams did not consider interviewing multiple stakeholders with varying expertise and subsequently performing an analysis in order to come to design decisions. For example, Team B believed that an expert in the physiological signal particular to their design project did not exist, yet the team could have interviewed physicians (who would have knowledge of the signal) and engineers (who would have knowledge of signal processing) and combined the data yielded from both types of experts. The team did not recognize the opportunity to collect, synthesize, and analyze the perspectives of multiple stakeholders in order to make their decision, and this consequently led to their frustration.

3.5 Discussion

3.5.1 Summary of findings

This study aimed to determine how students used and perceived their use of design ethnography when making design decisions. Students employed several design ethnography techniques during various design phases. Interviews with experts were the most common design ethnography technique students employed and were also used throughout all stages of the design. Availability, ease of communication, efficiency of gaining information, and confidence with the information gained from experts played a significant role in students' preferences for choosing to use interviews.

The thematic analysis of interview transcripts with regards to student perceptions of design ethnography use resulted in two overarching categories of themes: student-perceived benefits and student-perceived frustrations when using design ethnography. The benefits and frustrations students perceived had significant implications for their decision making process and this is summarized in Figure 3.2.

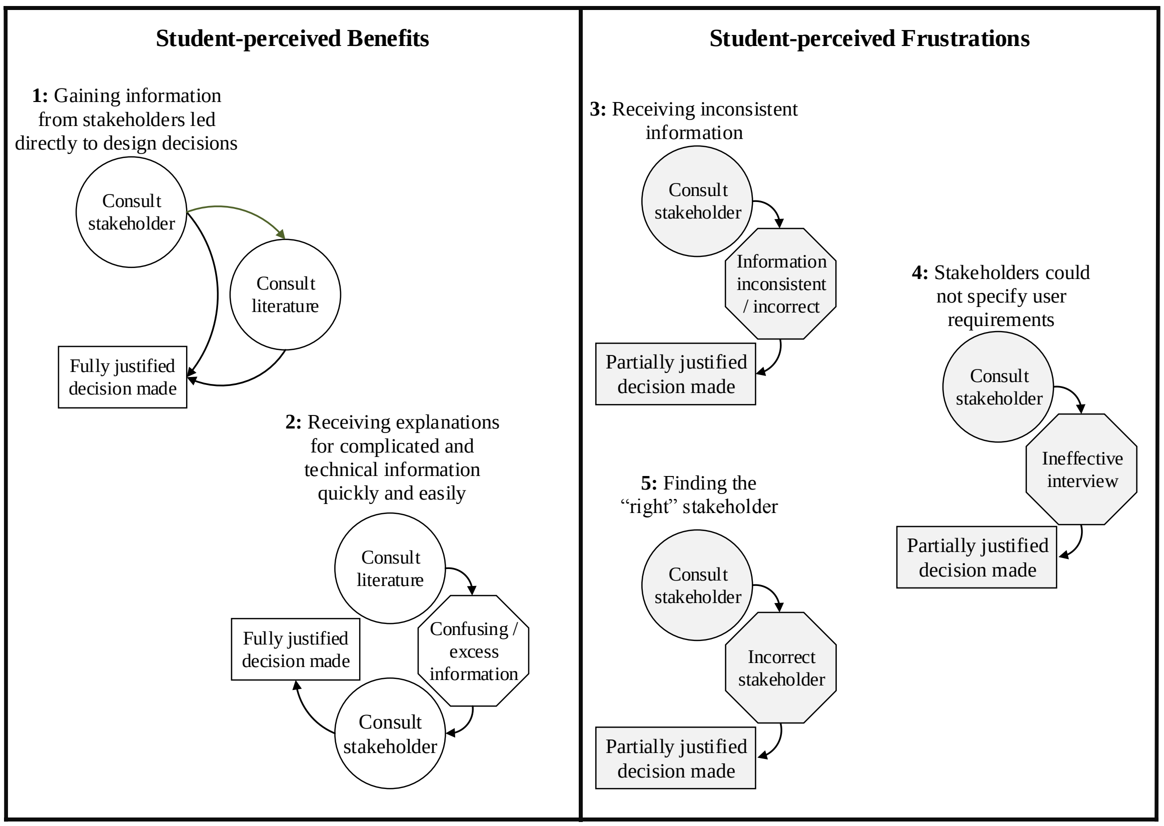

Figure 3.2: Decision-making processes followed by student teams when implementing design ethnography

As shown in Figure 3.2, when students perceived design ethnography to be beneficial, their decision-making processes followed two distinct paths, each of which produced what they perceived to be a fully justified decision. The first path involved consulting with a stakeholder and then making a decision based directly on this interaction or after consulting literature made relevant by the stakeholder. The second path represents an initial review of the literature and then consultation with a stakeholder to clarify the findings. While the students effectively used design ethnography data to justify their design decisions, an analysis of the content of these decisions showed that students gained largely surface-level benefits from design ethnography and not deep, detailed information that design ethnography data collection can yield.

Also shown in Figure 3.2 are three distinct decision-making paths that students followed when they perceived a frustration with design ethnography. These frustrations disrupted their decision-making processes and led to what students perceived to be partially justified decisions. The perceived frustrations with design ethnography seemed to stem from student errors when planning or implementing ethnographic methods or when utilizing the information collected. In the third path, students were frustrated when receiving inconsistent information that the study team believes stems from the students' unwillingness and/or inability to analyze multiple perspectives from stakeholders and make an informed decision. Conflicting viewpoints are common when interviewing stakeholders on most topics, but students expected each stakeholder to provide similar opinions and this assumption led to difficulties in decision making. The fourth path represents students' expectations that stakeholders would be able to clearly specify user requirements. However, planning and executing effective interviews is a skill learned through experience and time. Students had the unrealistic expectation that stakeholders would be able to list user requirements during interviews, which the students could then directly use in their design projects. However, the role of the designer is to translate ethnographic data into user requirements and engineering specifications, and students struggled to recognize this as their role and how to approach this practice. The fifth path represents students' frustration when they felt they could not find the "right" stakeholder to answer their questions. However, analysis of the interviews and design reports led the study team to recognize that students were actually struggling with the task of synthesizing information collected from multiple stakeholder interviews when making a decision. Students believed that each decision point had an accompanying single stakeholder who could answer their questions in order to determine what decision to make. This frustration may stem from the larger problem of students' difficulty with solving open-ended problems that have no clearly defined solution or methodology.

While my intention is not to make claims on the impact of an immersion experience on students' use of design ethnography, in the comparison among teams, I noted some distinctions. Recall that Teams A and B had performed eight weeks of clinical observations and interviews prior to the commencement of the capstone design course, whereas Team C learned about their project during the first week of the course. Analysis of the interview data revealed that all three teams provided approximately equal numbers of examples related to the benefits of design ethnography. However, Teams A and B spoke significantly more about the frustrations involved in using design ethnography. These two teams attempted to define user requirements and engineering specifications during their eight weeks of clinical observations and thus had more opportunities to encounter frustrations than Team C. Determining whether this difference arose from greater exposure to design ethnography or from the international/clinical setting of the immersion experience is outside the scope of this study. The small sample of teams interviewed precludes a generalization of the difference between immersion and non-immersion teams.

3.5.2 Characterizing student implementation of design ethnography

The findings discussed above are consistent with the limited research on design ethnography education previously cited. My finding that students were frustrated with extracting user requirements from stakeholders is comparable to Sugar's finding that students performed only minor design changes after engaging with users and conducting usability tests (Ahmed, Wallace, and Blessing 2003). Students in this study and Sugar's study performed only surface-level interactions with stakeholders and did not extract the underlying rationale for the stakeholders' responses. Students were not able to recognize opportunities to perform in-depth exploration of stakeholder knowledge. Similarly, all of the themes of student-perceived frustrations with design ethnography can be compared to the "tensions" found by Scott between students' preconceived notions of the value of stakeholder engagement and their practical efforts to implement it (Crismond and Adams 2012). In the interviews, the students spoke frequently of the challenges and frustrations with collecting, synthesizing, and using stakeholder information. This indicates that as their use of design ethnography increased, students better understood the complexities of stakeholder engagement and the non-trivial process of design ethnography. Their continued use of design ethnography in the face of these frustrations indicates that they also faced tension between the value they saw in using design ethnography and the difficulties associated with its use. In Zoltowski's work students experienced markedly different ways of understanding human-centered design, and my findings revealed that students displayed multiple levels of understanding with respect to how design ethnography can be effectively incorporated into human-centered design as they progressed throughout their design work (Zoltowski, Oakes, and Cardella 2012). The frequent references to the benefits of design ethnography suggest that the students understood why stakeholders are included during design; however, the students' surface-level perceptions of the benefits of design ethnography suggest that they did not fully understand these benefits and their frustrations point to their difficulty to achieve those benefits.

Based on the findings from this study, in conjunction with those of the previous studies mentioned above, I propose a model, shown in Figure 3.3, of students' desire to use design ethnography as they learn and implement the techniques. The trajectory shows that while students are learning the principles of design ethnography in the classroom, their desire to implement the techniques increases. Then, as they begin to practice design ethnography in the context of a real design project, they recognize the difficulty and complexity involved, and their desire to incorporate the techniques into their design process decreases. The mix of benefits of and frustrations with design ethnography during design causes their desire to perform ethnographic investigations to rise and fall. The dotted line in Figure 3.3 represents the development of expertise wherein a student becomes proficient enough to readily incorporate design ethnography into the design process. A key goal of design ethnography curriculum should be to provide students with the support necessary during the practical learning phase to speed them towards the point at which the benefits outweigh the frustrations of design ethnography.

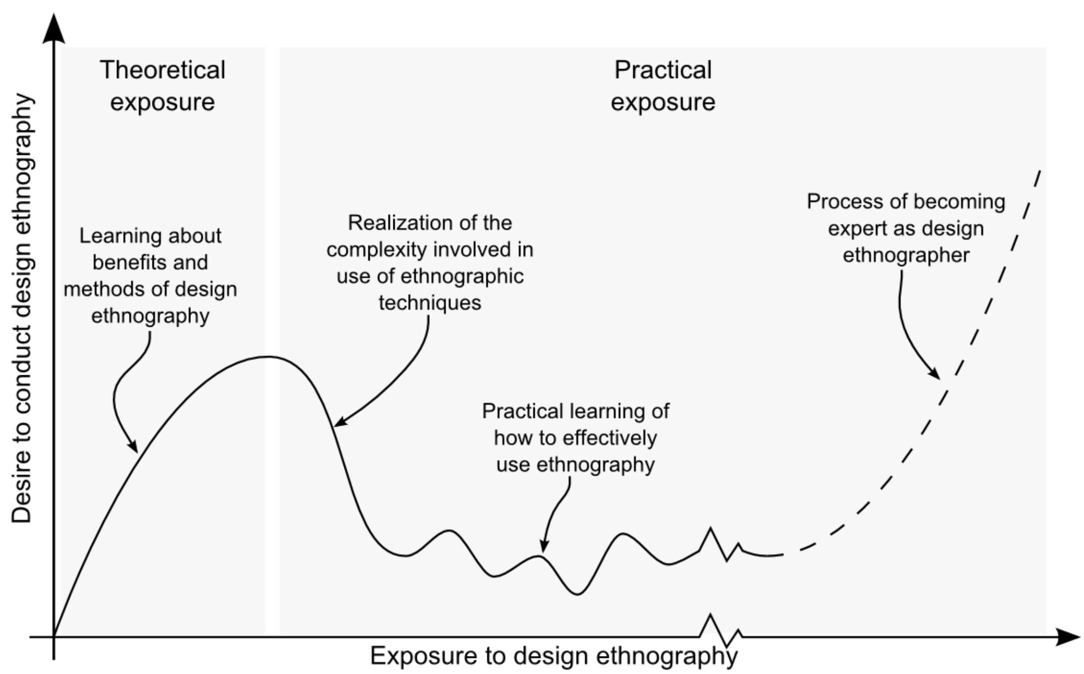

Figure 3.3: Model for student desire for using design ethnography

3.5.3 Pedagogical implications

The findings from this study point to aspects of design ethnography that present large obstacles to students, and thus where effort in developing pedagogy should be placed. Conducting effective interviews, recognizing opportunities to involve stakeholders, synthesizing large amounts or conflicting information, and identifying the correct stakeholders to approach are all areas in which students struggle.

Specific instruction can be developed based on the findings presented in this paper. For example, some students failed to recognize in time when they were interacting with stakeholders ineffectively or only at a surface-level. Realization did not occur until they attempted to use the information in the context of their design project, when the opportunity to perform follow-up stakeholder interaction was limited or no longer available. This delayed realization of ineffective implementation did not allow for students to learn from their mistakes and try again. Thus, a real-time feedback mechanism and related activities and reflection on interview quality could help students recognize mistakes early and improve their stakeholder interactions. Additionally, it is important to consider how the structure and timing of the course encourages and facilitates students' use of design ethnography techniques. Since perceived design values of the instructor and course format impacts student design choices [38-40], if design ethnography techniques are not emphasized or assessed, students may not recognize their importance and either apply the techniques less rigorously or not at all. Developing pedagogy and course structures to counter the other ways in which students were frustrated with design ethnography shown in this paper may provide the support necessary to move students from novice to more informed practitioners of ethnographic techniques.

3.5.4 Limitations

This study focused on an in-depth exploration of three engineering student design teams learning and applying design ethnography throughout their design projects. While a study of three teams is not generalizable, qualitative research aims for transferability, which means that the findings are rich descriptions of a specific context, and this rich description can be used by other researchers to make connections to their own situation (Borrego 2007; Leydens, Moskal, and Pavelich 2004). The immersion experience that Teams A and B participated in prior to the capstone design course heavily focused on front-end design phases and the teams were actively encouraged to use design ethnography. This may have potentially biased interviews by focusing on these phases of design. This study was limited by a focus on design decisions rather than the design process as a whole. Thus, while the semi-structured interview methodology allowed for the discussion of a wide range of uses of design ethnography, some experiences with design ethnography not related to decision making may have been overlooked. In addition, team-based interviews did not allow us to fully explore each student's individual perspectives on the use of design ethnography. Lastly, the focus on capstone design teams cannot be generalized to professional engineers practicing design ethnography.

3.6 Conclusions

Design ethnography is becoming more prominent in product development. Analyses of how design ethnography benefits designers in an industrial setting have been investigated, however, little work has been performed on understanding how students and novices learn and apply the principles of design ethnography. This study expanded upon the limited prior literature by investigating student perceptions of the use of design ethnography when making design decisions. Semi-structured interviews, using a group interview format, were conducted with three senior capstone design teams on two occasions during the semester. Interview questions centered on the various design decisions that students made over the course of the project and were identified by analyzing design team reports. Analysis of the interview transcripts led to the development of themes within two overarching categories: student-perceived benefits of design ethnography and student-perceived frustrations with design ethnography. The benefits of design ethnography reported by the students themselves suggest that students can gain a certain comprehension level of design ethnography via practical implementation, but students will require further support to move past the surface-level benefits of design ethnography that were found in this study. Trial and error allowed the teams to discover that ineffective implementation of this complex skill often produces unforeseen obstacles and frustrations. Themes related to the frustrations students' perceived when implementing design ethnography were prominent within the data and represent multiple areas wherein design pedagogy can be developed to support learning and implementation strategies.

These results informed the development of a proposed model for students' desire to use design ethnography, where the trajectory is characterized by an initial phase of theoretical learning followed by a practical phase of implementation wherein students face unforeseen obstacles and realize the complexities involved. While the active learning environment created by a design project allowed students to gain experience and knowledge in the use of design ethnography, more focused pedagogy appears to be needed to move students along the continuum of novice to more informed design ethnographers. Students were challenged by the open-ended nature of design ethnography techniques and the specific difficulties related to implementing these techniques. Developing pedagogy to help students conduct more effective interviews, be able to recognize opportunities to involve stakeholders, synthesize large amounts or conflicting information, and to identify the correct stakeholders for their design task would significantly improve students perceptions of design ethnography and the outcomes of their design projects. Limitations of this study include the small sample of design teams studied (making it difficult to generalize the results) and the focus on design decisions (which may have allowed uses of design ethnography unrelated to design decisions not to have been captured during interviews).

The results of this study motivate the need to dive deeper into students' interactions with stakeholders during the design process. In this study, I found that students obtained superficial benefits and were often frustrated when engaging with stakeholders. In the following chapter, I focus on these interactions with stakeholders to better understand what factors might be contributing to these superficial benefits and frustrations. In doing so, the results help form a basis for design tools and pedagogy that can directly counter these frustrations and enable students and novice designers to obtain the most utility from design ethnography techniques.

3.7 Acknowledgments

This work was supported by the University of Michigan's Rackham Merit Fellows program, the National Science Foundation's Graduate Research Fellowship program, the National Science Foundation's CAREER program (RAPD-0846471, funded under the American Recovery and Reinvestment Act of 2009), and the NCIIA's Course and Program grant (Development of an Undergraduate Minor Specialization in Sustainable Global Health Design). The study team thanks Mayla Harp for her help during the data collection process, Ann Stewart for her help in technical writing, and the senior design students who participated in this study.

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Chapter 4 Factors affecting the utility of stakeholder interviews during design decision making for students in capstone design

4.1 Introduction

In Chapter 3, I explored how student designers employed design ethnography techniques (observations and stakeholder interviews particularly) during a capstone design course. This elucidated the myriad frustrations that students encounter when implementing design ethnography and also revealed that students typically obtained only superficial benefits from employing these techniques. This raises the question of whether there are particular reasons why students find some interactions with stakeholders to be helpful while others to be unhelpful. Identifying these reasons would allow instructors to develop targeted pedagogy aimed at supporting students' ability to engage more effectively with stakeholders and provide novice designers in both academia and industry with a better understanding of how interviews with stakeholders can be performed more effectively. In this chapter, I look more closely at student interactions with stakeholders during the design process in order to identify these particular factors that affect whether or not student designers are able to engage with stakeholders usefully when making design decisions.

4.2 Background

4.2.1 Student engagement with stakeholders

Increasingly, engineering education has incorporated human-centered design processes to prepare students for the evolving design processes employed in industry (Klatsky 1998; Oehlberg, Leighton, and Agogino 2012). However, studies have shown that successfully engaging with stakeholders and incorporating the information gathered into the design process is challenging (Kujala 2003). Prior research on students' understanding and use of data generated during stakeholder interactions during the design process has found that students do not always interact with stakeholders successfully (Mohedas, Daly, and Sienko 2015b; Scott 2008; Sugar 2001). For example, due to the time constraints associated with an academic course, students may not gain enough practice or instruction in dealing with ambiguous information, synthesizing and analyzing qualitative data, and identifying design-relevant information during interactions with stakeholders (Mohedas, Daly, and Sienko 2014a, 2014b, 2014c). Additionally, the vast amount of data gathered using largely qualitative methods (Beyer and Holtzblatt 1998; Sachidanandam and Gill 2008) can easily overwhelm students' ability to synthesize it in a timely manner. Furthermore, when students are able to gather useful information from stakeholders, they may fail to apply it in a meaningful way (Sugar 2001). The challenges student encounter when attempting to interact with stakeholders has also been shown to cause them to neglect or dismiss stakeholder interaction during subsequent design phases (Mohedas, Daly, and Sienko 2014a; Scott 2008).

The literature on novice and expert behavior in design exemplifies the challenges students face during open-ended problem solving. For example, novices typically approach problem solving in a depth-first manner, whereas experts tend to take a breadth-first approach (Cross 2004). Experts also tend to define problems as broadly as possible in order to increase the solution space available (Cross and Cross 1998; A. Ericsson and Smith 1991; Holyoak 1991). Expert designers have been observed to employ a problem-solution coevolution strategy wherein a potential solution is utilized to understand and refine the problem definition (Dorst and Cross 2001; Kolodner and Wills 1996; Lawson 1979; Lloyd and Scott 1994), unlike novice designers who typically oversimplify and attempt to rigidly define initial states, variables, and procedures in order to arrive at the solution (Bursic and Atman 1997; Elio and Scharf 1990; Rowland 1992).

The major source of stakeholder engagement for students during design courses involves conducting interviews. Interviewing stakeholders is a practice that spans the vast majority of human-centered design approaches including participatory design, ethnographic fieldwork, contextual design, lead user approach, among others (Steen, Kuijt-evers, and Klok 2007). Few support structures are available to designers when interviewing or preparing to interview stakeholders (Browne and Rogich 2001; Moody, Blanton, and Cheney 1998). This leads to significant challenges when interviewing stakeholders including: ensuring that critical important topics are covered during an interview, asking appropriate questions, uncovering how people think or feel about certain topics, and obtaining broader social, political, or cultural factors that may affect the design (Burnay, Jureta, and Faulkner 2014; Donoghue 2010; Goguen and Linde 1993; Wetherbe 1991). Effective interviews with stakeholders tend to be semi-structured, thus requiring the interviewer to be flexible and opportunistic in order to elicit the "real" wants and needs (Agarwal and Tanniru 1990; Luck 2007; Nguyen, Carroll, and Swatman 2000; Strickland 2001). Additionally, one must not only consider the challenge of conducting a stakeholder interview, but the challenge of gathering information from multiple stakeholders, synthesizing these data, and analyzing data in order to make informed design decisions.

4.2.2 Theoretical framework: Information processing

Within this study, I view design as a decision making process that involves the collection, synthesis, and analysis of diverse streams of information. Information processing literature guided the data collection approach as well as provided a lens to interpret the data.

Design decision making requires an iterative information gathering process (Ingwersen and Jarvelin 2005). While some information processing work can be defined as "information transfer," where information is treated as an object and directly applied to the problem without further analysis or synthesis, "information use" requires that designers incorporate the information gathered into their existing knowledge and apply it to various design decisions, which is a more cognitively demanding task (Wilson 1999). Studies have been conducted to understand how individuals identify information needs, seek out information, and apply information to problems (Tanni and Sormunen 2008). Novices tend not to assess the quality and/or validity of the information obtained prior to applying it to their problem (Alexandersson and Limberg 2003; Hultgren and Limberg 2003; Limberg 1999; McGregor and Streitenberger 1998). Similar results have been found for engineering students' indiscriminate use of Internet sources (Wertz et al. 2013). Industry studies have shown that companies tend to rely on external information, use all information sources available, and devote significant time to gathering information during the problem solving process (Blandin, Brown, and Kock 1974).

Developing a deep understanding of end-users and stakeholders requires designers to perform extensive information processing. Designers need both technical and non-technical skillsets to accomplish successful information processing (Macaulay and Mylopoulos 1995; Mohedas, Daly, and Sienko 2014a, 2015a, 2015c; Nuseibeh and Easterbrook 2000). Studies have demonstrated the differences between novices and experts in how they approach information gathering and the effect on design quality (Atman et al. 1999, 2005, 2007; Bursic and Atman 1997). For example, a study of novices and experts performing a design task showed that novices spent less time gathering information and less time defining the scope of the design problem compared with experts (Atman et al. 2007). Another study found that novice designers who spent more time defining their design problems produced higher quality designs (Sobek II and Jain 2007). In a prior study, most novice designers understood the value and benefit of information gathering and synthesis, they typically gathered less information and performed less synthesis than originally planned during design projects (Mohedas, Daly, and Sienko 2014b). Moreover, although most novices acknowledged the benefits of incorporating stakeholders' input into front-end design processes, they encountered obstacles and often interacted with stakeholders in a superficial manner (Mohedas, Daly, and Sienko 2014a, 2014c).

4.3 Research design

This study asked two research questions:

1) What factors influence design teams' perceptions of the utility of stakeholder engagement for informing design decisions?
2) How do design teams approach stakeholder engagement over the course of a design project?

I sought to explore the roles of both intrinsic design team factors (e.g., preparation, motivation, perceptions of stakeholder engagement, etc.) as well as extrinsic environmental factors (e.g., availability of stakeholders, type of project, etc.) on stakeholder interactions. I traced the progress and decision making of seven undergraduate design teams over one semester of a capstone design course. The approach allowed us to understand how each team engaged with stakeholders during all design phases, and after aggregating all instances of design decisions and stakeholder engagement, to identify the most important factors affecting the utility of interactions (Case and Light 2011; Creswell 2013; Flyvbjerg 2011; Gerring 2005; Patton 1990). The study was approved by the Institutional Review Board of the University of Michigan and all study participants provided written informed consent.

4.3.1 Participants & context

The study participants were 23 undergraduate students spread across seven teams enrolled in a capstone design course in Mechanical Engineering. Each team was interviewed four times during the course. All students attended the same weekly lecture. Three different professors mentored the teams (Teams 1 and 4; Teams 5, 7, 2, and 6; Team 3). The projects (described in a general sense throughout the text to maintain participant anonymity) included laboratory equipment, medical devices, and consumer products. Design projects and sponsors are listed in Table 4.1.

Table 4.1: Description of design teams participating in study

Team	Project Description	Project Sponsor
Team 1	Design a piece of laboratory equipment for a research laboratory within biomedical engineering	Biomedical engineering professor
Team 2	Design a consumer medical device for use by pregnant women in a low-income country	Mechanical engineering professor & physicians from low-income country
Team 3	Design a consumer product	Durable goods company
Team 4	Design a piece of laboratory equipment for a mechanical engineering research laboratory	Mechanical engineering professor
Team 5	Design a consumer product for pregnant women	Physician, medical school
Team 6	Design a diagnostic device for community healthcare workers in a low-income country	Non-governmental organization
Team 7	Design a medical simulator for use in a low-income country	Mechanical engineering professor & physicians from low-income country

The capstone design course had four design review milestones. Design Review #1 required the teams to define their design problem, elicit product requirements, and develop engineering specifications. Design Review #2 required them to generate diverse concepts, down-select to a top concept, and develop a mock-up. Design Review #3 required them to perform an engineering analysis on one or more components of their design and use the results to refine the final design. Design Review #4 required them to develop a functional prototype.

4.3.2 Data collection

Primary data were collected during four semi-structured interviews with each team. Team interviews lasted between 40 and 70 minutes. Interview sessions were conducted in the week following each design review to coincide with the four course milestones. Interviews had the same overall structure for each team during the study. The overarching interview protocol structure was based on design as a decision making process: I asked teams to explain what decisions were made, how they were made, and all the information sources that contributed to the decision (Hatamura 2006). Table 4.2 lists example questions for each interview session conducted. Additionally, individual team interview protocols were customized to reflect the information students provided in their design reports. In reading design team reports, I was able to identify the key decisions teams had made. This ensured that interviews covered all major decisions made during the semester. By asking questions related to key decision points, and not directly asking about stakeholder engagement during design, I could investigate students' engagements with stakeholders without biasing the answers provided by design teams.

One design team (not included in this analysis) was recruited to pilot the protocol (both the general and customized questions) and the results were used to modify the protocol prior to interviewing the other teams.

Table 4.2: Example questions from protocols developed for design team interviews

Interview Session 1
Theme: problem definition, requirements elicitation, & engineering specifications *Example Questions:* What is the goal of your project? Tell me in general how you developed user requirements. Follow-up Questions: Where did they come from? What information did you use? Where did this information come from? Do you think the requirements are accurate? Follow-up Questions: Will satisfying those requirements result in a successful design? Let's pick a specific user requirement and talk about it in detail. Where did this user requirement arise from? How was it developed? What information did you use to generate the requirement? What do you still need to learn or information you need to collect/gather for your design project? In general and/or in specific.
Interview Session 2
Theme: concept generation, down-selection, and mock-up development *Example Questions:* First, let's go over your user requirements to date. Here we have your user requirements you had during the first design review and the updated list for the second design review. Could you go over the changes you made to the requirements and why those changes were made? Follow-up Questions: Was new information involved in the change? Where did this new information come from? Was this change important? What methods or information did you use/gather to decide on a final concept? How did you arrive at this idea or information source?
Interview Session 3
Theme: engineering analysis, prototyping & validation plans *Example Questions:* Did your team make any changes to user requirements or engineering specifications? Follow-up Questions: Was new information involved in the change? Where did this new information come from? Was this change important? How did you choose which components or systems to perform the engineering analysis on? What information did you gather to make this decision? From what sources? How has your design changed from what you had at the end of the second design review? Follow-up Questions: What were the major changes? Why did you make the changes?
Interview Session 4
Theme: final prototype & validation, overview of design experience *Example Questions:* Do you think your final design was successful? Why or why not? Follow-up Questions: What aspects make it most successful? What part of the design process do you think contributed most to the success? Who would you say are the stakeholders for your design project? Follow-up Questions: Why is this stakeholder important? How did you learn what was important to this stakeholder? How was this stakeholders needs incorporated into the design?

4.3.3 Data analysis

I used two methods of data analysis: an interactions level analysis and a team/semester analysis. The interactions level analysis considered each segment of the transcripts in which students discussed stakeholders in their decision making process as the unit of analysis. The team/semester analysis considered each team's data as a whole to understand how the team engaged with stakeholders throughout the semester and how this engagement changed as the project progressed. I describe the analysis approach for each analysis in the following sections.

4.3.3.1 Interactions level analysis: Answering research question one

To perform this analysis, I first created a coding scheme to organize the data collected (see Table 4.3). The unit of analysis was a section of a transcript that described an instance of stakeholder engagement and its associated design decisions. The first level of coding identified the sections in the transcripts where the teams discussed their stakeholders (either briefly mentioned or fully described an interaction). Within the discussions of stakeholders I coded five additional categories: 1) design phase in which the teams were engaged, 2) type of stakeholder they interacted with, 3) whether or not a design decision had been made, 4) how the communication with the stakeholder was conducted, and 5) whether or not the students found the interaction with the stakeholder to be useful in making the decision.

Table 4.3: Coding system for interactions level analysis

<table>
<tr><td colspan="5" align="center">Level I Coding</td></tr>
<tr><td colspan="2">Stakeholder Interaction</td><td colspan="3">Stakeholder Mention</td></tr>
<tr><td colspan="5" align="center">Level II Coding</td></tr>
<tr><td>Design Phase</td><td>Stakeholder Type</td><td>Design Decision</td><td>Communication Form</td><td>Student Perception of Utility</td></tr>
<tr><td>Problem definition
Requirements/specifications
Concept generation
Concept selection
Engineering analysis
Prototyping
Validation</td><td>Sponsor
Expert
End-user
Other</td><td>Decision made
No decision made</td><td>Interview
Observation
E-mail
Survey
Other</td><td>Useful
Not useful</td></tr>
</table>

Next, I used an iterative inductive coding method to identify themes within the data (Creswell 2013). These themes focused on determining what factors (either intrinsic design team factors or extrinsic environmental factors) were influencing whether students found particular interactions with stakeholders useful when making design decisions. A constant comparison methodology was used with the previously coded 'student perception of utility' as the dependent variable (e.g., what similarities existed within the interactions that were coded as useful to students' decision making processes, what similarities were there between interactions that students did not find useful, and what factors differentiated interactions students found useful from those they did not).

4.3.3.2 Team level analysis: Answering research question two

To perform this analysis, I used a technique that iteratively summarized each interview transcript until each team's stakeholder engagements during the entire semester were summarized within a two-page document. Once the summaries were developed, I identified the key longitudinal themes within each team as they related to stakeholder engagement during design. Again, I used a constant comparison methodology to understand the differences between how design teams engaged with stakeholders during the semester. Summaries of teams were read and compared with each other to identify the key similarities and differences across the teams. Particular emphasis was placed on whether or not design teams changed their perception of/approach to/use of stakeholder engagement over the semester and whether these changes could be attributed to specific causal factors.

4.4 Findings

First, I present the results of the interactions level analysis that elucidated five key factors before, during, or after stakeholder engagement that affected how useful students perceived this engagement when making decisions. Then I present the team/semester level analysis results comparing and contrasting the approaches to stakeholder engagement over the course of the semester. Pseudonyms have been used and project details changed to anonymize the study participants.

4.4.1 Interactions level analysis

Two factors (goal specificity and stakeholder's expertise) were found to be factors that emerged as important when students found interactions with stakeholders to be more useful when making decisions. Two factors (information variability and information applicability) emerged as important factors when teams found interactions unhelpful when making design decisions. The last factor that emerged from the analysis was the level of decision making responsibility design team's placed on stakeholders. General descriptions of these factors are included in Table 4.4, and I discuss them in more detail and provide examples in the following section.

Table 4.4: Factors that impact utility in student interactions with stakeholders

Factor	Description	Frequency
Goal specificity	Goal specificity refers to the level at which students pre-developed clear and explicit goals for a stakeholder interaction. Students noted that stakeholder interactions were more useful with a high level of goal specificity. The goals could be either very precise, e.g., ranking requirements, obtaining confirmation on an idea, etc., or very broad, e.g., gathering background on the context of the problem, understanding current technologies, etc.	7 of 7 teams
Stakeholder's expertise	Stakeholder's expertise refers to the level of alignment between a stakeholder's expertise and the project topic students were pursuing. Students noted that interactions were more useful when a stakeholder's expertise closely aligned with their project, e.g., a physician who performed research in the topic of the student's design project more reliably provided helpful information than simply a practicing physician.	6 of 7 teams
Information variability	Information variability refers to the level of variation in the information students receive from stakeholder interactions. Students found new information less useful when it was highly variable, e.g., stakeholders disagreeing (during multiple stakeholder interviews or between separate interviews), stakeholders changing preferences from one interaction to the next, etc.	7 of 7 teams
Information applicability	Information applicability refers to the level of directness with which design teams could apply the information obtained from an interaction to a design decision. Teams found interactions less useful when the information gathered was not directly or obviously connected to the design decision at hand.	5 of 7 teams
Decision making responsibility	Decision making responsibility refers to the level of responsibility design teams would take when engaged in design decisions. Design teams would often cede control of the decision making process to stakeholders in order to improve the utility of interactions, e.g., expecting sponsors to decide the proper course of action, expecting stakeholders to define requirements/specifications, etc.	4 of 7 teams

4.4.1.1 Goal specificity

Goal specificity refers to the level at which students pre-developed clear and explicit goals for a stakeholder interaction. Students were more likely to find interactions with stakeholders useful if they had developed (informally or formally) clear and explicit goals prior to the interaction (i.e., a high level of goal specificity). Goals could be either very particular (e.g., get feedback on the latest design change from a stakeholder) or very broad (e.g., understand the environment where their device would be used). For example, the team creating a clinical simulator for a low-income country visited the university simulation center with the broad goal of understanding simulators and interacting with the simulators available:

> "Initially, [we went to the simulation center] to go … see the simulator and be able to interact with the simulators there and [the director] who works there is an expert on simulation and sort of just to interview her on like common simulation practices in the US and like what are the design requirements for her simulator … it told us a lot about being able to design the pelvic models that we have [in the US] and that drove one of our engineering specs for the [appropriate] size of the [model]." [Team 07; DR1]

This team visited the simulation center with broad goals related to better understanding what it meant to design a quality simulator. Team 7 obtained useful and relevant information in the form of product requirements and engineering specifications. When Team 6 was asked to describe the main takeaways from interviews they had held with experts on their project topic, they exemplified the use of stakeholder interaction when the interaction had a particular goal:

> "…we got more of a ranking of the user requirements than the actual user requirements themselves from the interviews." [Team 06, DR1]

Team 6 used documentation from international health organizations to develop requirements and then used the interviews with experts only to rank the requirements. Team 6 used stakeholder interaction only after they generated a clear and explicit goal (the need to rank requirements by level of importance), not when the goal was less clear (e.g., gathering information to inform requirements development).

Team 4 interacted with their stakeholders during concept selection in order to determine the appropriate concept solution choice. In the following interaction, the stakeholder was given two options:

> “Well, I remember before that meeting, we were discussing the idea of a vacuum and we sat down with one of the grad students and we said ‘we can either make this enclosure that is supported by all this metal on the inside, which may disrupt your electric field, but you will be able to attain the vacuum that you want or we can make an enclosure that is made out of acrylic so it doesn't disrupt your electric field but you won't be able to have the vacuum.’” [Team 04, DR3]

The students formulated clear and explicit goals for the interaction by only presenting two options to the stakeholder. The team did not seek out broader information from the interaction.

4.4.1.2 Stakeholder’s expertise

Stakeholder’s expertise refers to the level of alignment between a stakeholder’s expertise and the project topic students were pursuing. Students found interactions more useful when a stakeholder’s expertise was closely aligned with their design project. In designing a medical device that had to interact physically with patients’ arms, Team 2 identified a professor whose expertise matched their project topic. The team developed a concept for assessing the validity of their design and used their interview with the expert to validate it:

> “[For] the … pressure [specification], [we performed] a lot of analysis of what's the best model for the human arm. Then we spoke to … a professor here who specializes in tissue mechanics and elastic materials. After talking to him and him saying, ‘Yeah, that sounds pretty good,’ we felt pretty comfortable progressing with that.” [Team 02, DR3]

This team was able to have a fruitful interview and confirm their design concept during this interaction with this particular expert. The following example shows what occurred when a stakeholder’s expertise was not entirely aligned with a team’s project:

> "We talked to [a doctor] from Cincinnati, it wasn't the most fruitful conversation but we did talk to her and I guess that we thought that she had more of expertise in this area and the drugs, but her research focuses much more of treatment of cancer rather than screening so it was kind of like, "Your project was awesome. Good luck." But I don't really have too much to help you with." [Team 07, DR1]

Ultimately, Team 7 could not guide the interview in a way that produced relevant information. They relied on the physician to provide information that would be relevant but were not able to adjust to the physician's particular area of expertise.

Figure 4.1 shows the effect of stakeholders' expertise on whether teams viewed interactions as useful or not useful during decision making. Design teams interacting with experts experienced three times more useful experiences over the semester. The useful experiences were more likely to lead to information that was incorporated into a design decision. Interactions with end-users were split evenly, and there were slightly fewer useful experiences, than not useful, when interacting with project sponsors.

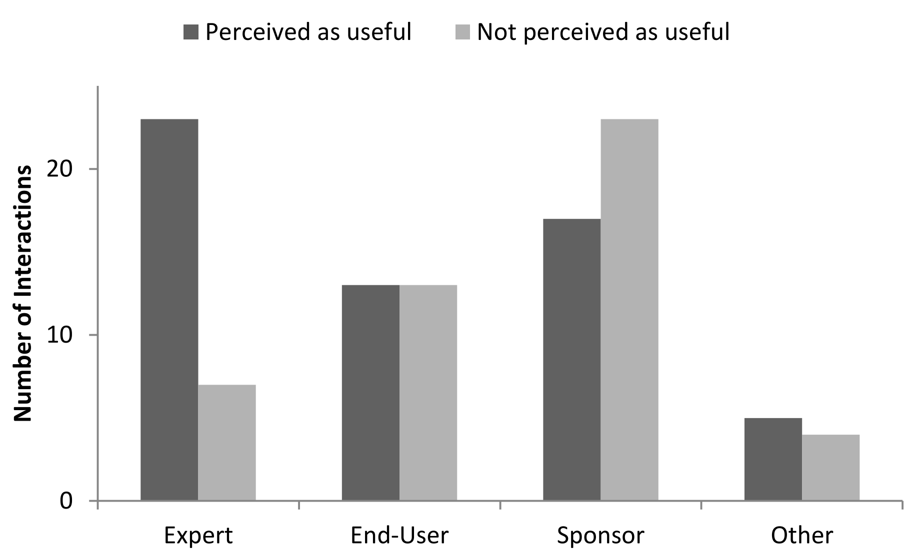

Figure 4.1: Perception of utility of stakeholder interactions as reported by design teams

4.4.1.3 Information variability

Information variability refers to the level of variation in the information students receive from stakeholder interactions. Receiving inconsistent information from stakeholders was a major factor that prevented students from finding stakeholder interactions useful during design decision making. The most common form of information variability encountered by teams was conflicting information from stakeholders. Team 4 was designing for multiple sponsors, a group of graduate students with differing areas of expertise, which produced conflicting statements:

> "I think we're still honestly getting conflicting messages. One graduate student, he's … the point person, and he's out [of the country], and so he has all of these things that he would like to implement. He'll give us those ideas, and then we'll take them back to [the] other graduate students who are also going to be using that system, and then they'll say "no, this is unfeasible."… And so, because, I think because they're producing slightly different particles … it's been hard to kind of get both voices on the page." [Team 04, DR2]

Team 4 struggled throughout the semester to satisfy the differing requirements of their sponsors/end-users. They stated that this aspect (dealing with multiple stakeholders with differing opinions) was more challenging than the technical aspect (creating their system) of their project.

Team 6 learned that information obtained from stakeholder interviews and other information sources could actually stall the design process:

> "We kind of got conflicting [information] from articles and … from [our sponsor]. Which one should we go with?" [Team 06, DR2]

Team 6 was unable to synthesize and determine what information was most applicable and appropriate.

4.4.1.4 Information applicability

Information applicability refers to the level of directness with which design teams could apply the information obtained from an interaction to a design decision. When information received from stakeholders was not directly or easily applicable to the design decision at hand, team's found interactions less useful. A team designing a product for low-income countries had difficulty using the information they gathered from experts who did not taken into consideration the context for application. Team 6 described their interaction with physicians at an American medical school:

> "Yeah, [the doctors] gave us a lot of ideas that we looked into but most of them, you know, for a country like Liberia would be way too expensive..." [Team 06, DR2]

Team 6 found that it could not manipulate, generalize, or synthesize the information to produce useful insights. Team 1 encountered similar problems when one stakeholder had a pre-defined idea of the solution:

> "We had a meeting with [a physician], talking about the device in general. He was more interested in a very simple device that can be used and reused for something else … I get the feeling that he already has a device in his mind. That's not necessarily a bad thing, but I think that might have also influenced how he answered the questions." [Team 02, DR1]

While the physician had significant expertise in the topic of interest, Team 2 was unable to elicit information they could use in their design because the physicians suggestions for a solution did not match their precise need statement. The team did not ask the physician why he preferred his solution, which might have led to useful information.

4.4.1.5 Decision making responsibility

Decision making responsibility refers to the level of responsibility design teams would take when engaged in design decisions. Teams would occasionally completely cede responsibility of the decision making process to stakeholders in an attempt to increase the usefulness of stakeholder interactions. Team 5 relied on its sponsor to articulate the project's requirements and specifications:

> I tr[ied] to nail down what [our sponsor] would consider as affordable and even something … as simple as that, she just didn't have any ideas." [Team 05, DR1]

The team believed it was the sponsor's role to develop the specification for the appropriate cost of the design. The team did not consider gathering information from the sponsor and combining it with benchmarking and other information sources to generate the requirement's specification. Team 4 encountered the same issue when it realized late in the semester, that it had never completely defined the goal of its project. The following example showed how they were overly reliant on the sponsor and ceded control of the decision making process:

> “[T]hey didn’t know what they wanted in [the project]. And, when we presented our design concepts later on, to the lab... Even among themselves, they didn’t know what they wanted, so it’s been really hard to get a grasp on what should we be making.” [Team 04, DR4]

The team was waiting for the sponsors and stakeholders to decide on what they were looking for in the design, instead of taking control of the decision making process and incorporating the multiple stakeholder perspectives into the design.

At first, Team 7 relied on stakeholders to make decisions, but better design decisions emerged after the team learned to take control:

> “For example, [the requirement that] it must be portable. In the beginning, Michelle and Jennifer (design team members) said they heard that [from physicians]. But then [early in the semester], [we asked], "Why is it portable?" and then, "Why does it have to [move around] and who exactly told you that?" [we checked with] studies that had been done on this method and whether it's something that should go [into] the smaller clinics instead of staying in the hospital, [to figure out if] it should be portable.” [Team 07, DR1]

Originally, the team approached the process of defining requirements by relying on stakeholders to make decisions, simply collecting the requirement of portability and never questioning it. As the semester continued, Team 7 began to critically examine their decision making. Eventually, the team reached a more informed decision and confirmed the validity of their decision during subsequent stakeholder interviews.

4.4.2 Team/semester level analysis

In the analysis of how each design team’s use of and approach to stakeholder interaction evolved over the course of the semester, I found major distinctions among how teams approached stakeholder engagement. Below I highlight several teams and specifically discuss how their approaches changed over the semester and differed from other design teams; teams are presented in pairs below to facilitate comparisons.

4.4.2.1 Teams 1 & 4

Teams 1 and 4 began the semester with very similar projects, but their level of and approach to stakeholder interactions over the course of the semester differed greatly. While Team 1 interacted minimally with their end-users and sponsors, Team 4 interacted extensively and discussed how engaging with stakeholders was a major component and challenge during their design project. The main cause for this difference in approach to stakeholder interaction was the level of definition for each team's project at the beginning of the semester: Team 1 had a very well-defined project and their sponsor provided a list of product requirements, Team 4's project was ill-defined and their end-users all had very different ideas of what the project should accomplish. Table 4.5 describes the key differences in stakeholder interactions between the teams and their perceptions at the end of the semester.

Table 4.5: Stakeholder interactions and reflections of Teams 1 and 4

	Team 1	Team 4
Project	Laboratory equipment	Laboratory equipment
Sponsor	Biomedical Engineering laboratory	Mechanical Engineering laboratory
Initial interactions	Sponsor had well-defined, clear idea of what the project needed to accomplish. Sponsor laid out the user requirements for the team and dramatically reduced the work required during initial phases.	Sponsor was a set of graduate students with diverse research areas and goals. Significant conflicts arose among the end-users about the user requirements. The design team had to conduct extensive interviews and group discussions to finalize the requirements and engineering specifications.
Mid-semester interactions	Team 1 began to encounter challenges when the sponsor changed her mind about the required capabilities of the design.	Team 4 worked through the conflicting needs of their stakeholders by developing better communication with their stakeholders and using group interviews instead of individual interviews.
End of semester reflections	Team 1 faced delays at the end of the semester related to the changing requirements because the sponsor and end-user were not fully aware of the design course expectations. The team acknowledged that at the beginning of the semester their interactions with the sponsor might not have been ideal: “we were … trying to get our bearings, so we weren't able to ask them a lot of the more in depth questions.”	Team 4 developed a successful prototype and delivered it to the sponsor. The team recognized to a much greater extent the importance of stakeholder interactions during design. One member said, “Stakeholders should provide the requirements and some specifications ... They should be able to have input on design selection and should be able to refine their expectations throughout the design process.”

4.4.2.2 Teams 5 & 7

Teams 5 and 7 had similar projects, but engaged with stakeholders in very different fashions over the course of the semester. The projects for each team were quite similar: both were developing a medical device, both were sponsored by clinicians, and both had opportunities to engage with diverse stakeholders (including end-users). Team 7 engaged with stakeholders extensively throughout the semester, interviewing clinicians, experts, and other stakeholders to make design decisions. This team displayed a design process most in line with human-centered design of any of the teams participating in the study. Team 5, in contrast, spent the majority of the semester with the perception that their project sponsor was the only stakeholder whose opinion was important. It was not until they were forced to engage with end-users by the mentoring course professor that they interviewed stakeholders other than their sponsor.

Table 4.6: Comparison of how Teams 5 and 7 approached stakeholder interactions over the course of the semester

	Team 5	Team 7
Project	Consumer medical device	Medical simulator
Sponsor	Medical school professor	Physicians at partner hospital
Initial interactions	Team 5 began with the view that the sponsor was the key stakeholder in the design process and relied on the physician to provide all of the requirements.	Team 7 selected the project after two months of immersion in a hospital located in a low-income setting prior to the start of the course. During the initial design process, Team 7 gathered as much information as possible from a diverse set of stakeholders, focusing on experts in the medical field.
Mid-semester interactions	Team 5 continued to rely on the sponsor for most design decisions until the course instructor told members to interact with end-users. Interacting with the end-users, which occurred after developing a full prototype, revealed major design problems and forced a significant shift in the final concept.	Team 7 continued to interact extensively with stakeholders as the design process progressed. Members transitioned from gathering background and requirements information from stakeholders to interacting with stakeholders to validate the team's design decisions and confirm analyses.
End of semester reflections	The team members had a dramatic change in their attitudes regarding stakeholder engagement. One member said, "when a prototype is developed, it should be presented to stakeholders…checking in with stakeholders during the design process ensures that the product is on track with their needs."	This team began and ended the semester with a human-centered view of the design process, e.g., one member commented, "stakeholders should be a huge source of information in the design process. It is important that the needs and wants of the stakeholders are clearly understood so that the designers can evaluate, work, and change with [design] ideas."

4.4.2.3 Teams 2 & 6

Teams 2 and 6 had similar projects and used very similar design processes with respect to stakeholder interactions. Teams 2 and 6 both engaged with stakeholders during early stages of their projects (particularly problem definition, requirements elicitation, and defining engineering specifications). During these interactions, however, both teams ran into issues with the information they obtained: Team 2 found that information they gathered from domestic clinicians conflicted with the information they had gathered from clinicians in a low-income setting and Team 6 believed that the information they were obtaining from stakeholders was not directly relevant to their project and could not be used. As a result, both teams reduced their interactions with stakeholders as the semester progressed, turning to other information sources such as academic literature, global health organizations, and benchmarking.

Table 4.7: Comparison of how Teams 2 and 6 approached stakeholder interaction over the course of the semester

	Team 2	Team 6
Project	Medical diagnostic device	Medical diagnostic device
Sponsor	Clinician	Non-governmental organization
Initial interactions	Team 2 selected its project after having performed two months of immersion in a hospital located in a low-income setting prior to the start of the design course. During the design course, Team 2 focused on gathering information from US physicians to compare to the information gathered during the immersion experience.	Team 6 began by consulting with diverse stakeholders, particularly clinicians with diagnostic expertise. The team had difficulty translating the information into something tangible.
Mid-semester interactions	The information Team 2 gathered from domestic doctors conflicted with the information they had obtained from clinicians in the low-income settings. As a result, the team interacted with stakeholders less as the semester progressed.	Team 6 re-engaged with physicians during concept generation, but did not obtain information that it deemed helpful to the project. Team 6 began to rely more on published literature to make decisions and it engaged less with stakeholders.
End of semester reflections	Team 2 focused on engineering-based validation of the design without stakeholder engagement.	Team 6 concentrated on the technical aspects of their project and they did not engage with stakeholders significantly after the mid-point in the semester.

4.5 Discussion

4.5.1 Interactions level analysis

Five major factors emerged from the analysis of the design teams' interactions with stakeholders during their design projects. These factors affected how useful students found stakeholder engagement to be and also provided information as to how students viewed stakeholder engagement during design and how the factors might positively or negatively affect team design processes.

Teams found interactions more helpful when they had high levels of goal specificity (e.g., ranking requirements, gathering feedback on a design concept, etc.). During less well defined phases (such as requirements elicitation) teams struggled to engage effectively with stakeholders when the goals were more ambiguous and the questions that needed to be asked were not obvious. Team 4 demonstrated the ability to overcome this obstacle in their engagement with stakeholders. They struggled significantly at the beginning of the semester, but due to the competing interests of their diverse stakeholders, were forced to engage extensively with their end-users to generate viable product requirements. Through this experience they demonstrated the ability to engage with stakeholders when goals were ill-defined.

Another factor that affected team's perception of the utility of interactions was the stakeholder's expertise in their project's topic area. This led most teams to engage with the stakeholders who were particularly knowledgeable and not to interact as much with the less well-aligned stakeholders who might also have provided valuable information. This behavior maps to the information transfer behavior found within information processing literature, where novices tend to look for information that can be directly applied to a decision (Wilson 1999). Gathering information from stakeholders who are not experts in a project's particular area would require students to perform information use, where the information gathered must be analyzed or synthesized prior to being applied to a decision (Wilson 1999). Some teams, however, were able to show this more advanced information process behavior. Team 7, for example, consulted a variety of stakeholders during the semester rather than focusing on closely matched experts. It was less clear, however, whether the team did so based on a more advanced knowledge/ability to process information, or based on the team having a more human-centered design philosophy than the other teams studied.

Two factors found in the analysis, variability within information gathered and indirectly applicable information gathered during stakeholder interactions, had negative effects on whether team's found interactions with stakeholders useful during decision making. Ambiguous design phases such as product requirements elicitation were especially troublesome since stakeholders tended to provide a wide range of responses to the teams' questions, and many requirements were related to end-users' specific preferences. Students knew to expect a variety of opinions, yet many of the teams struggled to synthesize their data and make informed decisions. The findings align with and expand upon studies that have identified similar struggles (Sugar 2001).

One can also see similarity between the factors identified and literature on novice designers/problem solvers where novices oversimplify problems and attempt to rigidly define the procedures and variables needed to solve problems (Bursic and Atman 1997; Elio and Scharf 1990; Rowland 1992). I also noted that when information from stakeholders varied or was not directly applicable, novice strategies such as problem simplification and rigid problem definition may cause more harm than good during the design process. The finding aligns with studies in other fields that have found that students tended to ignore conflicting information and arrive at conclusions without considering uncertainty (Schommer 1990). Information processing struggles were most evident in Teams 2 and 6, both of which received highly variable and indirectly applicable information from stakeholders during early design phases and as a result, moved away from stakeholder engagement as the semester progressed. Instructors who support design teams during initial interactions with stakeholders may need to reinforce the concept that all information gathered in the design topic area may be relevant and it is the responsibility of the design team to determine how/when the information can be applied.

The final factor that emerged in the analysis was design team's level of decision making responsibility. Team's would often cede control of the design decision making process to key stakeholders (most often project sponsors) to more easily reach decisions as a result of interactions. The behavior was more evident for teams whose projects originated from an external sponsor such as Team 3, which had a corporate sponsor, and Teams 1, 4, and 5, which were sponsored by research professors. I observed, however, that even teams such as Teams 7 and 2 with self-defined projects displayed this behavior occasionally, looking to experts to determine the best course of action. Deferring to stakeholders (particularly experts) during decision making, can be compared to students' tendency to use information from literature or the internet without assessing its quality (Alexandersson and Limberg 2003; Hultgren and Limberg 2003; McGregor and Streitenberger 1998). In both contexts, teams defer to an expert authority in order to arrive at an answer instead of focusing on the process of gathering information, synthesizing the data, and arriving at their own conclusions.

4.5.2 Team level analysis

While Teams 1 and 4 were presented with very similar projects, the key difference in the initial level of definition of their projects caused the teams to interact with stakeholder very differently over the semester. Team 4's experience, interacting extensively with end-users in order to bring definition to their project, also led them to better understand the importance of a human-centered design process. Team 1, however, only recognized the importance of effective stakeholder interaction at the very end of the semester when there was not enough time to develop a viable solution. Team 1's behavior was similar to other teams such as Team 5 (who relied on their sponsor for information but ignored end-users) and Team 3 (who were completely dependent upon their sponsor for requirements and specifications).

Teams 5 and 7 elucidate how the intrinsic design team qualities may have a dramatic effect on the level of stakeholder engagement during the course of a semester. The projects Teams 5 and 7 worked on during the semester were similar in many ways: both were developing a medical device, both were sponsored by clinicians, and both had opportunities to engage with diverse stakeholders (including end-users). However, from the beginning of the semester Team 7 continuously engaged with diverse stakeholders and sought out experts in the field while Team 5 relied solely on their project sponsor for relevant information. Team 5 believed that the value of engaging with stakeholders (particularly end-users) was during the validation phase, after prototypes had been developed. When forced to engage with end-users, however, the team realized that a dramatic redesign was required. As a result of their experience, at the end of the semester, Team 5 students' opinions of stakeholder engagement during design shifted toward a more human-centered design philosophy.

Teams 2 and 6 exemplify the dramatic effect certain factors (particularly those identified in the previous analysis) can have on how design teams use stakeholder engagement during the design process. Both teams began the semester gathering information from a range of stakeholders, focusing specifically on experts with diagnostic background. Initial interactions, however, did not lead the teams to information they wanted or were able to incorporate easily in their design process. As a result, both teams moved away from stakeholder interaction as a source of information, relying more on academic literature and competitor devices as their main sources of information. These experiences highlight the need to support students through the information processing challenges associated with a human-centered design process.

4.6 Limitations

This study focused on collecting an extensive amount of data on a small number of design teams. While the outcomes are not generalizable, the goal was transferability, meaning that the rich detail collected and the findings reported functions as a model for other researchers to apply and translate into their own contexts (Malterud 2001). Therefore, application of these findings to other contexts will depend upon the degree of similarity of the new context to that described in this study.

One important aspect not studied within this research was the effect of stakeholder interaction on final design quality or the quality of design decisions made. While I recognize this to be a critically important topic to study, the large number of confounding factors and small number of design teams within this study precluded judgements on whether stakeholder interaction had a significant effect on design quality.

A final limitation was that the unit of analysis for this study was the design team as a whole. Therefore, I do not know what individual students prior experiences were with stakeholder engagement and human-centered design prior to coming into the capstone design experience. Additionally, some students might have had a higher natural or developed talent for engaging with stakeholders that might have effected how useful they perceived stakeholder engagement to be when making design decisions. Further studies could first attempt to understand these students' characteristics at the beginning of a course in order to define a baseline of comparison.

4.7 Educational implications

Strategies developed by students to increase their success when interacting with stakeholders, such as pre-defining clear and explicit goals, interacting only with stakeholders with closely aligned expertise, or ceding control of decision making to stakeholders, were not always (or ever) appropriate. Teams may have utilized these strategies to circumvent the most difficult aspects of stakeholder interactions. Tools and pedagogy need to be developed to support students to prevent them from developing less than ideal strategies. For example, some design teams viewed stakeholder interactions as a way to quickly get the "right answer" to the design decisions being considered. This led to frustration when the information gathered was inconsistent and some teams even ceded control of the design process. Courses based on human-centered design could begin with clear explanations of the best approaches that elicit critical information, feedback, and help to build constructive relationships between designers and stakeholders. Instructors should emphasize that the decision making process is the responsibility of the design team and that decisions are reached after synthesis and analysis of multiple information sources. Resources provided by the Stanford d.school and IDEO.org could guide students through appropriate techniques for data collection and analysis during human-centered design ("D.school Methods" 2015; IDEO.org 2015). Additionally, challenges associated with stakeholder interaction will be mitigated when teams can receive feedback from instructors and colleagues in a supportive environment.

Another major finding is students' difficulty processing information during and following stakeholder interactions. Undergraduate students' struggles to effectively perform information synthesis have been well documented, particularly during writing tasks (Flower et al. 1990; Howard, Serviss, and Rodrigue 2010; McGinley 1992; Segev-Miller 2004; Spivey 1984). To effectively carry out human-centered design, students will need to overcome the challenges associated with information synthesis while adding stakeholder interaction as a major information source (an information source students are not typically exposed to prior to enrolling in design courses). For example, during the product requirements development stage, instructors could show teams how to document the entire information gathering process and how to work with conflicting or confusing information. A simple spreadsheet tool could prompt them to document (for each requirement generated) the information that led to the requirement, where it was gathered, information supporting the requirement, and information and sources contradicting the requirement. The emphasis would be on the process and information gathering rather than on the requirement itself.

4.8 Conclusions

Stakeholder engagement is a major component of human-centered design processes and design ethnography in particular. Properly training engineering designers to conduct stakeholder interviews is imperative to graduate designers prepared to work within industry. In this chapter, I investigated the specific factors that influenced whether undergraduate design teams perceived stakeholder engagement as useful to the design decision making process and how individual design teams differed in their approach to stakeholder engagement during design. The factors identified elucidate the specific areas in which students struggle to engage effectively with stakeholders and where they are potentially missing out on the myriad benefits from this engagement found in the literature. Additionally, some design teams overcame the challenges these factors represent by simplifying or circumventing the information processing required to engage with stakeholders in a human-centered design process. This points to the need to support students in several key challenges associated with stakeholder engagement (e.g., information collection, information synthesis, decision making processes) so that they might obtain the benefits associated with effective engagement and increase their motivation to engage in human-centered design.

The results of Chapters Three and Four, helped to form an understanding that engineering student use of design ethnography methods is significantly different from what is found within the literature. Students used interactions with stakeholders (the main design ethnography technique in use) in more superficial ways (e.g. as short cuts to design decisions) or were frustrated when the interactions did not quickly and simply lead to a design decision. These results emphasize the complex nature of design ethnography implementation and, perhaps, that a purely experiential, project based approach to learning this skill is not sufficient (i.e., the frustrations might outweigh the benefits for novices and this may cause students to move away from these techniques during the design process). To understand novice implementation of design ethnography at a more detailed level of data collection is required to better understand exactly how novices collect design ethnography data, analyze/synthesize this data, and then apply it to the design process. In Chapters Five and Six, I present a laboratory based design task that allowed for this level of detail and elucidated the particular behaviors and strategies that characterize novice design ethnography implementation.

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Chapter 5 Novice information processing behaviors and their effect on requirements quality during front-end design

5.1 Introduction

In Chapters Three and Four I found that students were often frustrated by the information processing challenges and requirements associated with interviewing stakeholders during use of design ethnography. In this chapter, I explore the information processing requirements of stakeholder engagement during front-end design through a structured, laboratory based design task. As a repeated and significant theme within both the novice studies (Chapters Three and Four) and the case study (Chapter Two), information processing must be considered as a critical design ethnography process that requires in-depth study. By developing a laboratory based study, I was able to collect exhaustive data on how student designers performed collection, synthesis, and analysis of a variety of information sources and how they applied this information during front-end design. This has provided a thorough understanding of the specific issues that prevent success and determined the relationship between information processing sophistication and the quality of design outcomes.

5.2 Background

5.2.1 Front-end design

The phases that make-up front-end design for new product development (NPD) have been variably defined, Table 5.1. However, generally this phase has been defined as the period between when a product/service opportunity is first identified up to the point at which the product/service is judged/evaluated ready for detailed development. This includes phases such as opportunity identification, problem definition, requirements elicitation, development of engineering specifications, concept generation, and concept evaluation.

Table 5.1: Definition of Front-end design phases

Front-End Design Definition	Citation
Consists of idea generation, product definition, and project evaluation	(R. G. Cooper 1988)
Includes product strategy formulation and communication, opportunity identification and assessment, idea generation, product definition, project planning, and early executive reviews	(Khurana and Rosenthal 1998)
Period between when an idea is first considered and when it is judged ready for development.	(Kim and Wilemon 2002)

Activities associated with front-end design phases are characterized by their "fuzzy" nature, because they are ill-defined and have high levels of uncertainty (Ashok et al. 1990). Front-end design phases present unique challenges as the understanding of the problem and acceptable solutions co-evolve through iteration, and the nature of this iteration is often unstructured and has little formalization (Dorst and Cross 2001; Murphy and Kumar 1997). Case studies have demonstrated that the success of new products depends upon how well the front-end design phases are executed (Khurana and Rosenthal 1998).

Many key decisions are made during front-end design phases. Defining who the customer is, determining what the product requirements should be, and generating/evaluating concepts are all key aspects of front-end design which have major effects on the success of new product development. Case studies have demonstrated that the success of new products largely depend on how well the front-end design phases are executed (Khurana and Rosenthal 1998). Studies have also shown that in many instances product failures are a result of critical decision errors made during the front-end design phases that could not be cost-effectively rectified later in the design process (R. G. Cooper 1988; A. M. Davis 1993; McGuinness and Conway 1989). Studies have indicated that investing time and resources during front-end design results in new products being developed in a more timely fashion (R. G. Cooper and Kleinschmidt 1994). This reduction in time to market, as a result of increased focus on front-end design phases, has also been noted by experienced managers of new product development companies (Rosenau 1988).

5.2.2 Product requirements elicitation

A key component of front-end design involves eliciting and developing product requirements. Product requirements are any function, constraint, or other property required for a designed artifact to meet the needs or wants of stakeholders; the requirements are translated into engineering specifications that are both quantifiable and measurable in order to guide the engineering design process (Dieter 2012; Pahl et al. 2006). The ambiguous and iterative process of developing product requirements and translating these requirements into engineering specifications is a challenging undertaking in design work (Ashok et al. 1990). To develop quality requirements, design experts have advocated the collection of information about end-users, stakeholders, and product-use environments from a variety of sources and using a variety of methods, such as interviews with end-users and other stakeholders, focus groups, surveys, customer complaints, sales data, and codes and standards (Dieter 2012; C. L. Dym, Little, and Orwin 2013; Nuseibeh and Easterbrook 2000). Newer information gathering methods based on the philosophies of human-centered and participatory design include focus group brainstorming techniques, consensus-building workshops, the use of prototypes during elicitation, protocol analysis, and comprehensive design ethnographies (A. M. Davis 1992; Goguen and Linde 1993; Maiden and Rugg 1996; Mohedas, Sabet Sarvestani, et al. 2015; Sommerville et al. 1993). These methods allow one to gain a better understanding of a product's stakeholders and its context of use in order to properly define product requirements.

5.2.3 Information processing during requirements elicitation

The development of product requirements and specifications can be characterized as a particularly open-ended and iterative information gathering process (Ingwersen and Jarvelin 2005). While some information processing work can be defined as "information transfer," where information is treated as an object and directly applied to the problem without further analysis or synthesis, developing product requirements more closely resembles "information use," where designers must incorporate the information gathered into their existing knowledge and apply it to the development of product requirements – a more cognitively demanding task (Wilson 1999). The importance of information gathering has also been demonstrated in practice, where companies in industries with higher uncertainty are more likely to rely on external information, more frequently use all information sources available, and spend more time gathering information during the problem solving process (Blandin, Brown, and Kock 1974). While these studies have formed a solid foundation for further research into how information is gathered and used during engineering design, few studies have explicitly investigated the ways in which designers gather and use information during design processes.

The process represents a significant challenge for novice designers, as one must be prepared to use both technical and non-technical skillsets (Macaulay and Mylopoulos 1995; Mohedas, Daly, and Sienko 2014a, 2015a, 2015c; Nuseibeh and Easterbrook 2000). Within the broader field of information gathering and application, and outside of the design context, studies have been conducted to understand how individuals identify needed information, seek out this information, and apply it during the problem solving process (Tanni and Sormunen 2008). Research has shown that novices do not tend to assess the quality and/or validity of the information they obtain prior to applying it to their problem (Alexandersson and Limberg 2003; Hultgren and Limberg 2003; Limberg 1999; McGregor and Streitenberger 1998). Similar results were found for engineering students' use of internet sources through studies of design report bibliographies (Wertz et al. 2013).

Within design research, studies comparing novice and expert designers have emphasized the challenge of information processing and its effect on final design quality (Atman et al. 1999, 2005, 2007; Bursic and Atman 1997). For example, a study of novices and experts performing a design task showed that novices spend less time gathering information and less time defining the scope of the design problem than experts do (Atman et al. 2007). It has also been shown that novice designers who do spend more time refining the scope of their design problems tend to produce higher quality designs (Sobek II and Jain 2007). My previous work has shown that while novices understand the value and benefit of information gathering and synthesis while developing requirements, during execution they typically gather less information and perform less synthesis than originally planned (Mohedas, Daly, and Sienko 2014b). In addition, while novices understand the benefits of incorporating stakeholders' input and field-based observations into the requirements development process, they encounter obstacles and use stakeholder interactions to gain only superficial benefits (Mohedas, Daly, and Sienko 2014a, 2014c).

Prior work has demonstrated that front-end design is critical to the success of new products, but detailed studies have not yet been conducted with respect to how novices perform requirements elicitation and development during front-end design. This study contributed knowledge to this topic by investigating novice designers who participated in a front-end design task.

5.3 Methods

5.3.1 Research goals

The goal of this study was to investigate novice designers' information gathering behaviors and how the behaviors related to the development of product requirements. To achieve this goal, I used a mixed-methods approach; using quantitative methods, I examined how participants' information use correlated with assessments of their requirements, and using a case analysis approach, compared the individual behaviors of design task participants who varied in their levels of success during the development of product requirements. Similar to other studies investigating design processes (Austin-Breneman, Honda, and Yang 2012; Daly, Adams, and Bodner 2012; Ensici and Badke-Schaub 2011; Lemons et al. 2010; Walthall et al. 2011), this study focused on collecting extensive data from a small sample of participants (rather than collecting limited data on a large sample) to obtain a deeper understanding of how the participants approached and executed the front-end design phases.

This study focused on the use of information sources and information gathering behaviors and each focus was guided by a corresponding research question:

- Use of Information Sources: How do novice designers use information sources to develop product requirements? How do the ways novice designers use information sources relate to the quality of their requirements?
- Information Gathering Behaviors: What differences exist in information gathering behaviors between participants who develop requirements that receive high and low scores from stakeholders?

5.3.2 Participants

Eight students (five male and three female) in their fourth year of engineering (seven mechanical engineering students and one biomedical engineering student) volunteered as participants. Students were recruited via email, using group lists from the fall and winter sections of the mechanical engineering capstone design course. Therefore, all students had completed or were in the final weeks of their capstone design course (i.e., had a minimum of one prior exposure to the front-end design process). Interested students completed a pre-selection questionnaire (Appendix A) designed to gather demographic and prior curricular, co-curricular, and extra-curricular design experience information. The pre-selection questionnaire prompted students to estimate the level of their experience using various design tools (no experience, little experience, some experience, and substantial experience) and performing design work during various phases of the design process. I used a stratified random sample from the group of volunteers to achieve diversity in front-end design experience. Of the eight participants selected to participate, four had participated in co-curricular multidisciplinary design experiences

(Participants 1, 4, 5, and 6), one participant had a minor outside of engineering (Participant 3, economics), two participants reported involvement in extracurricular design activities (Participants 3 and 4), and three participants reported having completed internships (Participants 2, 7, and 8). Participants were compensated $16 per hour.

5.3.3 Data collection

To minimize the variability associated with studying design processes, the same design task and access to information sources were given to all participants. The study was conducted in specific rooms on campus to facilitate detailed data collection of participant information gathering and use practices. The study was approved by the Institutional Review Board of the University of Michigan in accordance with the Helsinki Declaration and all participants gave informed consent.

The study spanned eight hours: three hours of participant design activity (9:00am-12:00pm), four and a half hours of design activity (1:00pm-4:30pm), and a one-hour break for lunch. After a brief explanation of the task (below) and a question and answer session, participants were free to schedule their time as desired.

Participants were presented with the following design task scenario (The term "user requirement" was used instead of "product requirement" to match the terminology used in the participants' capstone design course.):

> You are currently working for a large toy company that specializes in toys for young children (0 to 10 years old). You've just received a job assignment from your boss. The executives have decided they would like to begin to develop toys that aid young children, between 1 and 5 years of age, in developing their cognitive abilities, specifically children's ability to explore and learn about cause and effect. You have been assigned the job of investigating this idea in order to understand the design problem, develop user requirements, and translate these user requirements into engineering specifications. You will be using standardized templates that your company has developed in order to document the user requirements and engineering specifications. In the future, you and a team will design the toy based precisely on the user

> requirements and engineering specifications you are developing, so be sure to include as much detail as possible. For now, your boss only wants to see the user requirements and engineering specifications.

The task was made intentionally broad in order to best simulate front-end design where the problem itself as well as the purpose, requirements, and features of the desired outcome are not well defined. Furthermore, participants reported that they had not addressed this specific design task in prior curricular, co-curricular, or extracurricular activities. The design problem was formulated to be approachable by all participants and outside their domains of expertise, consistent with other novice-expert studies (Atman et al. 1999, 2007; Dally and Zhang 1993). Participants were given templates (Appendix B) to document each requirement, the priority level of the requirement, a justification for the requirement, and the information sources that contributed to the development of the requirement.

Each participant was assigned to a computer workstation to document the product requirements and engineering specifications and to access internet sources. Participants were also provided access to the following resources:

- Academic literature: electronic articles on childhood cognitive development
- Books: several books on children's cognitive development
- Guidelines: Consumer Products Safety Commission guidelines for determining proper age ranges for toys
- Observations*: children playing with various toys under parental supervision
- Stakeholder interviews*: various stakeholders including teachers, parents, a doctoral candidate studying cognition, an education expert (Ph.D.), and the director for a toy safety advocacy non-profit
- Standards: ASTM F963-11 (Standard Consumer Safety Specification for Toy Safety) and ASTM F2729-12 (Standard Consumer Safety Specification for Constant Air Inflatable Play Devices for Home Use)
- Benchmarks: numerous toys for young children

*Observations were available 11:00am-12:00pm and stakeholder interviews were available 10:00am-12:00pm and 1:00pm-3:40pm.

The data collection approach described below allowed us to track participants' activities throughout the day with minimal interference to their work. I collected various sources of data including overhead video camera footage of the computer workstation room, screenshots of participants' computers, computer and network surveillance data, audio/video recordings of stakeholder interviews, interview evaluations (by stakeholders), participant notebooks, post-task information use surveys, audio/video recording of a focus group discussion with stakeholders, requirements evaluations (by stakeholders), and audio recordings of post-task interviews with participants. This level of data collection allowed us to perform descriptive and exploratory quantitative analyses as well as in depth qualitative analyses of participants' design deliverables and their strategies and behaviors during the design task (Daly, McGowan, and Papalambros 2013).

5.3.4 Data analysis

To answer our research questions, the following data were used: product requirements developed by participants, stakeholder evaluations of requirements, overhead video camera footage, computer monitoring data, audio/video recordings of stakeholder interviews, and post-task interview recordings. The requirements developed by participants and the evaluations performed by stakeholders were used to address the first research question, and the remainder of the data was used to address the second research question. Analysis of the first research question included performing two assessments of participants' requirements and correlating them to descriptive measures of participant information use. Analysis of the second research question focused on identifying relationships and patterns in behavior of participants as they developed requirements.

5.3.4.1 Use of information sources

I investigated relationships between participants' use of information sources and both the stakeholder validity of their requirements and the degree to which they were tailored to the specific context and stakeholders of the design task. Several design texts describe criteria for assessing the quality of requirements. For example, Kotonya and Sommerville stated that requirements should be valid, consistent, complete, and accurate (Sommerville and Kotonya 1998). Garvin identified eight basic dimensions of quality including performance, reliability, durability, serviceability, conformance, perceived quality, aesthetics, and features (Garvin 1987).

Gause and Weinberg stressed the identification and reduction of ambiguity in requirement lists (Gause and Weinberg 1989). Requirements must also be solution independent (Dieter 2012). Taking into account these criteria for requirements quality and the aim of this study (i.e., to characterize how novice designers use information sources to develop product requirements), I developed two metrics to assess the quality of requirements that heavily relied on participants' abilities to gather, synthesize, and apply stakeholder and context-based information: 1) stakeholder validity as defined by Kotonya and Sommerville, and 2) the extent to which the requirements were tailored to the context of use and/or stakeholders through the application of Garvin's eight dimensions of quality.

Stakeholder validity is defined as the degree to which clients, end-users, and stakeholders confirmed that the product requirements accurately described characteristics that would meet their needs and wants (Génova et al. 2013). To measure stakeholder validity, the requirements developed by participants were presented to the stakeholders who had been available during the design task for interviews (n = 7). Stakeholders were given each participant's complete set of requirements and asked their level of agreement with two statements: 1) The requirements describe the important characteristics of a toy for young children, and 2) The requirements describe the important characteristics of a toy aimed at aiding children (between one and five years of age) in developing their cognitive abilities, specifically learning about and exploring cause and effect. A five-point Likert scale [Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, and Strongly Agree] was provided to capture responses. The metric for stakeholder validity, V_i, was calculated using Eq. (1),

$$V_i = \frac{\sum_{j=1}^{7}[R_{ij} - \tilde{R}_j]}{7} \qquad (1)$$

where i represents the participant's requirement list being evaluated and j represents the stakeholder who assessed the requirement list, R_{ij} is the rating (on the five-point Likert scale) given to participant i by stakeholder j and $\tilde{R}_j$ is the median evaluation score given by stakeholder j (across all participants). The sum is divided by the total number of stakeholders (7) who evaluated requirements.

I also analyzed the extent to which participants' requirements were tailored to the specific context and stakeholders for whom they were designing. Participants who developed a larger number of these tailored requirements were deemed more successful in understanding the context and stakeholders for whom they were designing and applying their understanding to the development of product requirements. This assessment was accomplished by considering two of Garvin's eight dimensions of requirements: aesthetics, and features (Garvin 1987). These two dimensions encompass requirements that must be specifically tailored to the end-use context and the stakeholders who interact with the product and therefore require a deeper understanding of the context of use, and the stakeholders who will interact with the product. Features are "frequently used to customize or personalize a product to the customer's taste" while aesthetics represents the customer's response to how the product "looks, feels, sounds, tastes, and smells" (Dieter 2012; Garvin 1987). Using this classification system, I calculated the number of requirements each participant developed that belonged to the first six dimensions as well as those that belonged to the last two (context and stakeholder specific) dimensions. Participants with a higher number of requirements pertaining to the dimensions of features and aesthetics (after being normalized by the total number of requirements generated by the participant) were deemed to have developed a more thorough understanding of the product's context of use and the stakeholders who would interact with the product.

To examine the relationship between the above-mentioned metrics and how participants used information, I developed metrics of information use. The first metric quantifies the diversity of information sources used by participants and the second characterizes participants' dependence on specific information sources while developing requirements. As part of the requirements template, participants were asked to cite the information sources that informed the requirements they developed. These information sources were subsequently classified into ten exhaustive categories (observations, interviews with parents/teachers, interviews with education experts (doctorate holder and student), interviews with the safety expert, academic literature, benchmarking, online resources, standards, given resources [e.g., books, guidelines], and the design task brief). These categories included all information sources cited by participants. The number of distinct information sources cited by each participant was then calculated, providing a measure for the level of diversity of the information sources participants used.

To quantify the level of dependence on specific information sources, I used the skew statistic for the distribution of information sources cited by participants (example distributions can be seen in Figure 5.3b). This measure was calculated using Eq. (2), where n is the number of information source categories, x_i is the number of citations within the i^{th} category, and $\bar{x}$ is the average number of citations per category. This measure of skew is insensitive to the ordering of information sources within the distribution.

$$Skew = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^3}{\left[\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2\right]^{3/2}} \quad (2)$$

The higher the skew of a participant, the more dependent he/she was upon a small subset of information sources when developing requirements. Skew was normalized across participants. In order for more positive measures to be associated with less dependence on a small subset of information sources, the metric shown in Eq. (3) was used for the correlations performed in this study.

$$1 - Skew_{norm} \quad (3)$$

The two measures of information use were then correlated with the two metrics of requirements quality. Spearman's rank-order correlation was used to capture the relationships between the variables in accordance with the nonparametric data from the Likert surveys (Hollander, Wolfe, and Chicken 2013). Spearman's correlation coefficient, *rho*, and *p*-values using two-tailed significance tests were calculated for all metrics of interest.

5.3.4.2 Information gathering behaviors

The objective of the case analysis was to identify the differences in information gathering behavior among participants whose requirements received high and low validity evaluations from stakeholders (Participants 2, 5, 6, and 7). Using a subset of the participants facilitated a detailed examination that included both quantitative metrics and qualitative coding and thematic analysis (Creswell 2013; Patton 1990; Ryan and Bernard 2003; Westbrook 1994). The variety of data sources allowed for a holistic description to be generated with respect to how each participant spent their time during the design task and how they performed specific information gathering activities (such as stakeholder interviews). Individual timelines showing minute-by-minute activities during the design task elucidated how each participant used their time (Atman, Deibel, and Borgford-Parnell 2009). Analysis of stakeholder interview transcripts was conducted by categorizing interview questions with an emergent coding system representing different topics of discussion (e.g., introductions, product requirements, validation testing). The time spent on each topic during interviews was calculated to determine the focus of participants' efforts, leading to the identification of specific behaviors and strategies displayed by the participants. The post-task interview transcripts determined whether participants acknowledged these behaviors and strategies and whether they were intentional or not.

5.4 Results and discussion

The study results are described below in two sections. First, I present the quantitative analysis results correlating participant information use behaviors with the quality of the requirements developed (answering my first research question). Second, I present the outcomes of the qualitative case analysis to explain why some participants were more successful in collecting and using information and thus more successful in developing requirements (answering my second research question).

5.4.1 Use of information sources

5.4.1.1 Requirements assessment

The first metric, participants' stakeholder validity scores, ranged from -0.33 to 0.50 for Question 1 (The requirements describe the important characteristics of a toy for young children.) and from -0.83 to 0.50 for Question 2 (The requirements describe the important characteristics of a toy aimed at aiding children (between one and five years of age) in developing their cognitive abilities, specifically learning about and exploring cause and effect). The theoretical minimum for the stakeholder validity metric was -1 and the maximum was 1. Figure 5.1 shows that Participants 4, 5, 6, and 8 performed above average when assessed by this metric, with Participant 6 performing markedly better than all other participants.

Q1: The requirements describe the important characteristics of a toy for young children.
Q2: The requirements describe the important characteristics of a toy aimed at aiding children (between 1 & 5 years of age) in developing their cognitive abilities, specifically learning about and exploring cause and effect.

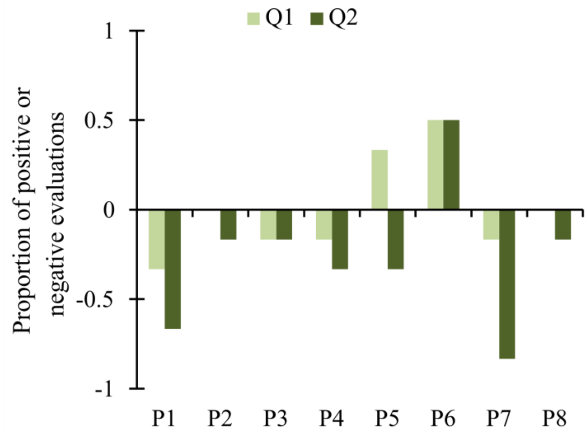

Figure 5.1: Validity of participants' (P=Participant) product requirements as evaluated by stakeholders

The second metric, the proportion of requirements that were tailored to the specific context and stakeholders of the design task, also revealed differences among the requirements developed by participants. Figure 5.2 shows that while all participants developed approximately the same number of basic requirements (requirements within the dimensions of performance, reliability, durability, serviceability, conformance, and perceived quality), Participants 4, 5, and 6 developed a larger quantity of requirements tailored to the specific context and stakeholders of the design task (requirements within the dimensions of features and aesthetics) than the other participants. The proportion of tailored requirements to the total number of requirements was used to establish correlations between information use and requirement assessment scores.

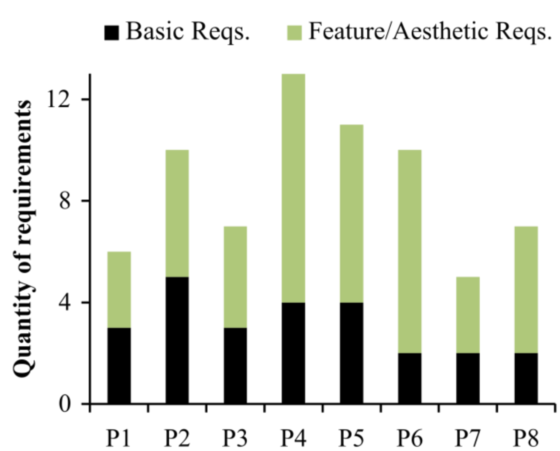

Figure 5.2: Numbers of requirements developed by participants as classified using Garvin's first six dimensions (Basic Requirements) and those requirements that were context/stakeholder specific (Feature/Aesthetic Requirements)

5.4.1.2 Assessing information use

Figure 5.3a shows the large variation with respect to how the eight participants used information to develop requirements. The number of distinct information sources cited by participants is displayed along the *y*-axis and the level of dependence upon particular information sources is displayed along the *x*-axis. Along the y-axis, higher values are associated with more diverse information use, and along the x-axis, higher values are associated with less dependence upon particular information sources. The large variation is most striking when comparing Participant 6, who used six distinct information sources and was not overly reliant upon any particular source, and Participant 1, who used only three distinct information sources and was highly reliant on one source (parent/teacher interviews) to develop requirements, Figure 5.3b. The variations suggest that participants used different strategies with respect to how they applied information when developing requirements, but the variations do not conclusively show that participants gathered and/or synthesized information differently.

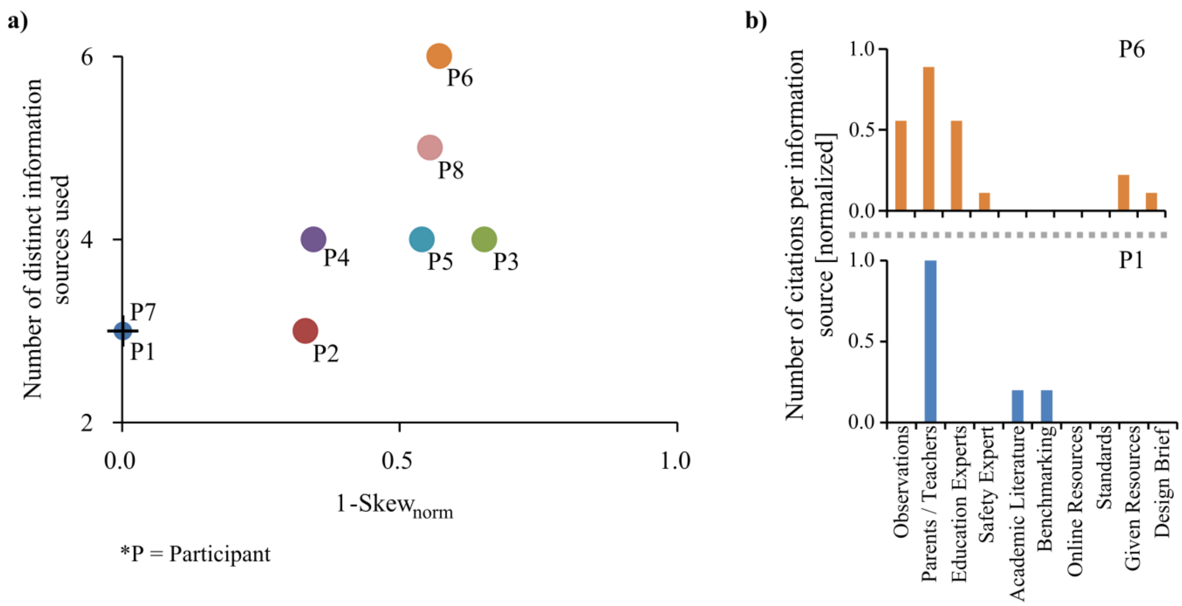

Figure 5.3: Participants' use of diverse information sources and their dependence on particular information sources. Citations were normalized in Figure 3b by dividing by the total number of requirements (i.e., 1.0 indicates that the information source was cited in every requirement)

5.4.1.3 Effect of information diversity and dependence on requirements assessment

A strong correlation (*rho*=0.70, *p*=.05) was found between the stakeholder validity of participants' requirements and the number of distinct information sources used; participants who used many information sources produced requirements that received higher scores from stakeholders (Figure 5.4a). Additionally, participants who used more diverse information sources developed more requirements tailored to the specific context and stakeholders of the design task (Figure 5.4b) as there was a strong correlation (*rho*=0.83, *p*=.01) between the proportion of context-specific requirements developed by the participants and the number of distinct information sources used. Participants who were dependent on particular information sources were more likely to receive lower validity scores (Figure 5.4c) from stakeholders as there was a strong correlation (*rho*=0.79, *p*=.02) between the stakeholder validity metric and the information dependence metric. There was a non-significant weak correlation (*rho*=0.48, *p*=0.23, Figure 5.4d) between the proportion of requirements specifically tailored to the context and stakeholders of the design task and the participants' dependence upon particular information sources.

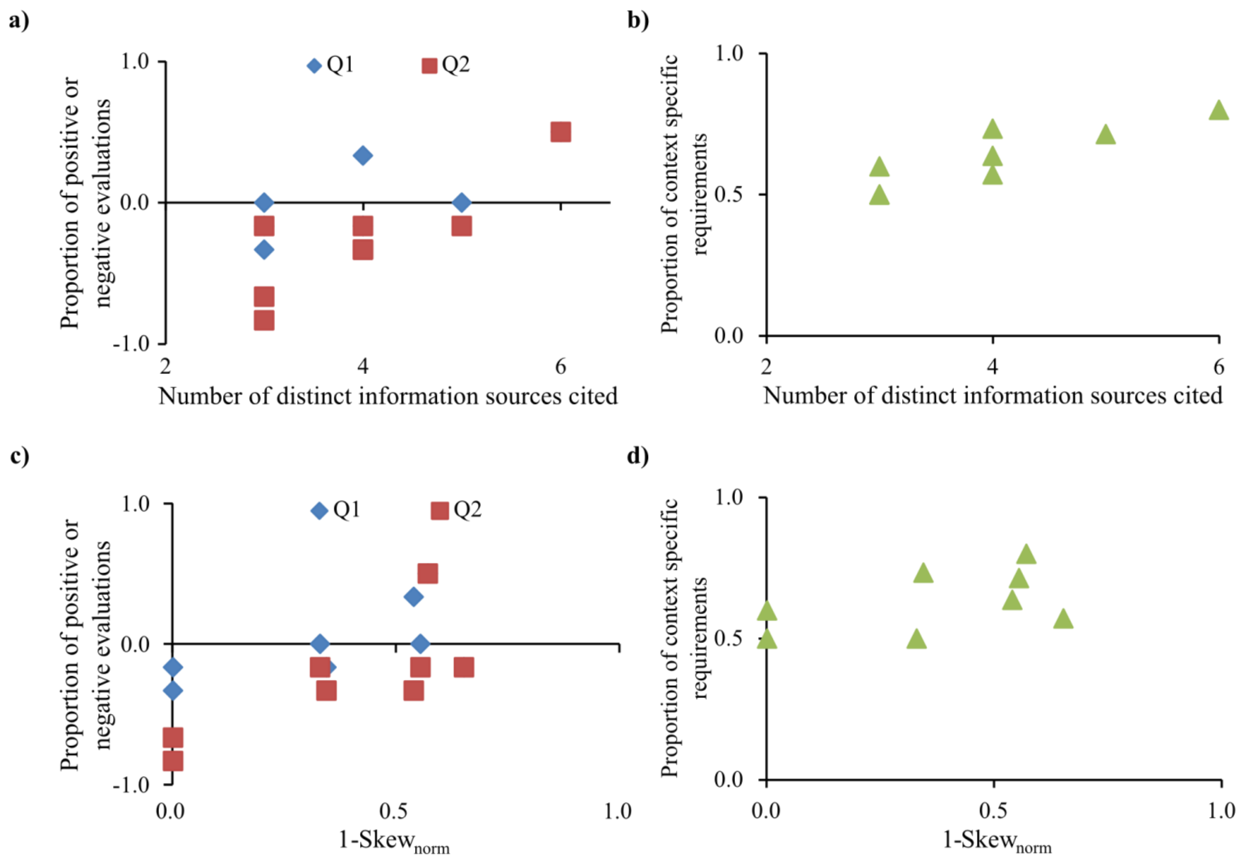

Figure 5.4: Correlations between assessment of participants' requirements and the diversity of information sources (a and b) and their dependence on particular sources (c and d)

The results suggest that use of diverse information sources and avoiding dependence on particular information sources are important factors for developing requirements that meet the expectations of stakeholders and are tailored to a product's context of use and the stakeholders.

The finding are consistent with common engineering texts that recommend consulting a variety of information sources during requirements development and confirming the requirements via multiple sources, rather than depending upon a small number of sources (Dieter 2012; C. L. Dym, Little, and Orwin 2013; Nuseibeh and Easterbrook 2000; Sommerville and Kotonya 1998). Some studies have found that experts tend to spend more time gathering information than novices, and that novices who gather more information produce higher quality designs than novices who gather less information (Atman et al. 2007; Sobek II and Jain 2007). The findings extend this prior work by showing that diverse sources of information are also critical to front-end design success.

5.4.2 Information gathering behaviors

Below I present the analysis of the behaviors and approaches of Participants 6 and 8 (high stakeholder validity assessments) and Participants 7 and 2 (low validity stakeholder assessments) to understand why some participants excelled and others struggled during the development of product requirements.

5.4.2.1 Case I: Participant 7

Participant 7 scored lowest in the evaluation of requirements by stakeholders and developed only five requirements during the design task (the average for all participants was eight), three of which were tailored to the context and stakeholders of the design task (the average was 4.87). Participant 7 also used the fewest number of distinct information sources and was the most dependent on particular information sources to develop requirements.

The timelines shown in Figure 5.5 display the activities of Participants 6 and 7 based on the minute-by-minute analysis. Time is shown from left to right (beginning to end of the design task) and a block is placed in line with the participant's activity at the time indicated on the *x*-axis. For example, Participant 7's use of time and handwritten notes shows extensive time spent in performing the data collection task (Figure 5.5a). However, Participant 7 did not begin to document the requirements until the final hour of the design task, which was markedly different from the higher performing participants, such as Participant 6 (Figure 5.5b), who began documenting requirements roughly two and a half hours prior to before the end of the design task. Participant 7's approach left little time to properly analyze the information gathered in order to apply it to his requirements and may have led to the lower validity scores received from the stakeholders.

Participant 7's time management approach was also evident in his handwritten notes that only captured information gathering activities and showed no attempt to analyze the information gathered. During the post-task interview, Participant 7 described how he spent time during the day:

> "…defining all of my user… requirements and engineering specs, that was a full out blitz from somewhere around 3:30ish to right at 4:00 and …so up until that point it was just all research based."

Participant 7's efforts to collect as much information as possible without anticipating the amount of time needed to synthesize or incorporate the information into the requirements likely prevented him from effectively leveraging the information collected, and may have led to receiving low stakeholder validity scores for his requirements.

5.4.2.2 Case II: Participant 2

Participant 2 performed just below average with respect to the stakeholder validity scores for her requirements. Only half of the requirements developed by Participant 2 were tailored specifically to the context and stakeholders of the design task; participants with above average stakeholder validity scores had approximately 70% of their requirements tailored specifically to the context and stakeholders of the design task. Participant 2 only used three distinct information sources, but was not overly dependent on any one of them. Unlike Participant 7, Participant 2 began documenting the requirements early and continued until the end of the design task. However, Participant 2 may have been overly reliant on online sources to complete the task. Figure 5.6 compares the time spent during the interactive design task by Participants 2 and 5. Compared to Participant 2, Participant 5 consulted a broader range of information sources and referred to them more uniformly.

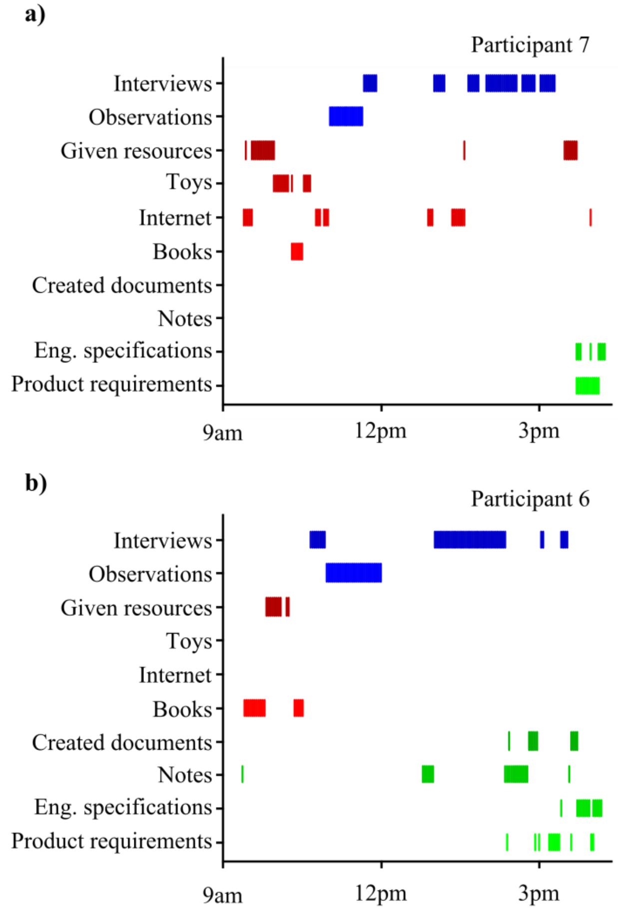

Figure 5.5: Timeline showing time use during the interactive design task for Participants 6 and 7

Participant 2 spent close to 90 minutes consulting online sources, which was more than twice as much time spent compared with any other participant assessed during the case studies. During the post-task interview, Participant 2 discussed this aspect of her approach:

> *Interviewer*: "What would you say was the most important resource during the day that you used?"
>
> *Participant 2*: "Probably the internet … because it's helpful talking to people, but…they're very subjective…to what they've just been through, …and it's not … a general sample."

Participant 2 associated online research with the acquisition of more "generalizable" knowledge and associated interviews with a more anecdotal form of knowledge acquisition, explaining why Participant 2 relied more on online sources and did not use some of the other sources as much as other participants. Participant 2's perception of the interview methods for requirements development may have hindered her from effectively leveraging the sources during the design task.

5.4.2.3 Case III: Participant 5

Participant 5 performed above average with respect to both requirement quality metrics. Participant 5 used the six types of information sources available without becoming dependent on any one source as shown in Figure 5.6. Participant 5 also displayed more advanced information gathering and use behavior with respect to interviews and observations. For example, Participant 5 developed a questionnaire for parents to complete during the observation session to better understand their perspectives. He then used the questionnaire to structure interviews with stakeholders and modified it as needed (Gause and Weinberg 1989). This approach allowed Participant 5's interviews to focus more on the requirements; other participants spent more time discussing background issues with stakeholders versus talking directly about product requirements. Participant 5 also displayed more advanced design techniques by narrowing the focus of the design task based upon the information he collected (Atman et al. 2007; Bailey 2008; Sobek II and Jain 2007). The original task indicated that the toy should be targeted to children from ages one to five; however, Participant 5 narrowed the focus to ages one to three given that most of the cognitive development for this specific attribute (cause and effect learning) occurs earlier in life. Other participants, such as Participant 2, mentioned the difficulty of developing requirements for such a large age range, but did not recognize the opportunity to redefine the problem more appropriately.

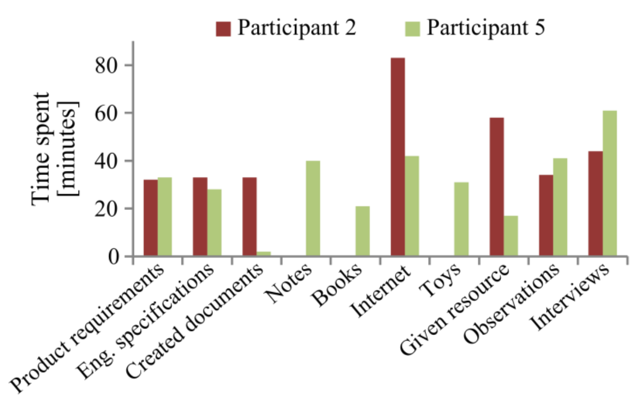

Figure 5.6: Summary of Participants' (2 and 5) time use during the course of the interactive design task

5.4.2.4 Case IV: Participant 6

The requirements developed by Participant 6 received the highest scores from stakeholders. Participant 6 cited the most diverse set of information sources and did not depend on any particular information sources. During the design task, Participant 6 spoke with more stakeholders than any other participant, holding seven interview sessions with stakeholders (four were conducted as focus group style interviews with two to three stakeholders each). Additionally, Figure 5.7 shows that that Participant 6 balanced her time during interviews with stakeholders and discussed a broad range of topics. The balanced interviews may have allowed Participant 6 to develop a more holistic understanding of the stakeholders interviewed.

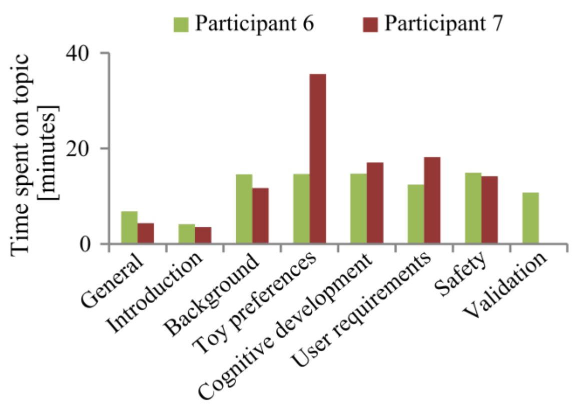

Figure 5.7: Time spent discussing specific topics by participants during interviews with stakeholders

Participant 6 was also one of only two participants to present stakeholders with the developed requirements. The direct feedback obtained from the stakeholders about the preliminary requirements displayed Participant 6's ability to employ a more participatory approach to stakeholder interaction during the design process (Schuler and Namioka 1993). During the post-task interview, Participant 6 mentioned the benefit of being able to interview parents while their children were playing in the same room,

"… I was glad that I was able to … interview parents during [the observation session], even though it was informally, because they were … in their setting … with their child … playing with them so the things they said were just more … candid and they were … in the mindset of … their kids paying with the toy"

Interviewing parents during the observation session allowed Participant 6 to ask questions based on the children's real-time behaviors. Unlike a neutral environment (an interview room), the natural environment probably aided the parents by providing them with contextual clues that could help inform their answers (Blomberg et al. 1993; Goffin et al. 2012).

The case analyses of Participants 2, 5, 6, and 7 show that participants who developed requirements that were scored more highly by stakeholders (Participants 5 and 6) also exhibited more sophisticated information gathering and requirements development strategies. I observed that Participants 5 and 6 used their observation sessions to talk to the parents in a more natural environment, developed surveys to provide structure to their interviews, performed more balanced information gathering (in general throughout the design task and specifically during interviews with stakeholders), and sought feedback from stakeholders about the final requirements (Blomberg et al. 1993; Gause and Weinberg 1989; Goffin et al. 2012; Schuler and Namioka 1993).

Previous studies have shown that time spent gathering information impacts design outcomes. In this work I found that the strategies participants used when gathering information also had an impact on outcome quality (Sobek II and Jain 2007). For example, Participants 6 and 7 used similar information sources and spent similar amounts of time gathering information, but received markedly different validity scores from stakeholders. From the findings I conclude that simply gathering an extensive amount of information while developing requirements does not yield high stakeholder validity scores. Instead, novice designers need to gather information effectively and then synthesize, analyze, and apply it appropriately.

Participants 5 and 6 displayed sophisticated information gathering techniques and were able to transfer their data into higher quality requirements. Participants 2 and 7, however, were less successful, because they were unable to translate the data collected during the design task into the development of appropriate design requirements. Other studies have found similar trends that engineering students in capstone courses encounter difficulties while attempting to incorporate diverse information sources into the development of product requirements (Mohedas, Daly, and Sienko 2014a, 2014b).

5.5 Limitations

The development of a structured design task that simulated aspects of front-end design allowed us to understand the processes by which novice designers gather and use information during the development of product requirements. However, there were limitations associated with the format of the design task. The group nature of the study wherein all participants performed the same design task simultaneously could have caused some participants to perform observations or stakeholder interviews simply because they noted that other participants were doing so, and they might not otherwise have used these sources. Also, allowing the participants to schedule interviews and focus group appointments with stakeholders as desired possibly benefited those who conducted their interviews later in the day, because earlier interviews could have "primed" the stakeholders. Additionally, I did not control for the effect of performance in the capstone design course or cumulative grade point average (GPA), however, a retrospective analysis of participants' grades in the capstone design course indicated that all of the participants were strong design students (grades ranged from B+ to A).

This study focused on collecting an extensive amount of data on a relatively small number of study participants. While the outcomes are not generalizable, the goal was transferability, meaning rich detail is collected and reported so that other researchers can apply and translate the findings into their own contexts (Malterud 2001).

5.6 Conclusions

In this chapter, I sought to better understand the processes used by novice designers to gather and use information during the development of product requirements. Participants with higher stakeholder validity scores and a larger proportion of requirements tailored specifically to the context and stakeholders of the design task cited the most diverse set of information sources and did not rely upon a singular (or small subset of) information source(s) during the requirements development phase. I suggest that a curriculum for teaching requirements development should encourage novice designers to gather diverse information and synthesize the information before developing requirements. Requiring a minimum number of diverse information sources as justifications for requirements and ensuring that each requirement is supported by multiple information sources may provide the necessary incentives until novices develop a deeper understanding of the benefits of such information gathering and use strategies. In addition, the literature on information gathering and use has demonstrated that novices tend to struggle with complex information processing tasks; therefore, novice designers may need instruction on general strategies for gathering and synthesizing diverse information.

The case analyses identified novice behaviors that could be countered with targeted pedagogy. For example, dependence on internet sources while ignoring information sources such as interviews with stakeholders or observations may be prevented by fully defining the breadth of information sources and methods for gathering information prior to when novices begin to develop requirements. Demonstrating the iterative process of requirements development could prevent novices from treating it as a one-time activity where information gathering fully precedes development of requirements. Furthermore, often in capstone design courses, the development of product requirements is performed on an accelerated timeline. Design course curriculum could provide opportunities for additional time for this design phase.

While Chapters Three and Four elucidated the frustrations that novice designers encounter when processing design ethnography data during design, the results within this chapter reinforce, experimentally, the important role that information processing has within the design process. I showed that gathering information from diverse sources and synthesizing them is a useful strategy for developing higher quality product requirements. This, in turn, provides experimental validation of the recommendations for gathering diverse perspectives from diverse information sources found within engineering design texts.

5.7 Acknowledgments

I would like to thank Kristen Ydoate and Linh Huynh for their help developing and executing the interactive design task and Gabrielle Fantich for her help transcribing the interview recordings. I would also like to thank the eight undergraduate design students who volunteered to participate in the study and Steve Skerlos and James Holloway for their data analysis suggestions. This work was supported by the University of Michigan's Rackham Merit Fellows program, the National Science Foundation's Graduate Research Fellowship program, the National Science Foundation's Research Initiation Grants in Engineering Education (RIGEE 1340459), the National Science Foundation's CAREER program (RAPD-0846471), and the University of Michigan Center for Research on Learning and Teaching's Investigating Student Learning Grant.

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Chapter 6 Assessing the quality of stakeholder interviews performed by novices during requirements elicitation

6.1 Introduction

A major conclusion from the results of Chapters Three and Four was the challenge and minimal benefits novice design students obtained from performing interviews with stakeholders during the design process. However, these studies used semi-structured interviews with students as the main data collection mechanism precluding detailed analysis of how these stakeholder interactions occurred and if the execution of interviews was a contributing factor to either the minimal benefit or the frustrations students encountered. To truly understand how to support novice designers during design ethnography data collection, a better understanding of what makes a design interview successful is needed as well as identification of the specific skills and strategies that are underutilized by novice designers. The study described in this chapter fills this critical gap by developing a novel methodology for assessing stakeholder interview quality and applying it to data gathered through an interactive design task (as described in Chapter Five).

6.2 Background

6.2.1 Requirements elicitation methodologies

As discussed in Chapter Five, activities associated with front-end design phases are ill-defined and have high uncertainty levels; thus being characterized as “fuzzy” (Ashok et al. 1990). Additionally, I discussed the importance of eliciting and developing product requirements as a method of reducing uncertainty and properly defining the design problem. Traditional methodologies of developing requirements (e.g., surveys, customer complaint data, sales data) have been shown to lack the information necessary to develop quality requirements (Abbie Griffin and Hauser 1993). To develop quality requirements, design experts have advocated the collection of information about and from end-users, stakeholders, and product-use environments using a variety of sources and methods (in addition to the traditional methods), such as interviews with end-users and other stakeholders, focus groups, and codes and standards (Dieter 2012; C. L. Dym, Little, and Orwin 2013; Nuseibeh and Easterbrook 2000). Newer information-gathering methods, based on the philosophies of human-centered and participatory design, include focus group brainstorming techniques, consensus-building workshops, the use of prototypes during elicitation, protocol analysis, and comprehensive design ethnographies (A. M. Davis 1992; Goguen and Linde 1993; Maiden and Rugg 1996; Mohedas, Sabet Sarvestani, et al. 2015; Sommerville et al. 1993). These methods allow one to gain a better understanding of a product's stakeholders and its context of use in order to properly define product requirements. A common theme amongst these methodologies is the importance of engaging with stakeholders to understand needs and preferences; often taking the form of stakeholder interviews.

6.2.2 Stakeholder interviews during front-end design

Stakeholder interviewing is a key source of information during the development of product requirements and engineering specifications. The importance of effective stakeholder interviews during the design process, particularly during requirements elicitation, has been documented in a range of fields including automotive systems, (Islam & Omasreiter, 2005) medical device development, (Martin & Barnett, 2012) human-computer interaction, (Light, 2006) and consumer product design (Kuniavsky, 2003). Furthermore, interviewing stakeholders is a practice that spans a large proportion of design processes and philosophies including human-centered design, participatory design, ethnographic fieldwork, contextual design, lead user approach, among others (Steen, Kuijt-evers, & Klok, 2007). Despite the importance of interviewing stakeholders during design, remarkably few support structures are available to designers when interviewing or preparing to interview stakeholders (Browne & Rogich, 2001; Moody, Blanton, & Cheney, 1998). Of the work conducted in this area, the majority have sought to categorize or create a taxonomy of questions that are relevant during design (Aurisicchio, Bracewell, & Wallace, 2006; Eris, 2003; Knuth, 2005; Ozgur, 2004). Materials available, such as the Ideo toolkit and interview materials from the d.school, provide strategies for interacting with stakeholders that novice designers can implement ("d.school Methods," 2015; IDEO, 2015). However, a systematic method of evaluating design interview quality, for the purposes of performing research or guiding design interview skill acquisition, do not exist.

Multiple challenges exist when eliciting from requirements during stakeholder design interviews. These challenges include ensuring that the most important topics are covered during a design interview (Burnay, Jureta, & Faulkner, 2014), that questions are appropriate and unbiased (Wetherbe, 1991), that questions focus on uncovering stakeholders' feelings and complete perspective on a given topic (Donoghue, 2010), and that interviews lead to a broader social, political, or cultural understanding of the design problem (Goguen & Linde, 1993). Additionally, one must not only consider the challenge of actually conducting a stakeholder interview, but the challenge of planning and preparing for interviews, gathering information from multiple stakeholders, synthesizing these data, and analyzing the data in order to make design decisions. These previous studies make clear the challenge of interviewing during the elicitation of product requirements and motivate the study of how novice designers execute stakeholder interviews and utilize the data gathered. In this study I discuss the development of a coding structure to evaluate interview quality and apply it to novice designers who participated in an interactive design task. The study I discuss below fills this gap by developing an evaluative methodology for assessing the quality of design interviews and applying it to novice designers who participated in an interactive design task.

6.3 Methods

6.3.1 Design task overview

The study presented below was guided by the following research questions:

RQ1: What type of assessment can reliably assess interview quality?

RQ2: What interviewing practices differentiate novice and more informed designers?

RQ3: What relationships exist between the execution of interviewing best practices and the relevance of information elicited to product requirements development?

To evaluate these research questions, a design task was developed to investigate the behaviors of novice designers as they interviewed stakeholders as a source for developing product requirements for a given design brief. Below, I briefly review the design task (for a full discussion, see Mohedas, Daly, and Sienko 2015).

Eight novice design engineers were given the same problem: Design a toy to aid young children in developing cognitive abilities. They were specifically instructed to understand the problem, develop product requirements, and translate them into engineering specifications. The problem was formulated to be easily understood by all participants, but did not coincide with any of the participants' prior experiences, consistent with other novice-expert studies (Atman et al., 2007; Atman, Chimka, Bursic, & Nachtmann, 1999; Dally & Zhang, 1993). The design task spanned eight hours: three hours of participant design activity in the morning, and three and a half hours of design activity in the afternoon. To perform the task, participants were given a broad range of resources: academic literature, books, Consumer Products Safety Commission guidelines, standards associated with toy development, example toys for the appropriate age range, the opportunity to observe children playing with toys, and the opportunity to interview various stakeholders. Participants were given standardized templates to document their product requirements and engineering specifications.

6.3.2 Participants

Eight students from two sections of a mechanical engineering capstone design course volunteered for the design task. Recruitment from this course ensured that all of the volunteers had completed or were in the final weeks of their capstone design course. Of the eight students who volunteered to participate, five were male, three were female, seven were mechanical engineering majors, and one was a biomedical engineering major. All volunteers provided written informed consent, and the study was approved by the University of Michigan Institutional Review Board.

6.3.3 Data collection

Throughout the design task, data collection included overhead video camera footage of the computer workstation room, screenshots (every 20 seconds) of participants' computers, computer and network surveillance data, audio and video recordings of stakeholder interviews, audio and video recording of a focus group discussion with stakeholders, audio recordings of post-task interviews with participants, stakeholders' evaluations of each interview, stakeholders' evaluations of each participant's requirements, participant notebooks, and post-task information use surveys. For the study reported here, data analysis focused on the audio and video recordings of all stakeholder interviews conducted by participants and the final product requirements and engineering specifications developed by participants.

6.3.4 Data analysis

Data analysis consisted of three phases. First, I developed a coding system based on academic literature on design interviewing best practices and used this system to evaluate the transcripts of the stakeholder interviews conducted by participants. Second, I developed a generalized linear model to compare the quality of stakeholder interviews among participants, where the dependent variable was the number of best practices per question asked by participants. Third, I related the results of the linear model to a metric of the relevance of the information elicited to evaluate "interview effect," which I defined as the level to which the information elicited during interviews was reflected in the product requirements and engineering specifications developed by the participants.

6.3.4.1 Coding system development

A literature search was conducted, drawing from a range of fields (e.g., automotive systems, medical device development, human-computer interaction, consumer product design, etc.) and a range of design philosophies and methods (e.g., human-centered design, participatory design, design ethnography, contextual design, lead user approach, etc.). The search was conducted on Web of Knowledge and included combinations of the following terms: stakeholder*, user*, end-user*, design*, engineer*, technolog*, interview*, talk*, and inquiry*. Of the 1,105 articles reviewed, 188 were found to be of direct interest, including some reference to stakeholder interviews during design. These articles were reviewed to identify best practices when interviewing stakeholders during design. The ensuing list of twenty best practices were furthered reduced/consolidated into a coding scheme of the twelve best practices that were both emphasized in the literature and could be identified by a coder within an interview transcript. These best practices were therefore not dependent on information that was not available to a coder (e.g., did not depend upon knowing the intent of the interviewer).

To refine the coding scheme, three coders evaluated each question asked by the participants for each of the twelve best practices, noting its presence or absence; 589 total questions were coded and the number of questions per participant ranged from 28 to 145. Initial coding was performed as a group, and the coding scheme was iterated to clarify the procedure. The coders then applied the coding scheme separately to five interviews conducted by participants. Inter-rater reliability was measured using Cohen's kappa (Cohen, 1960); this coefficient ranged from 0.77 to 0.86 (mean 0.82) for the five interviews coded. Kappa coefficients above 0.8 are considered extremely accurate (Krippendorff, 1980; Landis & Koch, 2008), while values above 0.60 indicate substantial agreement. Coders evaluated the remaining interview transcripts (37 in total) separately using the developed coding scheme (Table 6.1) as a deductive coding guide, meaning the codes were defined external to the data coded (Creswell, 2013; Patton, 1990).

6.3.4.2 Generalized linear Model

To differentiate between participants who performed higher quality interviews and those who performed lower quality interviews, a generalized linear model was developed. A linear regression allows one to understand the level of variance associated with a dependent variable that can be attributed to a specific independent variable, while controlling for other confounding variables (Coolican, 2009; Nelder & Wedderburn, 1972). In this case, I was interested in understanding how interview quality varied as a function of the participant (i.e., interviewer), while controlling for the interviewee, the question number (e.g. was it the first, second, third question etc.), and the interview number (e.g. was it the first, second, third interview, etc.). In the model, each question asked by a participant represented the unit of analysis. The dependent variable was the total number of best practices identified by the coder per question asked and formulated as:

$$y_j = \sum_{x=1}^{12} x_i \qquad \text{Eq. 1}$$

where x_i represents the presence or absence of a particular (i^{th}) best practice (1 indicates presence of the best practice, 0 indicates absence of the best practice), y is the dependent variable, and j is the question being evaluated. For example, if a participant asked a question that encouraged deep thinking and used a co-creative strategy, the value of the aggregate metric was two. My main interest was in identifying whether individual participants were differentiated by this model. Participants, therefore, represented the main independent variable. Other independent variables that could affect quality of interview were controlled for; these included: interviewee, interview number (e.g., first, second, third, etc.), and question number (e.g., first, second, third, etc.).

A secondary analysis was conducted to understand the particular best practices within the coding scheme that best differentiated participants. The top and bottom three performers as determined by the generalized linear model were compared using the twelve best practices categories. Fischer's exact test was used to determine the best practices in which a statistically significant difference was observed.

6.3.4.3 Interview effect metrics

The third analytical component sought to define a metric of interview effect on the product requirements and engineering specifications developed by participants. The interview effect metric consisted of two measurements: 1) the number of times relevant information was generated during an interview, and 2) the number of independent interview sources that generated information about requirements. The first metric assessed how effective participants' interviews were in eliciting information that was relevant to requirements/specification development. The second metric provided an assessment of how effective participants were in gathering a range of perspectives on each requirement developed (e.g. how many different stakeholder contributed to the development of individual requirements). The first metric was assessed by counting the number of times that a particular requirement was referenced (either through a question asked by the interviewer or brought up independently by the interviewee) within interview transcripts. The second metric counted the number of interviews during which a particular requirement was mentioned once or more.

6.4 Results

In this section, I provide an overview of the results of the literature review resulting in the coding system and the results of the generalized linear model (addressing the first research question). Second, I present the individual coding findings comparing the top and bottom three performing participants (addressing the second research question). Third, I present the metrics associated with the effect of the interviews on participant's requirements and their relationship with interview quality generated from the regression model (addressing the third research question).

6.4.1 Coding overview & generalized linear model

The literature review of interviewing best practices led to the coding system shown in Table 6.1. This system was based on a down selected set of best practices drawn from the overall results of the literature review. The system consists of twelve independent design interviewing best practices that can each be evaluated at the question level of an interview transcript.

Table 6.1: Best practices identified within literature and served as the coding structure for the analysis

Code/ Best Practice	Best Practice Description	Code Description	Example References
Encourage Deep Thinking	Deep thinking, defined as analytical thinking, integration of ideas, and use of logical reasoning, focuses interviewees to move beyond superficial responses and provide more in depth knowledge on a subject.	Designer asks question which require stakeholder to: 1) Analyze a situation: presents a situation (or multiple) and asks stakeholder to analyze, assess, make a determination, etc. 2) Integrate ideas: asks stakeholder to synthesize multiple ideas together to form larger picture understanding 3) Use logical reasoning: asks stakeholder to reason out why something is the way it is, or how something occurs, etc.	(Leifer, Lee, & Durgee, 1994; Rosenthal & Capper, 2006; Scheinholtz & Wilmont, 2011)
Develop a Rapport with the Interviewee	Interviewers should strive to develop a good rapport with respondents. This will lead to a more comfortable discussion and more open/honest responses.	Designer begins the interview with non-design related questions or small talk. Designer uses personal questions (when appropriate) to develop relationship with stakeholder 1) Conversation at beginning or end; non-design related conversation during interview 2) Questions about the stakeholders background to better understand them	(Dieter, 2012; Strickland, 2001; Tsai, Mojdehbakhsh, & Rayadurgam, 1997)
Avoid Misinterpretations	Misinterpreting an interviewee's responses can lead to erroneous information being collected. It is critical to document interviewee's exact wording or for the interviewer to present his/her interpretation back to the interviewee for verification.	Designer asks a clarifying question to ensure he/she fully understand a stakeholder's response Examples: "What does ASME stand for?" "What is a qualitative assessment?" "How do you spell that?"	(Byrd, Cossick, & Zmud, 1992; Dekker, Nyce, & Hoffman, 2003; Feltovich, Spiro, & Coulson, 1989; Spradley, 1979; Strickland, 2001; Wooten & Rowley, 1995)

Be Flexible & Opportunistic	Interviewer should not be rigidly attached to a pre-defined list of questions or topics. He/she must be able to identify relevant topics arising from interviewee's responses and dig deeper into this newly discovered information.	Designer probes into a topic area brought up by a stakeholder (tangential to the designer's original question) Designer adjusts his/her interview questions / approach after learning about the stakeholder 1) Example: stakeholder mentions that they research adults and student begins asking questions in this area instead of children 2) Example: stakeholder mentions that they do a lot of work on toy recalls and students begins asking questions in this area	(Agarwal & Tanniru, 1990; Dhillon, Ramos, Wünsche, & Lutteroth, 2011; Luck, 2007; Nguyen, Carroll, & Swatman, 2000; Strickland, 2001)
Verify the Conclusions Drawn from Interviews	If conclusions are drawn during analysis of interview results (or during interviews), interviewer should attempt to verify that these conclusions align with interviewee's perceptions.	Designer presents the stakeholder with his/her interpretation of the stakeholder's response for confirmation Designer verifies the requirements / specifications generated through interviews 1) Within Interview: stakeholder gives a response and the student interprets it and presents their interpretation of the response to determine if its correct 2) Between Interviews: student presents conclusions drawn from other interviews to stakeholders to see if it still holds true	(Firesmith, 2003; Nuseibeh & Easterbrook, 2000)
Designer Begins and Interviewee Concludes	At the start of the interview, interviewers should define the purpose and goals of the interview with the interviewee. At the end, interviewers should allow time for interviewee to discuss topics of interest that were not asked about.	Designer explains to the stakeholder the purpose of the interview (e.g., their goals, the design project, etc.) The designer leaves time at the end of interview to allow the stakeholder to offer any concluding thoughts that were not covered by questions	(Luck, 2007; Strickland, 2001)
Use Projective Questioning Techniques	Using stories, metaphors, drawings, analogies, role-playing, third party projections, etc., can enhance the information elicited.	Designer frames questions using 1) Hypothetical: how would you, what would be your preference if, if you had to choose, etc. 2) Story Telling: if you had to purchase a toy today, how would you go about it	(Donoghue, 2010; Rosenthal & Capper, 2006)

Use a Co-Creative Interview Strategy	Help interviewee take ownership of the goals of the interview; giving interviewee a stake in the outcome can result in more useful information elicitation.	Designer asks questions or makes comments that would increase stakeholders sense of ownership of interview / product requirements Questions give ownership of the process to the stakeholder 1) Example: if you were designing an experiment to validate the device, how would you do it? 2) Example: how would you design the toy to make it easier to clean up?	(Scheinholtz & Wilmont, 2011)
Introduce Domain Knowledge	Introducing domain knowledge (either from other information sources or other interviews) can elicit information about specific topics in which interviewee may be an expert.	Designer uses domain knowledge from prior interview or observation or literature or any other information source to frame question Example: "I read", or "I heard" or "others told me", etc.	(Bednar, 2009; Strickland, 2001; Tsai et al., 1997)
Have the Interviewee Teach You	Interviewer can profess ignorance to encourage interviewee to explain a specific topic or break complicated subjects into component parts.	Designer uses ignorance to get stakeholder to teach him/her about an idea/procedure/concept/etc. Example: "I'm not familiar with cognitive function tests, could you walk me through it," OR "I don't know anything about cause and effect, what are the basics?"	(Evnin & Pries, 2008; Strickland, 2001)
Explore Contradictions	Understanding contradictions (within an interviewee's own responses) or disagreements between different interviewees can lead to insightful information.	Designer asks about differences between answers between stakeholders or within stakeholders own responses Example: another stakeholder mentioned that a gender-neutral toy is important; do you think this is also important?	(Goguen & Linde, 1993; Kaiya, Shinbara, Kawano, & Saeki, 2005)
Break Down Expert Tasks	Interviewee experts may fail to mention all of the cognitive or physical processes required to perform a specific task or reach a goal. Interviewer should ask again to capture all information.	Designer probes stakeholder's responses to break-up complicated cognitive processes into more manageable steps Example: Stakeholder might mention some task they do (e.g., "I work on testing cognitive functions in children) and student asks stakeholder to break that task down (e.g., "what are the steps and processes involved in going through those cognitive function tests")	(Agarwal & Tanniru, 1990; G. Davis, 1982; Inoue et al., 2012; Johnson, 1983; Wetherbe, 1991)

A summary of the coding system results developed from best practices and applied to the eight participants is presented in Table 6.2. The number of interviews conducted by participants ranged from 3 to 7 and the total number of questions asked per interview ranged from 28 to 145 (interviews lasted approximately 15 minutes each). In total, 708 best practices were identified across all 37 transcripts. Participants exhibited between 0.9 to 1.6 best practices per question.

Table 6.2: Summary statistics for coding of Participants 1, 5, 6, and 7

	P1	P2	P3	P4	P5	P6	P7	P8
Interviews	7	3	3	3	4	7	7	3
Questions Asked	145	28	50	67	60	85	115	35
Questions per Interview	20.7	9.3	16.7	22.3	15.0	12.1	16.4	11.7
Best Practices Found	173	28	54	85	94	124	121	29
Best Practices per Question	1.2	1.0	1.1	1.3	1.6	1.5	1.1	0.9

The results of the generalized linear regression analysis are shown in Table 6.3 including coefficient estimates, standard errors, and significance levels for all variables examined. The variables included: all participants (Participants 1 through 8), all interviewees (two teachers, two parents, an education PhD, a psychology PhD, and a safety expert), interview number, and question number. In the model, Participant 1 and Teacher 2 were used as the reference within their respective categories. Participants 4, 5, and 6 performed significantly better than the reference (all statistically significant); whereas Participants 2, 3, 7, and 8 performed worse than the reference (only Participant 8 performed statistically significantly worse than the reference participant). The model also revealed that interviews conducted with Parent 2, produced significantly fewer best practices than those interviews with other stakeholders. Additionally, the positive and statistically significant coefficient associated with interview number indicated that participants' performance improved as they conducted more interviews.

Table 6.3: Estimates, standard error, and significance of the variables included within the generalized linear model

	Estimate	Std. Error	Sig.
P2	-0.048	0.158	
P3	-0.093	0.127	
P4	0.215	0.122	†
P5	0.528	0.120	***
P6	0.314	0.103	**
P7	-0.122	0.089	
P8	-0.379	0.148	*
Teacher 1	0.152	0.143	
Parent 1	-0.129	0.123	
Parent 2	-0.285	0.109	**
Education PhD	-0.009	0.104	
Psychology PhD	0.142	0.108	
Safety Expert	-0.189	0.133	
Interview Number	0.052	0.021	**
Question Number	0.000	0.005	

*** = p < 0.001; ** = p < 0.01; * = p < 0.01; † = p < 0.1

6.4.2 Best practice differentiation

To better understand what was driving the differences between higher and lower performing participants, the high and low performing participants were compared with respect to each individual best practice. Figure 6.1 shows that the higher performers displayed more instances of best practices in 10 of the 12 codes, of which four were statistically significant ($p < 0.05$): encouraging deep thinking, being flexible and opportunistic, using a co-creative interview strategy, and introducing domain knowledge. Minimal differentiation was observed in developing rapport with interviewee, avoiding misinterpretations, exploring contradictions, and breaking down expert tasks.

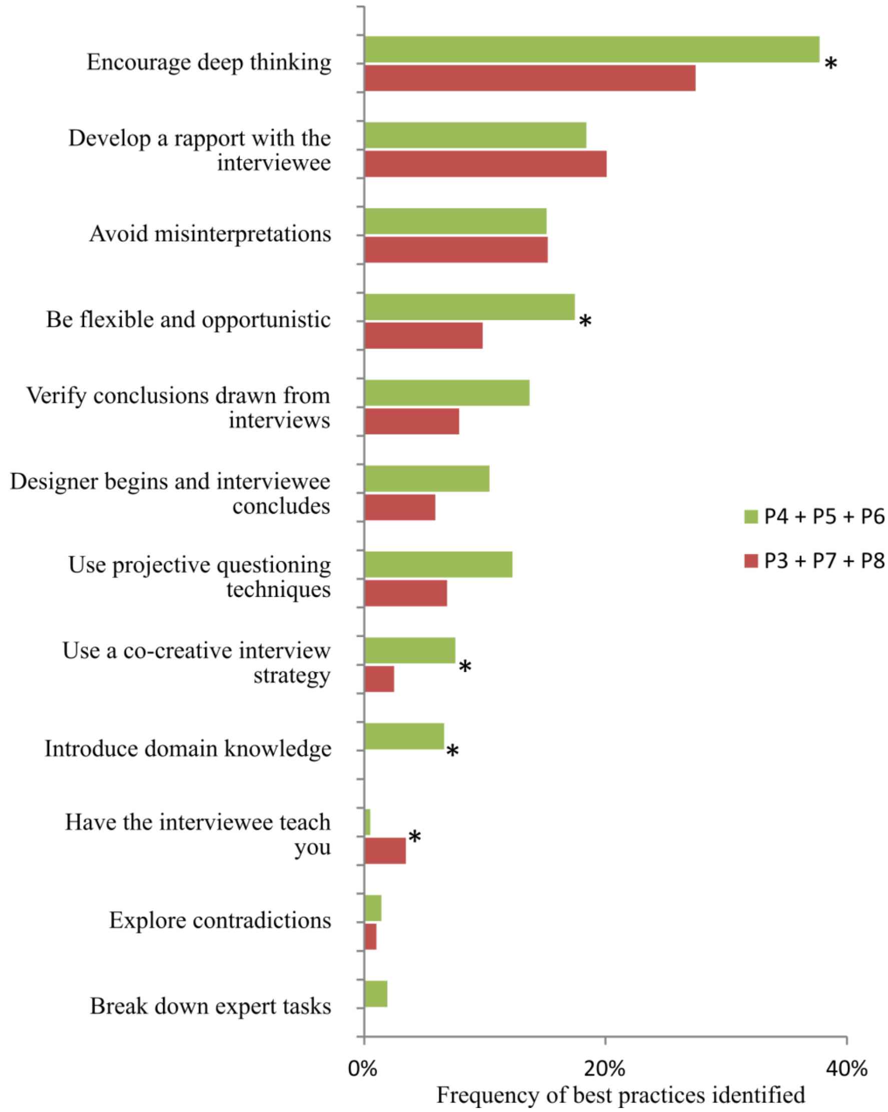

Figure 6.1: Results of best practices coding for Participants 1, 5, 6, and 7

6.4.3 Effect of interview quality on information elicited

The "interview effect" metric was created to investigate whether the performance of higher quality interviews (as assessed by the linear model) was associated with a higher likelihood of eliciting information that effected product requirements and engineering specifications, as developed by the participants. Two metrics were combined to establish the interview effect metric; 1) total references mentioned in interviews that impacted the final version of the requirements developed by the participants, and 2) independent interviewee sources for final requirements developed. Figure 6.2 shows the metrics for each participant. The combined metric (adding independent interview sources to requirements references) was used to assess the association with each participant's interview quality. Figure 6.2 shows differences in how individual participants used interviews to develop requirements. For example, Participant 6 used interviews extensively to develop all of her requirements and obtained information from multiple interviewees for each requirements. In contrast, Participant 2 incorporated interview information into fewer than half of her requirements and only obtained multiple perspectives on one requirement.

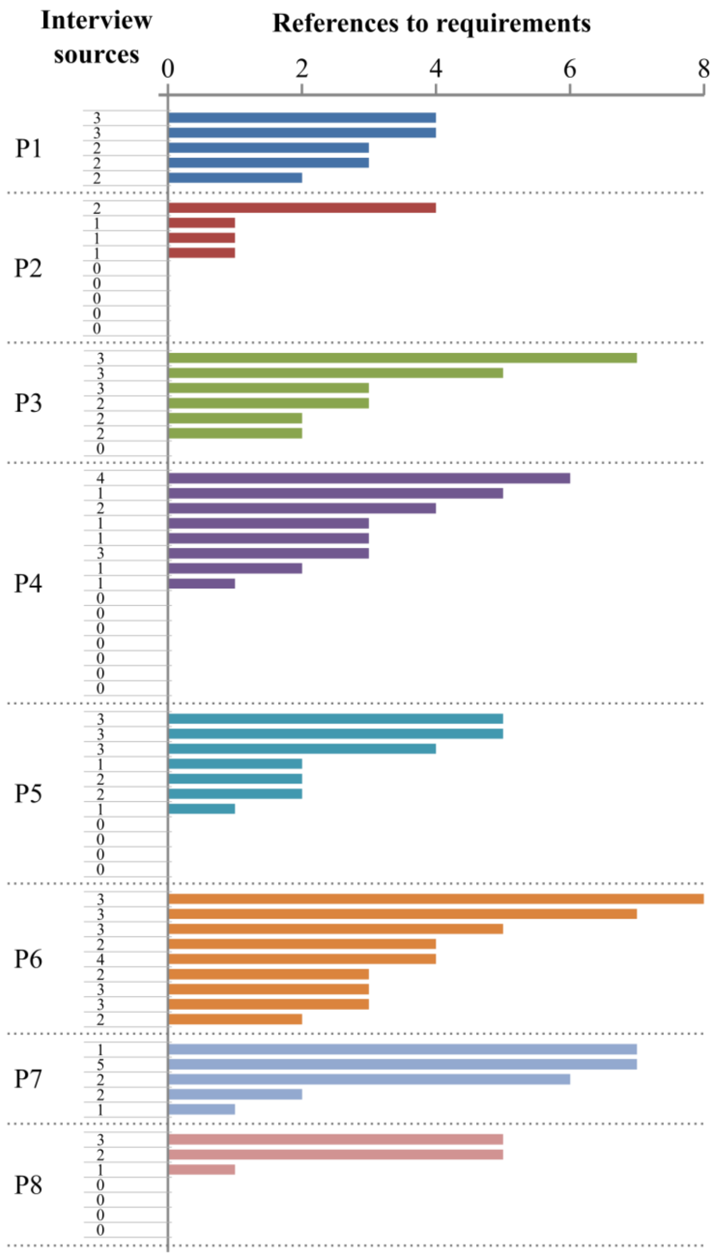

Figure 6.2: Interview references to final requirements developed by participants

Figure 6.3 shows the combined metric and participant performance during interviews as assessed by the coding system. Participants who performed higher quality interviews tended to extract and use information that was more relevant to the final requirements they each developed than those who performed lower quality interviews. This suggests that a designer who is able to perform higher quality interviews (in Figure 6.3 this would include Participants 4, 5, and 6) is able to elicit information that is more directly applicable to the development of product requirements.

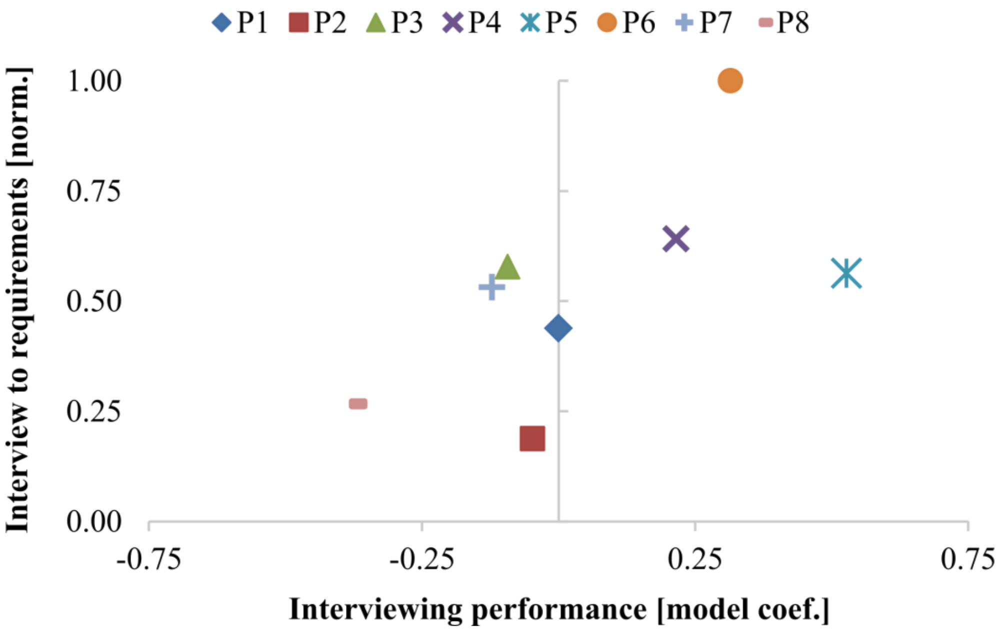

Figure 6.3: Relationship between a participant's performance during interviews and the level of requirements extracted from interviews

6.5 Discussion

The coding system developed in this study was shown to be a viable method for evaluating the quality of design interviews during front-end design phases. Grounding the coding scheme in the literature supports its validity and the high inter-rater reliability (mean kappa 0.82) demonstrated that it can be applied consistently. The results of the generalized linear model demonstrated that the coding system effectively differentiated between high- and low-quality interviews. A statistically significant positive effect with respect to the interview number (i.e. first, second, third interview, etc.) indicated that higher quality interviews resulted when a larger number of interviews were conducted, i.e., analysis showed that participants improved the quality of their interviews as their experience increased.

Differences between the higher and lower performing groups of participants were effectively identified by using the coding system. Both groups developed rapport with interviewees and avoided misinterpretations during interviews suggesting that these two best practices were executed equally across these participants. There were differences among students indicated by the significantly greater usage of specific best practices such as encouraging deep thinking, being flexible and opportunistic, using a co-creative strategy, and introducing domain knowledge, suggesting that these practices might be indicators of a more advanced design interviewer within the study sample.

The positive relationship between interview quality and the elicitation of information relevant to product requirements and specifications emphasized the importance of performing high quality interviews during front-end design. This study showed that participants who performed higher quality interviews were also able to extract more relevant information for the purpose of developing requirements. This study added experimental data to support the value of design interviewing during front-end design, which has been discussed extensively within the literature, but in broader, non-specific terms (Dieter, 2012; Dym et al., 2013; Griffin & Hauser, 1993; Nuseibeh & Easterbrook, 2000).

The results of this study, particularly the development of a reliable coding system to evaluate stakeholder interview quality based on literature, contribute to a wide range of design fields and to design processes such as human-centered design, participatory design, ethnographic fieldwork, contextual design, among others (Steen et al., 2007). This synthesis of best practices builds upon the strategies currently available within the literature, such as those provided within the Ideo toolkit or materials from Stanford's d.school ("d.school Methods," 2015; IDEO, 2015) by providing both a framework to guide design interviewing as well as a means to assess the quality of the interview immediately after. While design texts have encouraged extensive stakeholder interaction, this study 1) augments the existing literature by providing details about what it means to effectively interview a product stakeholder during front-end design, 2) provides novices with a tangible starting point from which to begin to develop this skill set, and 3) provides design students and practitioners with a reliable method of evaluating and improving their ability to engage with stakeholders.

6.6 Implications

This study, through the development and initial validation of a best practices evaluation framework, provides designers with a method for preparing for and evaluating the interviews they conduct with stakeholders. Within both industry practice and academia, this framework could be used as an efficient and low-cost method for designers to develop this skill set supporting peer-to-peer learning within training programs or through self-reflection exercises that could be implemented during real-world implementation of stakeholder interviews. Designers could use the best practices evaluation framework retroactively to asses where best practices were or were not used effectively (e.g., were there moments where the designer could have been more opportunistic in pursuing a line of questioning, were there times when the designer failed to verify a conclusion or interpretation drawn from a stakeholders response, etc.). The coding system developed can be adapted as a tool to help designers develop higher quality interview protocols by comparing the questions they develop to the best practices identified and adjusting them accordingly. Whereas design interview protocols are typically improved through pilot testing, use of the best practices framework would allow designers to improve the quality of their interviewing protocols during initial development leading to more effective initial interviews.

Within academia, the coding system can be used by instructors to evaluate students' interviews through transcripts or audio recordings. This would provide instructors with a method for measuring design students' ability to conduct interview and allow instructors to provide valuable feedback to students within design courses. Because the coding system can be applied retroactively to interview transcripts, instructors would be able to provide feedback on the interviews students conduct for their design projects (in project based courses) allowing for a more useful feedback than can be provided in a simulated setting (e.g., providing feedback in a mock interview). The analysis demonstrating which best practices differed most between higher and lower quality interviews may help instructors scaffold which best practices to introduce initially in a design course and which to incorporate during later phases. For example, in this study, encouraging deep thinking and being flexible and opportunistic were more commonly used by novices (and differentiated the high and low quality interviews). Instructors could begin by introducing these best practices before moving onto the less-common best practices such as using a co-creative strategy and introducing domain knowledge.

6.7 Conclusions

This study sought to better understand what it means to perform a high-quality design interview and to examine the relationship between the quality of interviews conducted and the information elicited from stakeholders. The coding system developed from best practices was shown to be a highly reliable method of evaluating the quality of stakeholder interviews and was able to differentiate between the highest and lowest performing participants within the sample. Additionally, the results provide experimentally-derived evidence to support the importance of performing high-quality interviews when developing product requirements during the fuzzy front-end of design. The coding system developed as part of this study could support both practicing designers as well as design students during stakeholder interview protocol development, aid in the performance of self-evaluation and reflection on interviews conducted, and provide a mechanism for facilitating peer-to-peer feedback on this complex skill set. This coding system could also be directly implemented by design instructors within the classroom to support student learning and assess learning progress.

These results begin to provide a clearer understand for why design teams had such varying experiences, with respect to utility, when interviewing stakeholders during the studies described in Chapters Three and Four. A large proportion of the student frustrations could have been due to a lack of interviewing skills and training. Without an appropriate level of skill, design teams may conduct low quality stakeholder interviews that, in turn, may not lead to the elicitation of relevant design information. This could then lead to the significant number of interactions I observed in Chapters Three and Four where design teams were unable to use stakeholder interviews effectively when making design decisions. Additionally, low-quality interviews may also contribute to an increased burden on designers with respect to information processing due to the fact that information elicited will be less relevant to requirements development and, therefore, more difficult to incorporate into the decision making process. The results of the studies presented in Chapters Two through Six represent a significant increase in our understanding of how novice designer use design ethnography techniques. In Chapter Seven, I synthesize these findings, with other relevant academic literature in order to fully understand the continuum of expertise in design ethnography and better understand design ethnography skill development.

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Chapter 7 Characterizing the novice to expert spectrum of design ethnography skill acquisition and its role in design tool and pedagogy development

7.1 Introduction

The studies described in Chapters Three through Six elucidated the behaviors and strategies used by student designers when implementing design ethnography in capstone design courses and within the context of an interactive design task. The students studied represented a range of levels of experience with design ethnography techniques and their ability to effectively use the techniques also ranged from novice to more informed levels of sophistication. The focus on student designers, however, provides a unique opportunity to study the novice to informed, and in some cases, expert continuum, which prior to this work was unknown. To better understand the behaviors and strategies that I would like engineering designers to exhibit, I must define what it means to be an expert and characterize the novice to expert spectrum of design ethnography skill development. In this chapter, I posit a novice to expert continuum of design ethnography skill development using a validated theoretical model of skill acquisition. In doing so, I developed a better understanding of the phases of design ethnography skill acquisition, that will support the development of more effective design and pedagogical tools and enable design instructors to more successfully scaffold design ethnography education into the curriculum.

7.2 Background

As evidenced by the studies described in Chapters Two through Six and within the academic literature more broadly, the application of design ethnography to engineering design is a complex cognitive skill requiring significant experience and expertise to properly execute (Brand-Gruwel, Wopereis, and Vermetten 2005). Design ethnography requires individuals to complete a full information processing cycle; identify a specific information need, determine appropriate information sources, gather and synthesize information, and then analyze this information in order to apply it to design decisions (Blomberg and Burrell 2003; Tanni and Sormunen 2008). Previous research has demonstrated that novices struggle with these aspects of information processing; for example assessing information quality and defining the information problem (Brand-Gruwel, Wopereis, and Vermetten 2005; Hultgren and Limberg 2003). During implementation of design ethnography, information processing tasks are complicated by many factors. For example, information needs may only be vaguely defined (e.g., during needs identification or requirements development) requiring design ethnographers to find information related to a problem that they cannot articulate clearly. Gathering information through design ethnography also requires one to use skill sets that may be underdeveloped in many engineering designers; design ethnography methods such as observations and interviews are used extensively by social science researchers, but engineering designers are rarely exposed to these methods during curriculum.

The benefits of using design ethnography seen in the literature are mitigated in novice populations by the barriers to implementation which are observed when novices attempt to implement these methods. This suggests that in order to introduce engineering design students to design ethnography effectively, evidence-based pedagogy is required. In this chapter, I analyze the results of the studies in Chapters Two through Six, previous studies on design ethnography use by novices, and general design ethnography literature through the lens of the Dreyfus and Dreyfus model of skill acquisition (S. E. Dreyfus and Dreyfus 1980). In doing so, I achieve a better understanding of why novices struggle with design ethnography, what characterizes the continuum of expertise in design ethnography, and how one can better support designers using design ethnography techniques. As a result, this research situates and organizes existing literature in this space and provides evidenced based proposals for pedagogy and design tools.

7.3 Theoretical framework

The Dreyfus and Dreyfus model of skill acquisition was developed through empirical studies of aircraft pilots and their training programs (H. L. Dreyfus and Dreyfus 1979a, 1979b, 1980, 1988; S. E. Dreyfus and Dreyfus 1980) and later applied by other scholars to a variety of contexts including medical education (Batalden et al. 2002; Benner 2004; Carraccio et al. 2008), computer programming (Mead et al. 2006), ethics (H. L. Dreyfus and Dreyfus 2004), sports (Duesund and Jespersen 2004; Moe 2004), and engineering (Honken 2013). The model represents how skill development is embedded in the context in which an individual solves a problem (Johnsonlaird 1970; Konečni and Ebbesen 1979). The model consists of five stages (novice, advanced beginner, competent, proficient, and expert) where the level of sophistication of one's mental functions increases with each stage of development. Below I detail each level of the model as described by Stuart Dreyfus in an updated description of the model (S. E. Dreyfus 2004).

Novice: Novices begin by learning context-free rules that can be applied without required skill or prior experience. Dreyfus describes a student driver being told to shift into 2^{nd} gear when the speedometer needle reaches 10mph. The novice driver uses this rule without regard to potentially relevant situational information. Therefore, when applied to real world situations, success is not guaranteed because situational factors typically disrupt the use of these simple rules (e.g., the car is on a hill). At this level, an individual does not modify these rules to adapt to a situation.

Advanced Beginner: At this level, a learner begins to recognize situational cues that must also be considered in addition to context-free rules. For example, a student driver using the engine sounds to know when to shift. An individual can also begin to identify similar contexts and recognizes when a rule from one context can be applied to a related context. He/she begins to develop heuristics that allow for abstract concepts to be generated from concrete prior experiences.

Competent: At this level, an individual recognizes the complexity involved in the problems he/she is solving and appreciates that context-free rules cannot be blindly applied. The individual becomes emotionally invested in the outcome (e.g., success or failure) and, therefore, it is more challenging to apply the detached context-free rules given to a novice/advanced beginner. Individuals recognize that the vast amount of potentially relevant information in a given context requires him/her to prioritize information during decision making.

Proficient: When an individual reaches the proficient level, he/she relies less and less on context-free rules, instead, transitioning to personal experience. Successes and failures now become the main learning tool as a proficient individual is seeking to increase their experience level to better prepare to tackle diverse and new situations. A proficient individual can use intuition to understand a situation, but continues to rely on analysis to make decisions.

Expert: At this performance level, an individual can discriminate between subtle situational differences and can intuitively make decisions. Experts intuitively understand situations and how to achieve goals. Evidence of this can be seen in expert chess players whose ability to assess and respond to situations does not degrade with increased rate of play or the addition of other cognitively demanding task, indicating that they are not relying on analytical decision making (S. E. Dreyfus 2004). Experts approach problem solving in a more open-ended and intuitive manner.

The model refers to four mental functions within each level of expertise: components, perspective, decision, and commitment (S. E. Dreyfus and Dreyfus 1980; S. E. Dreyfus 2004). Components are the contextual elements of a problem or situation that an individual can perceive (e.g., can they only perceive context-free elements or can they also identify important contextual elements). Perspective refers to an individual's ability to select which aspects of a situation or problem are most important to focus on. Decisions can be made in one of two ways: analytically or intuitively. Finally, an individual's commitment refers to whether or not (and in what way) an individual feels personally responsible in the process of understanding a situation, making a decision, and the subsequent outcome. As an individual moves along the continuum of novice to expert, he/she advances in each of these four mental functions. Table 7.1 displays a summary of the Dreyfus and Dreyfus model, from Carraccio et al., as it was applied to the development of clinical skills in medicine (Carraccio et al. 2008).

Table 7.1: Characteristics of each level of the Dreyfus and Dreyfus model of skill acquisition, from Carraccio et al. (Carraccio et al. 2008)

Novice	Is rule driven Uses analytic reasoning and rules to link cause and effect Has little ability to filter or prioritize information, so synthesis is difficult at best and the big picture is elusive
Advanced beginner	Is able to sort through rules and information to decide what is relevant on the basis of past experience Uses both analytic reasoning and pattern recognition to solve problems Is able to abstract from concrete and specific information to more general aspects of a problem
Competent	Emotional buy-in allows the learner to feel an appropriate level of responsibility More expansive experience tips the balance in reasoning from methodical and analytic to more readily identifiable pattern recognition Sees the big picture Complex or uncommon problems still require reliance on analytic reasoning
Proficient	Breadth of past experience allows one to rely on pattern recognitions such that problem solving seems intuitive Still needs to fall back to methodical and analytic reasoning for managing problems because exhaustive number of permutations and responses have provided less experience on particular problems Is comfortable with evolving situations; able to extrapolate from a known situation to an unknown situation Can live with ambiguity
Expert	Thought, feeling and action aligning into intuitive problem recognitions and intuitive situational responses to problems Is open to notice the unexpected Is clever

7.4 Design ethnography and the Dreyfus and Dreyfus' model of skill acquisition

This section presents a review of literature on design ethnography practice and education through the lens of the Dreyfus and Dreyfus model of skill acquisition and provide an illustrative example for various levels of expertise (Grant and Booth 2009). While the Dreyfus and Dreyfus model has five levels of skill acquisition, I condensed the levels of novice with advanced beginner and proficient with expert to represent three levels of skill development. The descriptions of each of the three levels include results from my work and the broader design ethnography literature, and also include an example developed from my experiences working with students as they progress in expertise.

7.4.1 Novice to advanced beginner level

A novice or advanced beginner design ethnographer focuses on the application of context-free rules, struggles with ambiguity, and is unable to identify the important focus areas in a complex situation. Context-free rules in design ethnography include: sample a diverse set of stakeholders and environments, ask open-ended questions, perform data analysis during and after data collection, verify conclusions drawn from design ethnography through stakeholder feedback, inductively develop conclusions, and identify data saturation to determine when data collection should be concluded (among many others) (Headland, Pike, and Harris 1990; Rosenthal and Capper 2006; Wasson 2000). The use of context-free rules within the social science literature has been highlighted as a foundational step to performing traditional ethnographies, however, this literature also acknowledges that these context-free rules should be adapted to an ethnographers particular domain of study (Keen 1996; Leblanc 1998). Another characteristic of novices is that they struggle to overcome the ambiguity associated with design ethnography use. Design ethnography, and qualitative research methods in general, require one to gather data and deal with inconsistencies and ambiguities (Creswell 2013). It is the task of the design ethnographer to consider all the data in order to identify patterns that could lead to relevant findings. One source of ambiguity within design ethnography implementation is determining who the appropriate stakeholders are as they may not be clearly defined or a combination of stakeholders might be required to fully understand a given context. Novices and beginners also lack perspective; they cannot yet identify the important focus areas within a complex situation (Forsythe 1999). This is a critical aspect of design ethnography as the amount of information being collected during data collection can easily become overwhelming if the designer does not have the ability to filter out inconsequential information.

To illustrate how a novice to advanced beginner might use design ethnography techniques I consider the example of a novice design ethnographer conducting an interview in order to develop requirements and specifications for a product. During the interview, the novice design ethnographer will focus on the use of context-free rules to develop questions. For example, he/she might exclusively use open-ended questions even when a close-ended question might be more appropriate. A novice design ethnographer will struggle to identify the most relevant information provided by the stakeholder and this may cause challenges when the novice attempts to generate relevant follow-up questions. The novice will additionally struggle with the ambiguity generated by interviewing multiple stakeholders who often have differing opinions on a single topic. The novice will struggle to synthesize information from multiple stakeholders if the information gathered does not align.

Through studies of novice design teams, I have observed the behaviors described above when novices employ design ethnography. A study of capstone design teams exemplified novices' reliance on the use of context-free rules during use of design ethnography and their struggles to deviate from these rules when contextual details demanded an adapted strategy (Mohedas, Daly, and Sienko 2014a). Deviating from context-free rules is a major component of using design ethnography and an area in which novices struggle (Salvador, Bell, and Anderson 1999). The results have also demonstrated students' struggles with ambiguity and difficulties when attempting to synthesize and analyze ambiguous data collected during design ethnography (Mohedas, Daly, and Sienko 2014a, 2014b). Studies from other scholars have investigated novice difficulties determining important focus areas when performing design ethnographies. One study found students struggled to differentiate between design relevant information obtained during observations and cultural differences that did not necessarily represent design relevant information (Mohedas, Daly, and Sienko 2014c). Novices similarly discussed challenges associated with the immense amount information that is associated with performing design ethnography and how they find it difficult to determine what is the most important information to focus on, particularly when collecting and analyzing data (Mohedas, Daly, and Sienko 2014a).

7.4.2 Competent level

When a learner reaches the competent level of skill acquisition, their approaches and behaviors become more refined, enabling them to understand the complexity of a given situation and develop appropriate strategies as well as identify important situational details allowing them to refine their focus. Understanding the complexity of a given situation and developing appropriate strategies for dealing with these complexities (e.g., not blindly applying context-free rules and knowing how to navigate some ambiguity) is a primary differentiator of a competent performer. He/she will begin to use their repertoire of prior experience in order to inform decision making and better deal with novel situations that arise. The transition to becoming a competent performer involves the ability to discriminate between important and unimportant situational details associated with a given context. This is a critical transition stage since performing thorough design ethnography requires designers to perform an assessment of the context of use for a product and its stakeholders in order to determine what aspects are most relevant to the design process.

In the example, the competent design ethnographer approaches stakeholder interviews with more experience and the ability to identify and adapt to contextual-information. For example, the competent design ethnographer does not restrict him/herself to a pre-defined list of questions for an interview, but rather adapts the interview protocol based upon the expertise of the stakeholder and the answers provided by the stakeholder. These questions are not strictly guided by context-free rules (e.g., they are not strictly open-ended), but rather vary based upon the designers prior experience. He/she is able to formulate follow-up questions that are relevant and important to the eventual design. The ability to identify important areas of focus by the competent design ethnographer is critical as they determine what the stakeholder's particular area of expertise is and adapt their line of questioning to better suit the particular stakeholder in question. Experience and the ability to adapt allow the competent design ethnographer to perform more effective interviews and gather deeper information from stakeholders (compared with more superficial interviews conducted by novices).

While my previous studies on students have largely elucidated the behaviors of novice design ethnographers, some students have demonstrated behaviors that align with the competent level of Dreyfus and Dreyfus model. For example, during a design task study investigating students' ability to use design ethnography during requirements development, I found that some students combined observations with interviews using the situational details guide the questions they posed. This strategy allowed these particular students to perform more effective interviews with stakeholders, distinguishing themselves from the more novice behaviors of other students (Mohedas, Daly, and Sienko 2015b). These students understood the rich contextual information available during observations and leveraged it to conduct more effective interviews with stakeholders. Previous studies of students using design ethnography have also elucidated the challenges novices face when attempting to improve their skill in using design ethnography. For example, in an academic setting, students face logistical hurdles to gaining experience and frequently lack enough time to effectively employ design ethnography (Mohedas, Daly, and Sienko 2014a, 2014b). Another major hurdle to learning to perform design ethnography is the possible delayed recognition of the importance of certain information and/or stakeholders. For example, a design team might conduct interviews with stakeholders during the problem definition phase of the design process, but not realize that they did not ask the appropriate questions until later in the design process when the information is needed (e.g., engineering specifications development) making it increasingly difficult to learn from errors (Mohedas, Daly, and Sienko 2014a, 2014b).

7.4.3 Proficient to expert level

Once an individual reaches the proficient level of skill acquisition, experience and intuition dominate the execution of a particular skill. Individuals rely on experience to determine which aspects of a situation or problem are most important to focus on, instead of relying alone on context-free or general rules. Practitioners have argued that extensive experience with the qualitative methods of design ethnography is critical to successfully implementing the techniques within a design project, and that novices tend to ignore or circumvent important steps (particularly with respect to data analysis)(Forsythe 1999; Sommerville et al. 1992). Intuition is a central feature of the expert level of skill acquisition. Individuals no longer rely on purely analytical reasoning to solve problems, but use personal experience to inform decision making. For example, during design ethnography interviews, one cannot pre-formulate every question that might lead to meaningful and design relevant responses; follow-up questions, based upon interviewee's responses, are critical to conducting successful interviews and must be generated on short notice and in a fluid manner (Blomberg and Burrell 2003). The expert design ethnographer can draw from a large bank of effective follow-up questions, allowing him/her to perform a deep dive into a given topic and avoid gaining an only superficial understanding of a topic.

In the example, the proficient or expert design ethnographer would conduct a very different interview than the novice. The expert would develop an interview protocol that is particularly suited to the stakeholder being interviewed based upon prior interviews (conducted with a variety of stakeholders) and/or observations of the stakeholder in their natural environment. During the interview, the expert would not hesitate to deviate from the interview protocol in order to pursue a line of questioning that the design ethnographer believes would generate beneficial information for the design process. The design ethnographer would rely largely on his/her prior experience and intuition to determine what the most important line of questioning is and pursue questions that would result in a deep understanding of both the stakeholder and the context of use for the eventual product. The expert also has a strong understanding of how information will be used during subsequent phases of the design process based on substantial prior experience, and can generate more appropriate follow-on questions to elicit the relevant information in single setting interactions.

Intuition and experience are central features of the expert level of skill acquisition. Individuals no longer rely on purely analytical reasoning to solve problems, but use personal experience to inform decision making. Within design ethnography, this is exemplified by the need to generate relevant follow-up questions, based upon interviewee's responses, on short notice and in a fluid manner (Blomberg and Burrell 2003). Design ethnography literature emphasizes that successful design ethnographers must build a repertoire of experience in both data collection and analysis to become experts (Forsythe 1999). There is relatively little literature on how expert practitioners perform design ethnography within industry; future work should focus on this area in order to more fully understand the developmental trajectory of design ethnographers.

7.5 Pedagogical implications

While a four year curriculum may not allow for students to reach in the proficient or expert levels of design ethnography skill, prior studies have shown that a broad range of skills in design ethnography implementation exist among students. In a study of students' use of observations and stakeholder interviews (key components of design ethnography) some students demonstrated more advanced interviewing and observational behavior (interacting with stakeholders as co-designers, rather than simply as customers) (Mohedas, Daly, and Sienko 2015b). Pedagogy and tools need to support novice/advanced beginner design ethnographers during implementation to enable them to progress to higher skill levels where the benefits of design ethnography for students would more closely match those discussed in the literature. Below, I draw on Kolb's theory of learning to describe how design ethnography pedagogy could be constructed to support deep student learning.

Kolb's theory of learning (Figure 7.1) consists of four stages: 1) a learner has a concrete experience, 2) he/she then reflects upon this experience, 3) through reflection, the learner develops abstract concepts enabling him/her to generalize his/her experience, and 4) the learner implements these new abstract concepts to a new experience and begins the cycle again (Kolb 1984). Kolb's theory of learning has been applied to a range of contexts including nursing

(DeCoux 1990), political science education (Brock and Cameron 1999), higher education (Healey and Jenkins 2000), and engineering laboratory education (Mahmoud and Nagy 2009).

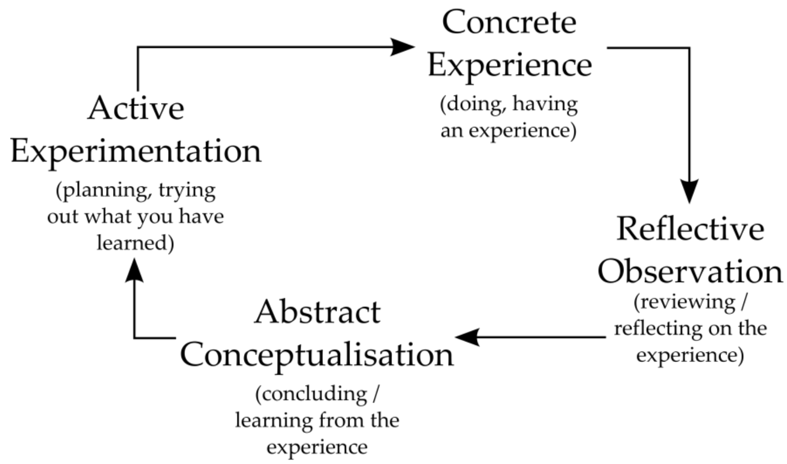

Figure 7.1: Kolb's theory of learning

In typical engineering courses, students complete problem sets and can reflect on each problem set when they receive feedback from an instructor and can then apply their learning to future problem sets or tests (enabling a full cycle as described by Kolb). In contrast, design ethnography is composed of an interwoven series of data collection, analysis, and application experiences. In some cases, data collection might precede application to a design decision by weeks or months. Reflecting upon a data collection experience prior to applying the data to a design decision means that one does not have all the relevant information when developing abstract concepts through reflection. For example, during interviews with a capstone design team developing a surgical tool, the team described how they realized that a size specification obtained from a surgeon during early design phases was highly inaccurate. The team was only able to recognize this after 3D printing their concept solution, several weeks after the interview with the surgeon. To adequately reflect upon the interview, the team would need to recall their interview with sufficient detail and assess what may have caused the inaccurate specification (Mohedas, Daly, and Sienko 2014a). This large gap in time (between experience and reflection) significantly increases the challenge of performing Kolb's learning cycle in a meaningful way. Therefore, to appropriately implement Kolb's theory of learning in the context of design ethnography, instructors need to ensure that students are performing multiple rounds of reflection throughout these extended concrete experiences (e.g., reflecting after collecting data, reflecting after each round of data analysis, and finally reflecting after the data is applied to a design decision).

Developing abstract conceptualizations based upon reflection is how an individual applies prior experience to new situations. During use of design ethnography (particularly during data collection) researchers are encouraged to sample diverse situations and stakeholders to obtain both breadth and depth of knowledge. Students may encounter challenges identifying how experiences with one context/stakeholder can be applied to the next context/stakeholder. Pedagogy must focus on helping student obtain abstract conceptualizations that are helpful during future experiences (e.g., are not overly specific to their immediate, prior experiences). For example, during reflection students might be required to develop a list of question they believe they should have asked a stakeholder (or specific observations they wish they had made); students could then apply these new questions to future interviews and observe the differences in the data they collect. I also believe that this should be enabled by formalizing the process of abstract conceptualization within design courses (e.g., students are required to reflect on experiences and write-up the abstract concepts that they believe are relevant to future use of design ethnography).

7.6 Conclusions

Design ethnography is a complex cognitive skill requiring engineering students to employ skillsets not typically required in engineering coursework. Based on principles of qualitative research, design ethnography requires an extensive level of information processing to be performed prior to obtaining design relevant conclusions. Previous literature has demonstrated that students tend to struggle during implementation of design ethnography and do not typically obtain the benefits documented in studies of expert practitioners. By assessing the results of novice studies through the lens of Dreyfus and Dreyfus model of skill acquisition I have elucidated several potential reasons for this mismatch. Additionally, it was shown that to better support students during learning and implementation of design ethnography, pedagogical tools and teaching methods need to be developed that take into consideration the specific challenges associated with novice use of design ethnography.

The study presented within this chapter represents a synthesis of the findings from Chapters Two through Six in addition to the available literature on the use of design ethnography. This represents the first systematic attempt to understand the novice to expert continuum with respect to design ethnography and begins to help characterize the developmental trajectory of the design ethnography skillset. In doing so, we better understand what aspects of design ethnography are most likely to prevent successful use by novices, what behaviors and traits define each level of design ethnography skill development, and can develop tools and pedagogy to bridge the gap from novice to expert design ethnographer.

7.7 Acknowledgements

This work was supported by the University of Michigan's Rackham Merit Fellows program, the National Science Foundation's Graduate Research Fellowship program, the National Science Foundation's Research Initiation Grants in Engineering Education (RIGEE 1340459), the National Science Foundation's CAREER program (RAPD-0846471), and the University of Michigan Center for Research on Learning and Teaching's Investigating Student Learning Grant.

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Chapter 8 Contributions, implications, and future work

8.1 Situating this work

Design is a central, distinguishing feature of engineering (C. Dym et al. 2005; Simon 1996). A 2011 study by ASME and ASCE found that ‘design’ was the second most common primary job function among practicing mechanical and civil engineers (Engineering Income and Salary Survey Publishing Group 2012). For an engineer to be able to effectively develop a design solution, he or she must be able to deeply understand the problem, the stakeholders, and the context in which the designed artifact will function (Prahalad and Ramaswamy 2004). Design ethnography is a set of tools that, when employed effectively, allows designers to develop this deep understanding of the problem, stakeholders, and context; allowing designers to design more successful products. The emergence of human-centered design processes in both industry and academia, which stress extensive engagement with and understanding of stakeholders during design, reinforce the need to provide the design ethnography skill-set to future engineers. For engineers to be able to employ design ethnography and develop more successful products, however, a better understanding of this methodology and how novices employ it is required. The research within this dissertation sought to address this need by investigating how design ethnography is implemented and how novice designers develop this unique skillset.

As a fully established research branch within mechanical engineering (and engineering more broadly), the study of design processes and effective methodologies for developing designed artifacts is critical to creating innovative solutions to today’s global challenges (Bayazit 2004; Forty 1986). My dissertation research focuses on a unique design approach wherein traditional research techniques from anthropology are used to complement the conventional technology focused design processes often found within engineering. By studying novice development through an inside perspective (e.g., performed by a mechanical engineer within a mechanical engineering department) I was able to understand the development process differently than if the work had been conducted via an outside perspective. Additionally, the exploratory nature of this dissertation work required a mixed methods research approach, making use of rigorous qualitative research techniques to identify emergent themes and generate hypotheses as well as quantitative research techniques to characterize trends in behaviors more broadly and test these hypotheses.

8.2 Objectives

Through my dissertation research I:

I) Determined how and to what effect design ethnography techniques could be applied to the design of medical devices for low-resource settings.

II) Characterized how novice to more informed designers implemented design ethnography techniques (including data collection, synthesis/analysis, and application) throughout design with an emphasis on front-end design phases.

III) Characterized how novice designers collected and synthesized data while developing product requirements and translating requirements to engineering specifications.

IV) Determined the differentiating factors between novice to more informed designers when stakeholder interviews were conducted during front-end design.

V) Developed a model that described the developmental trajectory of novice to more informed practitioners of design ethnography during front-end design phases.

These objectives map to major gaps within the literature, highlighted in Figure 8.1, including the lack of detail with respect to how design ethnography data should (or can) be synthesized, analyzed, and then applied in practice as well as the lack of literature among all aspects of design ethnography across the novice to informed practitioner spectrum. Objective I maps to the gaps within the 'Use in Practice' column of Figure 8.1 while Objectives II through IV map to the 'Novice to Informed' column of the figure. Additionally, Objective V spans the entire 'Novice to Informed' column, providing a synthesis of design ethnography as a whole. Within this dissertation, chapters have also corresponded directly to these objectives. Chapter Two included the case study prompted by Objective I. In Chapters Three and Four I described studies of novices in capstone design to achieve Objective II. Chapters Five and Six included research on novices during a design task to accomplish Objectives III and IV. Chapter Seven summarized these findings to develop the model discussed in Objective V.

Aspects of Ethnography	Social Science Use began during 1920s	Design Use began during 1980s	
		Use in Practice	Novice to Informed
Data Collection	Various methodologies have been developed and used in many studies	Thoroughly described in business & design literature; studied within HCI community	Few studies have looked into this area and few descriptions of skill development process
Synthesis & Analysis	Various methods developed and is considered key to research process	Few methods or detailed descriptions available in literature; formal use is not well-documented	No studies looking specifically at this area with respect to novice development
Application	Applied anthropology is well-established and has increased in use over time	Outcomes of design ethnography are described in general but not in particular	No studies looking specifically at this area with respect to novice development

Dissertation focus

Figure 8.1: Literature gaps within design ethnography

8.3 Summary

8.3.1 Chapter Two Summary

In Chapter Two, I detailed a case study example of how design ethnography could be used in the evaluation of medical devices designed for a low-income country. The purpose of this case study was to 1) contribute a detailed account of the methodology used to carry out design ethnography in the field (to act as a template for designers), and 2) investigate how design ethnography techniques are best deployed in low-resource settings and what affect they have on the designed artifact. In this case study, a prototype (of an assistive device for administration of sub-cutaneous contraceptive implants) was evaluated in Addis Ababa, Ethiopia. This involved engaging with over 50 stakeholders from a broad range of fields including community health extension workers, physicians, nurses, midwives, as well as officials from the Ministry of Health, the Food, Medicine and Healthcare Administration and Control Authority, and the Pharmaceutical Fund and Supply Agency. The use of a design ethnography to evaluate the prototype led to major design changes, including the inclusion of critical latent needs (such as the need for the device to reduce patient fear of the procedure) and the inclusion of needs that were previously identified as not necessary (including the fact that the device must accommodate anesthesia deliver and the device must address cross-contamination in a different manner). Additionally, this case study elucidated the ease with which a designer can make inappropriate assumptions about their stakeholders and how design ethnography can bring these assumptions to light. Through this case study, additional methodological insights were garnered. For example, a coding system structured around the previously determined product requirements dramatically increased the efficiency and ease of performing data analysis. This methodology also forced the data analysis to be conducted in a systematic fashion and prevented key insights from being lost. The case study also elucidated critical obstacles to performing design ethnography such as access to key stakeholders (a major concern in low- and middle-income countries) and the necessity to develop separate interview protocols for diverse stakeholders. This case study provided an extensive level of detail on the process that was used (as opposed to the artifact being designed) following similar approaches taken within the design science literature (Garmer, Ylven, and Karlsson 2004).

8.3.2 Chapter Three Summary

The goal of the study described in Chapter Three was to understand how novice designers employed specific design ethnography techniques (mainly observation and interviewing) during a capstone design course. As the main techniques used by novice designers during the design process, it is critical to understand how they perceive the use of these techniques, how they benefit from their use, and what challenges they face in order to better develop targeted pedagogy. In this study design, three design teams were studied over the course of their capstone design project. Two of these teams had had extensive exposure to design ethnography methods during a two-month summer immersion experience. Data collection consisted of two semi-structured interviews conducted with each design team at the middle and end of the semester. Interviews focused on understanding how design teams made design decisions and the role that observations and interviews specifically had in this process. Using an inductive coding approach, five major themes emerged with respect to student-perceived benefits of and frustrations with using design ethnography. Students-perceived benefits included: 1) gaining information from stakeholders that led directly to making design decisions, and 2) receiving explanations for complicated and technical information quickly and easily from stakeholders. Student-perceived frustrations with using design ethnography techniques included 1) receiving inconsistent information from stakeholders, 2) stakeholders not specifying product requirements directly, and 3) difficulty finding the ‘right’ stakeholder to engage with. When students found design ethnography to be beneficial, they were more likely to reach a fully justified design decisions (typically affirming the information received from stakeholder through literature searches). When students found design ethnography to be frustrating, they were more likely to make only a partially justified design decision. The results of this study point to specific challenges associated with design ethnography that require pedagogical support if students or novice designers are to gain the benefits discussed within design ethnography literature. For example, support structures to help students conduct more effective interviews, recognize the opportunity to engage with stakeholders, synthesize large amounts of or conflicting information, and identify the correct stakeholder or set of stakeholders to inform design decisions.

8.3.3 Chapter Four Summary

The study detailed in Chapter Four was focused on identifying the specific factors that influenced design teams' perceptions of the utility of stakeholder engagement when making design decisions and how the approaches these teams took to stakeholder engagement changed over the course of their design projects. This study expanded upon the findings of the study in Chapter Three, taking a closer look at the specific interactions students had with stakeholders and identifying the positive and negative influences specific factors had on these interactions. To explore this, seven undergraduate design teams were studied over the course of their capstone design semester. Data collection included administration of pre- and post-course surveys, collection of four sets of design review reports, and performing four semi-structured interviews per team. Semi-structured interviews were based on design as a decision making process that requires extensive information processing (from a range of sources). Therefore, questions were focused on how design teams made design decisions and the information (and information sources) used to make these decisions. When stakeholder engagement was mentioned as a specific information source used, extensive follow-up questions were used to develop a deep understanding of how this engagement impacted the decision making process. Data analysis was conducted in two phases; during the first phase, interactions with stakeholders by all teams were pooled together to identify the internal and external factors influencing student-perceived utility of stakeholder interactions; during the second phase, each team was assessed holistically and over the entire semester to determine how the team's approach to stakeholder engagement evolved over time.

This analysis identified five important factors that influenced student perceived utility: goal specificity (referring to the level at which students pre-developed clear and explicit goals for stakeholder interactions), stakeholder expertise (referring to the level of alignment between a stakeholder's expertise and the project topic students were pursuing), information variability (referring to the level of variation in the information students received from stakeholder interactions), information applicability (referring to the level of directness with which design teams could apply the information obtained to a design decision), and decision making responsibility (referring to the level of responsibility design teams would take when engaged in design). When a team's stakeholder interactions had a high level of goal specificity or when the stakeholder's expertise was well-aligned with their project, teams tended to perceive interactions as more useful. However, when information received was highly variable or not directly applicable, teams tended to perceive interactions as less useful. Additionally, teams would transfer the decision making responsibility to the stakeholders during interactions to increase the utility of these interactions. Comparisons between teams on a holistic and semester level identified fundamental differences in what drove students toward or away from stakeholder engagement. For example, teams with rigidly defined projects, strongly opinionated key stakeholders (particularly sponsors), and negative initial interactions with stakeholders tended to minimize they engagement with stakeholders as the semester progressed. In contrast, teams with projects that required further definition, that had multiple and diverse stakeholders, and who had more human-centered design philosophies tended to continue with strong stakeholder engagement throughout the course. These results exemplify the dramatic effect that project definition, type and quantity of stakeholders, and student perceptions can have on the level of stakeholder engagement performed by design teams.

8.3.4 Chapter Five Summary

Having identified information processing as a major challenge to effective stakeholder engagement during design (through the studies described in Chapters Three and Four), I sought to more deeply explore how novice designers use information sources during front-end design and what behaviors differentiate novice from more informed designers through the study described in Chapter Five. To explore these topics, an interactive design task was developed that allowed for the behaviors of novice designers to be closely examined as they conducted front-end design, particularly problem definition, product requirements elicitation, and engineering specification development. Eight senior level design students volunteered for an eight-hour design task where they were asked to develop product requirements and engineering specification for a ‘toy to aid in the cognitive development of young children’. Participants had access to a wide range of information sources and were allowed to manage their own time. Data collected and used as part of the analysis included: the product requirements developed by the participants, stakeholder evaluations of the requirements, overhead video camera footage, computer monitoring data, audio/video recordings of stakeholder interviews, and post-task interview recordings. Data analysis included the development of two metrics related to the quality of product requirements developed (stakeholder validity and the level at which requirements were tailored to the specific context and stakeholders) and two metrics related to information use by participants (number of distinct information sources used and the level of dependence on particular information sources).

The analysis found a strong correlation between stakeholder validity and the number of distinct information sources used (participants who used more diverse information sources produced requirements that received higher stakeholder validity scores). There was also a strong, positive correlation between the number of information sources used and the level of tailoring that participant’s requirements had to the stakeholders and the context of the design task. Finally, there was a strong, negative correlation between participants’ dependence on a particular information source (or sources) and the validity of their requirements (the more dependent a participant was on a small number of information sources, the less valid were their requirements). These results demonstrated the importance of information processing on the development of high quality requirements and also elucidated the significant difference in ability that novice designers (with very similar backgrounds) can have in this area.

8.3.5 Chapter Six Summary

Chapter Six describes a study in which I took a deeper dive into a fundamental aspect of stakeholder engagement, namely interviewing stakeholders during requirements development. Understanding how designers can better interview stakeholders and learn to develop this skill is critical to promoting more competent designers. Requirements development is a critical aspect of front-end design and interviews are one of the main ways in which requirements are elicited and developed. Specifically, this study sought to 1) develop a system, based on best practices found within the literature, that could assess the quality of a stakeholder interview, 2) identify the best practices that differentiate novice from more informed designers during interviews, and 3) determine whether designers who perform higher quality interviews also gain more relevant information for requirements development. To accomplish these objectives, the data from the interactive design task (discussed in Chapter Five) was used, specifically the audio/video recordings and transcripts of the stakeholder interviews participants conducted. Data analysis consisted of the development of a coding system based on best practices found within the literature for performing stakeholder interviews during design. The coding system consisted of twelve best practices that were assessed (by coders) for each question asked by participants (i.e., was the best practice present or absent). The results were then used to develop a generalized linear model that helped to 1) differentiate between the participants with respect to interview quality, and 2) control for variables such as interviewee, interview number, and question number. Additionally, a metric was developed to assess the impact of interviews on the product requirements developed. This metric was then related to the results of the generalized linear model (i.e., the quality of the participant's interviews) finding that participants who performed higher quality interviews elicited information more directly applicable to the requirements they developed.

8.3.6 Chapter Seven Summary

Based on the collection of my studies, including those described in this dissertation and additional work not presented, as well as design theory and literature, I proposed a model for how designers progress from novice to informed to expert design ethnographers in Chapter Seven. The goal of this work was to understand the continuum (from novice to expert) of expertise with respect to design ethnography 1) using a theoretical foundation based on a validated skill development model, 2) incorporating academic literature on expert practice, and 3) synthesizing the results of the novice studies described in Chapters Three through Six. In this chapter I proposed the Dreyfus and Dreyfus model of skill acquisition as a representative model for how one learns and develops design ethnography skills. Examples of novice behavior found in my previous work, as defined by the Dreyfus and Dreyfus model, include rule driven behavior (such as focusing on asking open-ended questions or verifying conclusions drawn from stakeholder interactions) and difficulty filtering data from the environment (such as challenges dealing with ambiguity in data gathered or the challenge of being overwhelmed with data during immersive design ethnographies). As we look at the competent level of the Dreyfus and Dreyfus model, we continue to see parallels to design ethnography. A competent performer begins to be able to deal with ambiguity as I saw in some studies of students who were able to synthesize multiple information sources to make design decisions. Additionally, competent performers learn to discriminate between important and unimportant information; a critical skill when conducting immersive design ethnographies where the designer might be overwhelmed with potentially valuable information. Finally, at the expert level of the Dreyfus and Dreyfus model, emphasis is placed on extensive experience, where experience and intuition dominate execution of a skill. This is particularly relevant in design ethnography, where the ability to generate relevant and effective follow-up questions and pursue deeper information when presented with the opportunity must occur quickly and effectively.

8.4 Contributions & implications

My graduate research, as represented in this dissertation, contributes to the advancement of a foundational understanding of how design ethnography is implemented and how novices develop and implement the unique skillset required of design ethnography. This foundation provides evidence for the formulation of targeted design tools and pedagogy for both student and practicing engineering designers. Below I outline the contributions made to mechanical engineering design, design science, design ethnography practice, design ethnography education, human-centered design education, design education research methods, among other areas.

Through the case study research, I investigated how design ethnography can be used in the design of medical devices for low- and middle-income countries. The case study in and of itself can serve as a template for designers who are beginning to learn the process of using design ethnography as part of a product development process. Furthermore, this case study exemplified the benefit of approaching data analysis during design ethnography systematically and proposed structures for the analysis. For example, such product requirements / specifications documentation can be used to systematically code data gathered during design ethnography or, during earlier design phases, Garvin's eight dimensions of quality could form a preliminary coding system. This would be particularly helpful to novices who struggle with the ambiguous nature of design ethnography data analysis. Demonstrating the benefits of design ethnography within a novel context (medical devices for low-resource settings) provides further evidence that this technique should not be simply associated with the fields of human-computer interaction or computer supported cooperative work, but should be more broadly applied to product and engineering design.

Design ethnography is used by novice designers mainly during the front-end phases of design (e.g., problem definition and requirements elicitation). Of the design ethnography techniques available to them, novices tend to focus their energies on performing stakeholder interviews and heavily prefer engaging with experts (over end-users or peripheral stakeholders). This reliance on experts may stem from the availability of experts (perhaps due to the diverse expertise available on the University of Michigan campus), the ease of communication with experts, the efficiency when gathering information from experts, and the confidence in the information gathered. This implies that to broaden novice use of design ethnography, they must be actively pushed to engage with non-expert stakeholders, such as end-users, to prevent them from focusing their energy on the easiest form of stakeholder engagement. Additionally, through the assessment of novices' use of stakeholder engagement, I found that interactions were largely used in a superficial manner as opposed to using stakeholder engagement to develop a deeper understanding of the problem/solution. Novices might be engaged only at this surface level due to the frustrations they face when attempting to use stakeholder interaction more thoroughly. For example, novices were frustrated when receiving inconsistent information or incomplete product requirements, and were also frustrated when the 'right' stakeholder could not be found. An analysis of these frustrations, however, shows that many can be linked to the challenges of planning an interview, implementing an interview, and using the information gathered during an interview. An implication, therefore, would be to provide novices with a foundational education on interacting with stakeholders during design. Despite challenges faced, many novices did recognize the benefits of stakeholder engagement during design and, as a design project progresses, they began to recognize that stakeholder interaction can sometimes represent the largest obstacle during design, as opposed to technical challenges encountered. This demonstrates, however, that while their understanding of design ethnography techniques might become more refined over the course of a project-based course, their ability to execute and obtain useful information does not necessarily improve.

The studies of novice engagement with stakeholders during capstone design also revealed some pedagogical strategies that could be implemented to increase students' efficacy when interacting with stakeholders. For example, students felt interactions were more useful when they had previously defined a specific goal for the interaction. Design instructors, therefore, could introduce design students to design ethnography and stakeholder engagement by first having them consider the major goals they are hoping to achieve during a stakeholder interview and tailor their interview protocols to match these explicit goals. As students designers gain experience conducting design interviews they will be able to take a more flexible and opportunistic approach wherein they pursue lines of inquiry that are not necessarily in line with their original goals, but which might lead to design relevant information.

Additionally, novices found interactions with stakeholders to be less useful when they were faced with information processing challenges, particularly dealing with variable information and applying information that is tangential to the design decision at hand. Developing information processing skills, however, is critical to obtaining the most benefit from stakeholder engagement and design ethnography because a deep understanding of the design problem comes from synthesizing the opinions and beliefs of a broad group of stakeholders and understanding the complexities of satisfying diverse preferences. These results point to the need for information processing structures to support designers in organizing the collected data, recognizing where variation exists, navigating those differences to determine a next step and eventually, to make informed design decision. Formal structures for information processing could take the form of qualitative data analysis software (e.g., Atlas.TI, NVivo, etc.), pedagogy in the use of both deductive (e.g., a priori coding schemes) and inductive (e.g., thematic analysis) analysis approaches, and decision making procedures where information gathered and source documentation is integrated into design processes. By introducing formal data analysis software, novice engineering designers would recognize that qualitative data analysis can (and should) be just as rigorous as quantitative data analysis; this would also help to overcome the common perception within engineering that qualitative methods are less effective than quantitative methods (Borrego 2007). Furthermore, this type of software allows design teams to continually add information over the course of a design project, emphasizing the process of synthesizing old information with new information, resolving conflicts between information sources, and allowing information retrieval from early design phases during later phases. I also believe that formal instruction in deductive and inductive analysis approaches must be incorporated into design courses that hope to emphasize human-centered processes, design ethnography, and stakeholder engagement. Deductive analysis strategies during initial design phases might be based on Garvin's eight dimensions of quality and the use of product requirements and specifications could form the analysis structure during later design phases. Inductive analysis is a more challenging process and could be introduced in a scaffolded manner during design courses. For example, any data not covered by Garvin's eight dimensions of quality (based on an initial deductive analysis) could form the data set for an inductive analysis. This would serve two purposes, 1) it would reduce the total data the students would need to deal with during their inductive analysis, and 2) it would eliminate the most obvious themes already covered by Garvin's eight dimensions.

In addition to the development of a design ethnography synthesis structures, novices would benefit from explicit instruction discussion on the nature of design ethnography data. Discussions in design courses could include that 1) information gathering during open-ended design will naturally lead to variable and sometimes conflicting information, 2) it is within the designer's scope of responsibility to synthesize this information and make design decisions, and 3) information retrieved during early design phases should not be discounted (even if not directly applicable) as it may become necessary or integral during later design phases. Discussing these challenges right up front can prepare students for what they will face and thus, they can seek strategies to support them as they engaged in these endeavors.

My work has also provided insight into how design projects (within an academic setting) might be formulated to better encourage human-centered design processes and increase stakeholder engagement by design teams. First, design projects with easily accessible and clearly defined stakeholders tended to lead to design teams conducting more stakeholder engagement during the semester. Design team's that had difficulties defining or accessing stakeholders quickly fell back on more traditional information sources such as academic literature or benchmarking, avoiding the greater challenges associated with gathering information from stakeholders or observations. Team's that began with at least some clear and accessible stakeholders were more likely to perform this first interaction and positive initial interactions lead to more sustained stakeholder engagement during courses. As design students progress, instructors can then introduce the process of identifying peripheral stakeholders that may be non-obvious to students and encourage the collection of a broader range of perspectives during design. Second, design projects with multiple primary, distinct stakeholders resulted in students conducting more stakeholder engagement during the semester. If a design project consisted of just one type of stakeholder (e.g., a sponsor or the same kind of end-user), students did not readily see the value in engaging with a broad set of stakeholders. The existence of multiple key stakeholders forced students to perform an initial diverse set of interactions during which they had the opportunity to recognize the importance of incorporating multiple perspectives. By requiring design teams to conduct this initial set of interactions, students are more likely to see the value in human-centered design processes and engage with stakeholder later in the design process.

A second implication for design course structures is that students should have the opportunity to work on design projects that are ill-defined. This will provide students with a more authentic experience, but will also give them the opportunity to perform a context assessment, refine the design project scope, or, redefine the design problem. These phases, in turn, require extensive stakeholder engagement and, therefore, lead to design teams using more human-centered design processes. Additionally, this would also prompt teams to collection observational data and obtain deeper stakeholder engagement.

A final important consideration in design course structures is consideration of the role of the sponsor in a design project. It is the sponsors who, in some design courses, provide expertise and funding for design projects. Within the sample of design teams, sponsor behavior and perceptions had a major effect on whether design teams pursued a more human-centered design process with extensive stakeholder engagement. Projects whose sponsors had strong opinions or previously defined ideas about the final design concept caused design teams to over rely on the sponsors for information and decision making; in these cases, the design teams did not readily consult other stakeholders, thereby yielding a more technology-centric design process. To have design teams engage with stakeholder more broadly the project sponsors will need to recognize the importance of human-centered design, encourage design teams to engage with other stakeholders, and resist the temptation to overly define the design project.

My research, through the interactive design task, was able to uncover specific novice designer behaviors with respect to information processing and the effect of these behaviors on the final quality of requirements. The results add experimental validity to recommendations in engineering design texts to utilize diverse information sources and to avoid reliance on specific information sources by showing a correlation to an increase in the validity of requirements and the capacity of requirements to address context-specific needs. Additionally, I observed specific behaviors that differentiated high-performing from low-performing designers with respect to information processing. For example, an iterative approach to requirements development was used by higher-performing designers, wherein product requirements and specifications were documented early and changed over the course of the design process. The fact that I saw this behavior only in the higher performing participants implies that students were differentially obtaining this advanced strategy within courses and/or extra-curricular activities. More effort, therefore must be made to reinforce the importance of an iterative design strategy at all phases, including during information gathering and to make this iterative process obvious to design students. Within design courses, for example, this could take the form of requiring design students to validate product requirement through the use of multiple information sources and to require the addition of unique information sources between each design report. As teams collect multiple perspectives from diverse information sources to satisfy course requirements, they will become aware of the truly iterative process of information gathering and front-end design, thereby reinforcing this crucial aspect to students.

My work also contributes to understanding the best practices associated with conducting stakeholder interviews during the design process, particularly during requirements elicitation. Through a systematic literature review of research and case studies involving stakeholder interviews during design, a coding system of best practices for stakeholder interviews was developed. This coding system brought together the best practices from a diverse array of design contexts including automotive systems design, medical device development, human-computer interaction, consumer product design and broad design processes including participatory design, design ethnography, contextual design, lead user approach, among others. In doing so, it appears to be the first thorough, systematic literature review of this topic that has spanned the entire array of fields in which stakeholder interviews are critical. The research study demonstrated that the best practices coding system differentiates between high- and low-performing designers during requirements elicitation, and the high interrater reliability indicates that the coding system can be used by design instructors to differentiate between novice design interview quality.

The coding system, therefore, could be used by: 1) novice designers, to help develop and evaluate the interview protocols they create, 2) design instructors, to provide tangible feedback for students conducting stakeholder interviews as part of a course, 3) students, as a tool for peer-to-peer feedback within design courses, and 4) designers, as a tool for self-evaluation. Furthermore, because the study was able to identify the key practices that best differentiated between the low- and high-performing novices, design instructors could use the results of the study (e.g., the differentiating best practices) as a simplified method for identifying high- and low-performing students. Students performing low-quality interviews, having been identified via the coding system, could then receive supplemental instruction to close the gap in skill with the higher-performing students. Furthermore, design instructors who assess that their students have grasped the most prevalent best practices could begin to emphasize the lesser used best practices such as: using projective questioning techniques, using a co-creative interview strategy, and introducing domain knowledge. This approach provides a scaffolded methodology of introducing novice designers to the best practices that high quality stakeholder interviews consist of.

As a result of the research conducted on novice to more-informed design ethnography use, and the insights gained from the case study conducted and extensive literature reviewed in the areas of design ethnography and stakeholder engagement, this work has led to a detailed understanding of the novice to expert spectrum of design ethnography skill acquisition. This model, based on the Dreyfus and Dreyfus model of skill acquisition, allows one to not only understand the various levels of skill development with regards to design ethnography, but also anticipate the kinds of issues novices might encounter as they attempt to improve their level of design ethnography skill. This, in turn, allows design instructors to anticipate student needs and develop pedagogy that directly addresses the challenges students will face and allow them to gain more utility from employing design ethnography. For example, at the novice level of design ethnography skill acquisition designers should be provided with context-free rules that they can follow and use tools to more easily filter and interpret data. For this, design instructors could provide the best practices identified in Chapter Six as context-free rules for developing stakeholder interview protocols. Novice designers could review the questions they develop through this framework and edit their questions accordingly, enabling them to grow confidence with respect to interview protocols. At this stage, novices will struggle with the ambiguity and the amount of data collected during design ethnography use. Therefore, methods that break down this large data set into more manageable pieces are required. For example, using Garvin's eight dimensions of quality as an initial analysis system would separate data collected into eight distinct groups. Novices would then perform inductive coding within these groups, a more manageable task due to the reduction in data size of the individual groups. When a designer begins to reach the competent level of design ethnography skill acquisition, they will be better prepared for the more challenging aspects of design ethnography. Competent design ethnographers are able to understand the complexity of a given situation and develop appropriate strategies for the context as well as filter information to better focus on the most critical data. Additionally, instructors should begin to focus on the slightly more difficult to apply, but still critical, interview best practices such as using projective questioning techniques, using a co-creative interview strategy, and introducing domain knowledge. Furthermore, as designers reach this level, the Dreyfus and Dreyfus model of skill acquisition tells us that designers will be able to more successfully employ design ethnography because they are able to filter out superfluous information and focus on what is most critical. The skills and strategies described by the Dreyfus and Dreyfus model of skill acquisition for a competent performer coincide with the requirements necessary for effective design ethnography implementation found within the literature. One would therefore expect designers at this skill level to reap more benefits from design ethnography use and experience fewer frustrations than what I observed in the studies of student use of these techniques.

The studies within this dissertation involving novice designers' use of design ethnography techniques have also elucidated key findings that must be considered when developing pedagogy for this unique skillset. There is often a delay between performing a skill associated with design ethnography (e.g., conducting an interview or performing observations) and obtaining feedback with respect to the success of its use. For example, during initial requirements elicitation, a designer might obtain a certain requirement or specification from a stakeholder they believe to be accurate. However, it is often the case that design teams cannot accurately assess these requirements until an initial prototype is developed. Once the prototype is developed, the team will know the requirement or specification was incorrect, but too much time will have passed for them to be able to accurately identify what went wrong during their stakeholder interview leading to the erroneous requirement. This creates an extended feedback loop, making it more difficult for students to trace back their errors. Thus, one implication is to provide students with tools that allow them to evaluate their performance in real-time and minimize the reliance on downstream design phases for obtaining feedback. Additionally, if students were to implement more structured data collection and analysis frameworks (such as using qualitative data analysis software), they would be better able to pinpoint which interactions or information sources led to particularly erroneous or particularly beneficial data.

8.5 Pedagogical structures and design tools

When one considers the results of the research presented in this dissertation as a whole, it provides evidence to support the generation of specific pedagogical structures and design tools to be incorporated into engineering design curricula and used by novice designers p. Below I detail three pedagogical tools and support structures that would help students move from novice to more informed design ethnographers and/or allow them to gain more utility from the use of design ethnography techniques as novices.

A major challenge when teaching stakeholder interaction in the classroom setting is the difficulty in developing “real-life” situations that can be used to explain important concepts and strategies. In work associated with this dissertation, students commented on the noticeable discrepancy between how stakeholder interaction was presented to them in the classroom (e.g., how stakeholder interaction theoretically might occur) and how it was experienced in the field. Students encountered challenges in the field that were not encountered in the classroom setting, and the information they gathered from users and stakeholders was more ambiguous and more challenging to interpret. Therefore, the first pedagogical structure I would recommend would be a series of videos that demonstrate examples of stakeholder interviews and how they impact specific design decisions and the overall design process. Videos could be generated by hiring actors to play the parts of interviewers/designers as well as stakeholders, and should represent situations that occur in the field. Videos would demonstrate best practices during interviews as well as ineffective techniques often employed by novices. The series of videos would support classroom-based instruction as well as asynchronous study by students pursuing co-curricular design work. Design instructors could then lead a discussion during class based on the students’ offline analyses. The class would collectively generate ideas for how the interview could be improved. In doing so, students will learn to treat interviewing stakeholders as a critical design activity and one that requires practice and reflection in order to improve.

Performing effective interviews was found to be a major barrier to design ethnography implementation within this dissertation. Additionally, a significant challenge to scaling educational pedagogies in this area is the individualized attention required by students and design teams to provide relevant real-time and/or semi- real-time feedback regarding the quality of their interactions with stakeholders. To address this, I propose an interactive interviewing software program that will support simulated stakeholder interviews while providing real-time feedback. The software should present students with a front-end design task to which they can relate, but are not so familiar with that they might have domain specific knowledge about the design task (e.g., similar to the task used during Chapters Five and Six). Students could then be given a list of resources to use including observational videos and virtual access to stakeholders whom they could interview. The students will select the stakeholder(s) they want to interview and determine questions to pose to the stakeholder(s) from a built-in repository of questions. Students will be prompted to pose a question in their own words in an open text box. The software would use a fuzzy string-matching algorithm to determine which questions in the repository most closely match the question posed by the student. The student would then select from a limited set of the most relevant questions. Pre-recorded responses to each question would be presented and students can take notes on what they heard and develop an appropriate follow-on question. Responses from stakeholders would be designed to push students to dive deeper into the most relevant topics, prompt follow-up questions by giving vague responses, and require them to be attentive listeners by providing certain highly relevant pieces of information mixed into long answers. After each stakeholder response, the student will have the opportunity to ask follow-on questions (using the same matching algorithm) and investigate topics further. After three to five sets of questions, the student will then have the chance to obtain feedback on the questions they selected. At the completion of the interview, the student would be guided through an analysis by the software program of their interview as a whole to determine: 1) areas where they could have probed deeper on a specific topic, 2) topics that they did not cover that would have been relevant to the stakeholder, 3) information overlooked from responses that would have guided the interview in a different direction, and 4) questions that could have been framed in a different manner to reduce their bias. This software content would be directly based on the results of this dissertation such as the interviewing best practices elucidated, the ineffective novice behaviors observed in capstone design, specific challenges novices face as shown in the Dreyfus and Dreyfus model, amongst other results. This pedagogical structure would provide critical real-time feedback for students and allow them to gradually improve their ability to conduct stakeholder interviews.

The last tool that I recommend be developed as a result of this dissertation research is a self-evaluation guide to support students as they interact with stakeholders. The need for this tool is grounded both in foundational, empirically-based learning practices and in the results of the studies of undergraduate capstone design students in Chapters Three and Four. Pedagogical research studies highlight the value in reflection and self-assessment when developing complex skills such as stakeholder interaction (Bransford, Brown, and Cocking 2004; National Research Council 1999). The work in this dissertation revealed that students struggled to assess their stakeholder interactions and the information obtained from these interactions. This occurs because stakeholder interaction during design is an interwoven series of data collection, analysis, and application phases. In some cases, data collection might precede application to a design decision by weeks or months. Reflecting upon a data collection experience prior to applying the data to a design decision means that one does not have all the relevant information when developing abstract concepts through reflection. Students would benefit from a more guided approach that allows them to assess their performance during stakeholder interviews at various stages of the design process. The best practices for stakeholder interactions that were synthesized in Chapter Six should inform the self-assessment rubric. In order to develop a practical guide, one should aim to identify and include only the best practices that are most likely to support undergraduate student development from novice to competent/proficient practitioners. Using a guiding rubric, students will be able to reflect after each interaction, allowing them to better understand at each step how they might better engage with stakeholders and provide more value to their design process.

8.6 Limitations

The work presented within this dissertation was largely based on the study of student designers using design ethnography techniques within an academic setting. As such, there are key limitations that must be considered when applying the knowledge gained and lessons learned through this work to unique and diverse contexts. The major limitations include 1) lack of comparable study of expert design ethnographers, 2) no longitudinal data aimed at understanding novice to expert skill development, and 3) sample sizes that limit broad generalization.

Within these studies, I have observed behaviors that range from novice use of design ethnography through advanced beginner levels according to the Dreyfus and Dreyfus model. Additionally, I have seen some evidence that certain students reach the competent level of the Dreyfus and Dreyfus model with respect to some aspects of design ethnography. Within my own work, I have not seen behavior that could be classified as “proficient” or “expert”. This leaves a large proportion of the novice to expert continuum unstudied and, furthermore, does not allow one to compare the findings within this dissertation to the behaviors and strategies used by expert practitioners (most likely to be found within industry design settings). Expert practitioner studies would clarify what design ethnography behaviors and strategies students should eventually be aiming for and better define the developmental trajectory.

Another limitation that must be considered to this body of work is the lack of multi-year longitudinal data, tracking designers as they develop from novices to more expert design ethnographers. The data collected within this work spanned the novice to competent spectrum of design ethnography skill, but was not collected from students that progressed along this path, but rather students who were currently at that level of expertise. No one (or one set of) team(s) was followed for an extended period of time, which would allow for a better understanding of the transition from one level to the next. Future work, starting with novices (perhaps freshman) and following these students for an extensive period of time (throughout undergraduate and into their careers) would allow one to gain a better sense of the developmental trajectory of this skill set.

A last limitation to this body of work is the small sample sizes. As a new field of study, understanding engineering designers' use of design ethnography necessitated the use of qualitative research methods in order to form a strong foundational understanding of how the techniques are employed. These small sample sizes, however, reduce the generalizability of the findings. The goal, therefore, was to focus on the transferability of the findings by providing the requisite level of detail so that others might be able to judge whether the results are applicable to their own contexts. As a first step towards understanding design ethnography use, gathering a deep level of detail was the most appropriate research path. Others can build off of this work to move toward more broad generalizations.

8.7 Future work

My work focused on the use of design ethnography within a novel context (medical devices for LMICs) and the use of design ethnography techniques by novice designers. In doing so, a significant amount of information on the development of design ethnography as a skill set has been uncovered with significant implications for design education. Future work, however, should focus on understanding how expert practitioners employ design ethnography techniques and implementing/evaluating pedagogy and design support structures suggested by the results of the work in this dissertation.

Future work on expert use of design ethnography should span three broad categories, 1) macro-level design ethnography practices within industry, 2) design ethnography strategies and behaviors of expert practitioners, and 3) development of expertise by design ethnographers within industry.

The first area I would recommend future study is in the wide scale use of design ethnography within industry. While popular media articles and a small subset of academic literature has clearly shown that design ethnography techniques are in use at major firms (e.g., Microsoft, Xerox, Intel, Ideo, etc.) it is less clear, what types of design ethnography activities these firms actually engage in. Is the use of design ethnography systematic and founded on the principles brought over from anthropology (e.g., the use of design ethnography by Lucy Suchman at Xerox) or is design ethnography more typically distilled down to its bare essentials and implemented in a 'quick and dirty' fashion in order to minimally achieve design objectives (e.g., more in line with the approaches featured at Ideo). Determining what forms of design ethnography are used within industry, in what contexts different design ethnography forms are utilized, and how prevalent any of these forms are is critical to understanding expert level practitioners and developing tools and pedagogy to prepare future designers. This analysis would lead to a more thorough understanding of how design ethnography techniques are used in real-world product design and would help determine what the most important research areas are moving forward.

The second research area I would recommend is in understanding the strategies and behaviors of expert practitioners. As we learn more about the wide scale use of design ethnography within industry, it is also crucial to identify how design ethnography use by practitioners within industry differs from novice use within academia. This would require research into the specific behaviors of expert practitioners use within industry. Determining the typical background of design ethnographers within industry, how practitioners characterize their work in the design field, what the goals of their design ethnography use typically are and how the goals are defined, what phases in the design process design ethnography is typically employed, what forms of data collection methods are used (how they are chosen), what preparation is involved, how is information collected and documented, who is involved in data collection, what data analysis strategies are employed (formal, informal, structured, unstructured, etc.), when is data analysis performed (during data collection, after data collection, iteratively), what conclusions are typically generated from the work, what impact does it have on the product design, etc. Answering the above questions would allow us to form a holistic understanding of design ethnography practice in industry and allow for direct comparison to the prior research of novice use of design ethnography discussed in this dissertation. This would, in turn, allow us to better understand the gap between novice and expert practices and develop pedagogy and tools targeted to closing this gap.

The third area of future work within design ethnography expert practice is in better understanding the methods by which practitioners develop this skillset within industry. Determining whether early stage practitioners within industry learn mainly via experience, are provided support structures, or learn through workshops (or some combination of the above) is important to developing pedagogy within academia that compliments industry practices.

The second major area of future work that I would recommend is in implementing and evaluating the pedagogical strategies and design ethnography support structures suggested by the work in this dissertation and detailed in Section 8.5. Evaluating the stakeholder interview videos, the real-time interviewing feedback software, and the self-evaluation rubric is critical to improving design ethnography education and better preparing engineering graduates pursuing a career in design. Evaluation of these tools and structures could be performed using the research methods detailed in Chapters Five and Six, using an interactive design task to assess how effectively design students can engage with stakeholders and apply the information obtained to front-end design decisions. Assessing students before and after they engage in the design tools and pedagogical structures detailed in Section 8.5 would provide a clear understanding of how they affect designer ability. Furthermore, one could use the Dreyfus and Dreyfus model of skill acquisition to better understand precisely where in the spectrum a skill development a designer is (and whether or not they significantly increased in level as a result of the intervention).

8.8 References

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Appendix A

Below is the pre-selection questionnaire participants completed during recruitment.

First Name:	Last Name:
Email:	Major/Minor:
Semester when ME450 (capstone design) was taken:	Current Year of Study:
List all courses you have taken during your undergraduate career that have had a design component/project. Instructions: Give the name (e.g., ME450), the year and semester you took the course (e.g., Fall 2013), and a one sentence description of the design component.	
List all co-curricular and extracurricular activities you have participated in during your undergraduate career that have had a design component/project. Instructions: give the activity name (e.g., XYZ), the time span you participated in the activity (e.g., Fall 2013 – Summer 2013 or Winter 2012 – present), and a one sentence description of the design component.	
List all internships, work experience, or research projects during your undergraduate career that have had a design component/project. Instructions: Give the experience name (e.g., internship with XYZ), the time span you participated in the activity (e.g., Fall 2013 – Summer 2013 or Winter 2012 – present), and a one sentence description of the design component.	
Based on all the design experiences above how much experience do you have with the following design tools, methodologies, or information sources (four options available: no, little, some, and substantial experience):	

	Experience					Experience			
Design tool, method, or information source	No	Little	Some	Substantial	Design tool, method, or information source	No	Little	Some	Substantial
3D Printing					Focus Groups				
6-3-5 Method					Usability Tests				
C-Sketch					Gantt Chart				
Benchmarking					Pugh Chart				
Sketching					Market Analysis				
Brainstorming					Design Heuristics				
CAD Programs					Patent Search				
Cost/Benefit Analysis					Life Cycle Analysis				
QFD					Functional Decomposition				
Design of Experiments					Reverse Engineering				
Black Box Diagrams					Modeling and/or Simulation				
End-User Observations					Surveys of Stakeholders				
Academic Literature					Finite Element Analysis				
User Requirement Elicitation					Engineering Specification Development				

Appendix B

User Requirement Template and Instructions:

Instructions: Below is the template used by your company to organize the user requirements developed for all the toys they produce. Fill out the sections using the following format.
Column 1: Priority Level: you must rank the user requirements in order of most important (ranked as 1) to least important. User requirements with the same level of importance may have the same priority level designation.
Column 2: User Requirement: provide a clear description of the user requirement that you have developed.
Column 3: Justification: in the form of full sentences explain why the user requirement was included.
Column 4: User Requirement Information Sources: list the information source(s) that contributed to the user requirement developed.

Priority Level	User Requirement	Justification	User Requirement Information Sources
**Add as many rows as needed			

Engineering Specification Template and Instructions:

Instructions: Below is the template used by your company to organize the engineering specifications developed for all the toys they produce. Fill out the sections using the following format.
Column 1: User Requirement: state the user requirement for which the engineering specification was developed.
Column 2: Engineering Specification(s): state the engineering specification(s) that was developed, multiple engineering specifications can be used for a single requirement if needed.
Column 3: Justification: indicate why this engineering specification is needed to satisfy the user requirement.
Column 4: Engineering Specification Information Sources: indicate what information was used to develop the specification, provide as much detail as possible so that future design engineers would know exactly what information went into the engineering specification.
**Add as many rows as needed

User Requirement	Engineering Specification	Justification	Engineering Specification Information Sources
**Add as many rows as needed			