Pre-Design Empiricism for Information Visualization: Scenarios, Methods, and Challenges

Matthew Brehmer
University of British Columbia
Vancouver, BC, Canada
brehmer@cs.ubc.ca

Sheelagh Carpendale
University of Calgary
Calgary, AB, Canada
sheelagh@ucalgary.ca

Bongshin Lee
Microsoft Research
Redmond, WA, USA
bongshin@microsoft.com

Melanie Tory
University of Victoria
Victoria, BC, Canada
mtory@uvic.ca

ABSTRACT
Empirical study can inform visualization design, both directly and indirectly. Pre-design empirical methods can be used to characterize work practices and their associated problems in a specific domain, directly motivating design choices during the subsequent development of a specific application or technique. They can also be used to understand how individuals, existing tools, data, and contextual factors interact, indirectly informing later research in our community. Contexts for empirical study vary and practitioners should carefully consider finding the most appropriate methods for any given situation. This paper discusses some of the challenges associated with conducting pre-design studies by way of four illustrative scenarios, highlighting the methods as well as the challenges unique to the visualization domain. We encourage researchers and practitioners to conduct more pre-design empirical studies and describe in greater detail their use of empirical methods for informing design.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces–*Evaluation/Methodology*.

Keywords
Empirical research, applied visualization design.

1. INTRODUCTION
By its very nature, any situation that will benefit from visualization is complex. There is a growing awareness that, to approach an understanding of complex situations, at least some of the research must consider the system as a whole. This includes analysis of individuals' work practices: their tasks, strategies, and activities, their interactions with other individuals, and their use of artifacts in their environment. However, it is hardly straightforward to study highly personal contexts such as individuals' homes, or sensitive professional contexts such as hospital wards or industrial control rooms. Thus if we want to design and develop a visualization system for situations like these, many of the common types of empirical methods in which one selects and closely examines the situation are not sufficient. We need to identify, adapt, and develop new methods for these needs. In this paper, we invite researchers and designers to consider the benefits and challenges associated with applying empirical methods as a means of informing visualization design.

BELIV '14, November 10, 2014, Paris, France.

http://dx.doi.org/10.1145/2669557.2669564

What do we mean by *empirical methods*? For some, this term may bring to mind methods for observing human behaviour in controlled laboratory settings. However, we are referring to a larger palette of methods, including observational field studies, interviews, and contextual inquiries [18]. Many different methods have been used to better understand the work practices of current or prospective stakeholders of visualization applications [17], and yet few papers appearing in visualization venues report upon how these methods are used early in the design process, or how they have been modified in the face of challenges unique to visualization design. Use of these methods can result in rich descriptions of individuals' activities or work practices, directly informing design in the case of visualization design studies, or indirectly informing design by providing a detailed analysis of certain aspects of behaviour, such as how co-located teams collaborate around a shared surface [14], or how individuals use visualization in personal contexts [29]. Only a small number of papers published in our domain offer a rich description of individuals' work practices as a primary contribution [22]. We argue that there is a need for more of this work in our community, and for a more detailed reporting of methods.

Our interest in methodological details reflects the unique challenges associated with applied visualization design and confronted when conducting empirical work. These challenges relate to exploratory pre-design work, which often involves specific populations, sensitive or private data, and sensitive or private environments. We encapsulate these challenges below in four example scenarios drawn from our previous and ongoing work. Specifically, our scenarios discuss the study of personal data practices, professional environments, remote and decentralized experts, and new interactions and experiences.

2. THE BENEFITS OF EMPIRICAL WORK
Conducting empirical research at early stages of design increases the likelihood that the resulting visualization tool or technique will be appropriate for the dynamics of its target audience and its unique contexts of use. With access to these contexts, we can shed more light on individuals' objectives and constraints impacting their activities and software needs. While individuals may not be able to verbalize or articulate their work practices and activities, we can nevertheless observe their nuanced behaviour, reflecting upon relevant theories and building upon what is already known. Furthermore, pre-design empirical research can complement empirical research at later stages of design and evaluation, by providing a baseline to compare against.

It is still unusual to place emphasis on empirical study at early stages of the design process, as this approach is still in its infancy. The vast majority of empirical studies have been conducted after the system is built [17,24]. However, indications are that a pre-design empirical approach may be key. For example, Munzner

advocates the acceptance of more papers characterizing the tasks and data in the vocabulary of the problem domain [22]. The tasks and data need to be grounded by empirical data collected while engaging the target population. Buxton has also pointed out to the human-computer interaction community that too much attention is currently given to getting the *design right* (or evaluating and improving a given design) and not enough attention is given to getting the *right design* (or making sure that the design is appropriate for the given situation) [5]. Design processes incorporating empirical research at early stages of design will better equip our community to get the *right design*.

3. EXAMPLE SCENARIOS

We describe four example scenarios, drawn from our previous and ongoing work, that highlight the use, adaptation, and triangulation of empirical methods to inform design, each with goals, benefits, and challenges unique to the situation. These challenges relate to private or sensitive data, environments where researcher presence would be intrusive or logistically difficult, and explorations of novel interactions. The scenarios also highlight the following methods: cultural probes, immersive observation via impersonation, screen-capture interviews, artifact analysis, and *Wizard of Oz* (WOz) studies. Note that we do not aim to comprehensibly cover all possible scenarios in which empirical methods may inform visualization design; nonetheless, we expect that practitioners will be familiar with some aspects of the following scenarios. While a comprehensive survey focused on pre-design empirical studies in visualization research is beyond the scope of this paper, such a survey would be immensely useful.

3.1 Personal Data Practices

When individuals examine data in a personal context, they may have a wide variety of personal goals. Traditional usability or performance objectives such as time and accuracy are rarely the most important for visualizations in personal contexts. For example, if a visualization of home energy use is realized as an ambient display in one's living room, fitting into the aesthetic of the room may be a critical design goal [26]. Design goals may also vary considerably among individuals. While some individuals may track their physical activity to meet a personal objective (e.g., weight loss), others may do so simply out of curiosity or to share with their friends. Therefore, early in the design process, we need ways to discover the diverse design goals and considerations, and it is imperative to deeply understand the motivations, goals, and use contexts of individuals who will use these tools.

However, conducting early empirical study in personal contexts presents some challenges, most notably intrusiveness. Personal data management and analysis is often sensitive and private, so it can be too intrusive to "be there," to continuously observe individuals as they perform these processes, or to make video recordings. For instance, consider the sensitivity of personal finance or health information, or the intrusiveness of observing someone in their home environment. One solution to this constraint is to rely on indirect observational methods such as self-reports, software logging, artifact collection, and diaries. These methods may not provide data that is as rich as direct observations, though when used in conjunction, a partial reconstruction of a process may be possible.

Cultural probes. In one recent study we aimed to understand what motivates individuals to use visualizations in a personal context [29]. Understanding what factors are important in motivating tool use is a first step towards designing tools that are likely to achieve initial and long-term adoption. One challenge we faced in the design of this study was how to observe real life instances of individuals being motivated (or not) to use a visualization tool. If we had brought individuals into the lab to use some pre-selected tool, we would have set up artificial motivators (financial compensation or desire to please the experimenters) rather than observing real motivational factors. We also feared that a simple interview about past experiences with visualizations would be unproductive because few examples may come to individuals' minds; moreover, individuals are very unlikely to remember instances where they encountered a visualization but were *not* motivated to use it, a case we also were interested to learn about. Our solution was to use a cultural probe technique [10], an approach in which participants are supplied with a kit to record their activities and opinions. Cultural probes are similar to diaries, but data collection methods can be more diverse (e.g., our participants took screen shots or photos of visualizations they encountered) and they sometimes tend to be more playful or evocative. For two weeks, our participants made a visual record of each visualization they encountered during the day, and filled in a daily diary describing the circumstances surrounding their encounter and use of those visualizations.

Using cultural probes had several advantages. The daily journal reminded individuals to remain aware of visualizations they encountered in their daily life. The photos and short journal entries were simple enough to not discourage artifact finding but sufficient to get immediate impressions about an artifact before long-term recall errors became too pronounced. Later interviews enabled us to gain more detail about interesting cases, with the photographs and journal providing a reminder. This approach also provided multiple data sources, enabling triangulation.

This study was a general exploration of what motivates people to use visualizations in daily life, and mainly included static visualizations such as maps and charts in posters and news articles. However, we have since used knowledge gained from this study to design ecofeedback displays of home energy consumption [12]. Specifically, our findings directed our designs towards those that integrate ecofeedback information within environments that people regularly encounter, eliminating the need for people to actively seek out the information.

3.2 Complex Environments

When designing visualization techniques is for complex environments, traditional interview techniques may not provide a deep enough understanding of the situation. For example, in some professional situations there may be an approved protocol, which may vary from actual practices perhaps due to unexpected factors such as interruptions. In these situations, methods such as interviews and "fly-on-the-wall" observations may not be appropriate. For instance, use of these methods can be too disruptive in hospitals. We need ways to obtain rich data but with less intrusive means.

A different approach is to become a member of the team [7,15]. However, to become a member of the team it is necessary for the experimenter to have the required skills. In other words, this is only possible if the experimenter is qualified to be considered an expert himself or herself. It is very rare to be in such a position where the experimenter has this expertise; however, if possible immersive observation with a 'dual' expert is an exceptionally rich approach. Below we discuss an alternate variation.

Immersive observation via impersonation. Another possible approach is to impersonate a member of the team. While there are obvious advantages to this type of approach, it must be done

carefully, respectfully, and with appropriate ethics approval. Here is an example scenario that illustrates how this can work in practice [34]. The challenge in this project was to build a decision support tool for use by doctors when diagnosing pulmonary embolism, which is a very tricky diagnosis to conduct. On one hand, the symptoms can often be vague, do not always all present together, and are often indicative of other conditions. On the other hand, pulmonary embolism is a life and death situation so there is intense pressure to get the diagnosis right. Therefore, it was important to understand the current decision practices in order to create an acceptable tool that would work in a supportive role for the doctors. Ethics approval was obtained to enter non-existent (i.e., fake) patients in the hospital database and for the experimenter to be allowed to ask doctors for a consult on these non-existent patients. A medical doctor entered the non-existent patients into the database ensuring that they were realistic cases where it would be reasonable to ask for a consult for pulmonary embolism. He also worked with the experimenter about how to behave in context, how to approach doctors, and how to ask questions. Because the patients in question were not real patients, the doctor being observed could go ahead and order tests, etc. without impacting an actual patient. In this manner the experimenter was able to observe the diagnostic decision practices as they happened. While this type of observation can be done with deception, in that the people being observed do not know this is an observational study, it is also quite effective to do it with consent where the people being observed know that an experimenter will approach and have given consent. This latter case has enabled the design of a decision support tool that is of considerable interest to the medical community and is currently going forward for clinical trial. It is probable that at least some of the success of this tool results from the careful observations that provided an understanding of the diagnostic processes.

For this type of immersive observation it is necessary to be able to work closely with one or two experts who consider the research important enough to invest time to set up the situation effectively. While immersive observation presents its own challenges that will change from situation to situation, it does offer possibilities of rich insights into work practices.

3.3 Remote Experts

Many visualization techniques and tools are used by individuals with expert domain knowledge while performing activities specific to their domain of practice. While understanding the work practices of domain experts is a critical component of many visualization design studies [28], the analysis of experts' work practices can provide valuable insights without directly relating to the design of a tool or technique [3,16].

However, there are many scenarios in which domain experts work remotely, and it is not feasible to deploy researchers to these remote locales. As a result, it is not straightforward as to how practitioners should apply empirical methods to better understand the work practices of these individuals, when practitioners cannot be co-located with remote experts. New methods are undoubtedly needed to obtain rich data from remote experts. There are a number of methods that researchers may employ in order to triangulate on a partial reconstruction of experts' work practices. These methods take advantage of the fact that visualization researchers and designers are inherently interested in artifacts: in the software that experts currently use, in the raw and processed data that experts work with, and in the reports, figures, and other deliverables that experts produce in the course of their work.

Screen-capture interviews and artifact analysis. One of our recent design study projects exemplify this scenario [1]. We studied the data analysis practices of six investigative journalists, each working in a different newsroom and in different cities across North America. We performed semi-structured interviews via a teleconferencing application equipped with a screen-sharing capability. We asked these journalists to share their screen and demonstrate how their investigative work was performed using the software tools at their disposal. We recorded these demonstrations using a screen-capture application. While these recordings were immensely useful, we were well aware of their limitations: we could not observe nonverbal communication or cues, nor could we observe journalists' contexts. We note that some teleconferencing applications allow for simultaneous presentation of webcam and screen content; however in practice we encountered bandwidth limitations with screen sharing alone. Since we could not directly observe journalists' contexts, we explicitly asked them to describe their work environment. To supplement these recordings, we also collected various artifacts from these journalists prior to and after the interviews, such as their original and annotated datasets, their personal notes, as well as the published stories resulting from their investigations. These artifacts served both as interview prompts and as objects of study.

These atypical empirical methods performed before and during early stages of visualization design provided us with an invaluable understanding of journalists' work practices: we learned about the myriad data formats that journalists dealt with, how they wrangled this data into forms that were conducive to subsequent analysis, and the importance of web-based data storage. Our analysis of the collected interview and artifact data led to a major redesign and large-scale deployment of a web-based visualization tool [1]. We are currently applying the same remote interview and artifact collection methods in another design study in the domain of energy management, in which we are analyzing the work practices of energy managers working at remote organizations.

Remote experts who work in academic settings may provide additional artifacts. In a recent interview study with two dozen academic researchers, we focused on their work practices relating to high-dimensional data analysis [3], in which we were able to characterize these practices as sequences of abstract tasks. Many of the interviewees in this study were working at remote institutions. In addition to performing methods similar to those used in the design studies discussed above, we also collected these academics' published papers, theses, and unpublished manuscripts, as well as the figures and visualizations that they produced for use in publications or for their own data analysis. As academic documents tend to provide detailed reporting of methods, collecting these artifacts provided yet another perspective on experts' practices.

3.4 Novel Experiences

With the advances in input technologies, we are now facing a new paradigm characterized as post-WIMP interfaces, those which support more freeform interactions than traditional "point and click" WIMP interfaces. However, we have a limited knowledge about how individuals would interact with a system equipped with new input technologies such as pen and touch. It would be useful to expand our understanding of how individuals use these new technologies during data analysis to express their interaction intents. To create new and better interaction experiences, it is important to understand the behaviours and reactions of target audiences during the early stage of system design by observing how they naturally interact with systems.

***Wizard of Oz* studies**. Given the freeform nature of interactions, there exist a plethora of possible interactions worth investigating; the same result can be achieved through multiple interactions. As advocated by Nielsen [23], *Wizard of Oz* (WOz) studies are a promising way to explore the many interaction possibilities in a realistic setting without implementing a whole slew of costly recognizers. In a WOz study, a person (i.e., the "wizard") can employ a certain degree of control over how the system responds to a participant's interaction intents. The system appears fully functioning to the study participants, though slow to respond.

For example, we recently investigated how individuals respond to a robust and flexible pen- and touch-enabled digital whiteboard for creating and manipulating simple, standard charts using a WOz study [32]. Each time the participant performed an action, such as a pen stroke or a drag of a chart; the wizard interpreted the action and sent the appropriate command to the charting program. One of the main challenges in running a WOz study is to respond in a consistent and timely manner throughout the study (or at least for the duration of a session). For example, once the wizard "assigned" a meaning to a specific action, this assignment should not be changed during that session. The wizard also needs to respond only to actions that could reasonably be interpreted (not only by just human but also by a system) as having a particular meaning. Another challenge is to avoid legacy-inspired interactions; participants tend to transfer their knowledge from past systems to new ones when interacting with new technologies [21]. For example, the wizard decided not to respond to a single tap (or tap-and-hold) for pop-up menu invocation after the first two sessions to encourage participants to explore the freedom of expression a pen offers compared to a mouse.

Note that conducting a WOz study is not cheap. Even though a WOz study setup reduced the cost of implementing an interaction recognizer, it still involved a significant amount of effort in study design and system development. We had to prepare study protocol and material such as dataset and tasks, and design the basic interactions. In addition, we had to implement other features in the charting program, the wizard's control panel, and the networked communication between the two.

On the other hand, the WOz study setup had allowed us to see how individuals might react to a new, sophisticated interface before we actually created the real interface. It also allowed some degree of flexibility in how we responded to participants' actions, which is nearly impossible when we study a completed interface. For example, we could allow participants to perform an action even when they tried to trigger it in a way we did not expect, such as moving a chart was performed by circling the chart with the pen and drawing an arrow to the destination. After we develop a working system, the dataset and tasks we prepared for the WOz study could be used to test the working system.

4. DISCUSSION

The scenarios discussed above are not representative of all the possible contexts in which pre-design empirical work can be performed. In this section, we aim to be more general, offering practical guidance for collecting and analyzing data when conducting empirical work to inform visualization design. We also include pointers to recommended reading.

As illustrated in the scenarios, it is often beneficial to employ multiple data collection methods in conjunction to later triangulate on the object of study, especially if direct observation is not available. Collecting artifacts and studying work environments can be very illuminating, even if it is not possible to observe the actors of interest using these artifacts or performing activities in these environments in real time. To quickly become familiar with additional data collection and analysis methods, we recommend the set of IDEO Method Cards [13].

Understanding prospective behaviour often entails the collection of large amounts of rich qualitative data. There are various approaches to analyzing this data. One is bottom-up which encourages multiple iterations of coding interview transcripts and recorded observations toward the development of novel theory [9,15]. Alternatively, a structured approach that leverages concepts from cognitive work analysis (CWA) [31] may also be beneficial for informing design. CWA inspires a compartmentalization of analysis, shifting between a *normative* perspective (how tasks and activities are supposed to be done), a *descriptive* perspective (the actual strategies employed by individuals to perform these tasks and activities), and a *formative* perspective (how tasks and activities could be performed given environmental constraints). A complementary approach to this analysis could integrate vocabulary relating to data and task abstractions in the visualization domain, such as a recently proposed abstract task typology [2], which explicitly separates *why* a task is performed from *how* a task is supported. We have found that it is helpful to ask *why* and *how* at each stage of design and evaluation [1,3].

4.1 Further Reading

There is a growing and vibrant body of work describing the use of qualitative empirical work to inform visualization design. For methodological and logistical guidance in specific design contexts, Sedlmair et al. [27] provides *pre-design* advice for developing visualizations in the context of large companies. Sedlmair et al.'s design study methodology paper [28] discusses processes and pitfalls at nine stages of a design study, which assumes that the researcher is able to collaborate with a target population. The *discover* and *design* stages of this methodology are particularly relevant to our current discussion. McKenna et al. have recently built upon this work in their *design activity framework* [19], classifying *generative* and *evaluative* methods used throughout the visualization design process. They point to a large number of methods for *understanding* a design problem.

A number of visualization papers discuss empirical methods themselves in detail, including qualitative observational lab studies [11,14,20], and field-based observational studies leveraging a grounded theory approach [15,30]. Carpendale also describes and compares many of these methods in detail [6].

Another source of inspiration comes from the papers included in Lam et al.'s survey of empirical study in the visualization literature [17]. They identify seven scenarios in which empirical studies are performed. Perhaps the most relevant scenario to our current discussion is that of *understanding work practices*, an activity that typically occurs at or before early stages of design. We recommend consulting some of the papers coded with this scenario [4,8,25,33] for examples of methods, which predominantly included field observations, interviews, and laboratory observations.

5. CONCLUSION

We hope that this position paper serves as a call to action, prompting visualization researchers and designers to reflect upon the unique challenges confronted during their own use of empirical methods at early stages of design. While it is still uncommon to emphasize this type of research in visualization

papers [17], we hope to see more papers dedicated to the reporting of methodological details and to rich descriptions of individuals' practices and activities with or without software. In addition, there remain methodological challenges associated with special populations, sensitive data, and inaccessible environments, and we encourage the BELIV community to identify, adapt, and develop methods that address these challenges.

Acknowledgments

This work was funded in part by the U.S. Department of Homeland Security VACCINE Center under Award Number 2009-ST-061-CI0003, as well as NSERC, Canada. We also thank Tamara Munzner for her comments on the paper.

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