This paper presents a design science research study that proposes a design for a requirements engineering (RE) procedure for blind users. We motivate the need for the procedure by pointing out that blind users represent a large and growing population of end-users for whom efforts are being made to develop system applications and features and whose preferences need be accommodated in RE methods. We theorize needs for data collection and analysis techniques to accommodate blind users' limitations in the use of textual and visual media and propose a design. Furthermore, we demonstrate use of the procedure in a requirements engineering effort among users in New Zealand and Germany to develop requirements for mobile service applications and features for blind users and validate its use in a follow-up survey among such users. We present a Virtual Voyager concept service as an outcome of the RE effort. Our theoretical evaluation of the procedure shows that we were able meet most of the requirements for a procedure for blind user requirements engineering. However, we also see that more work should be done in efforts to make the requirements engineering process more accessible to blind users and stakeholders. The proposed procedure should be a beginning for such research efforts.

**Keywords:** requirements elicitation, requirement discovery, requirements engineering, blind, and design science research
INTRODUCTION
People who are blind or otherwise vision disabled have special requirements when accessing information systems. Computers and mobile devices are visual media, first and foremost; user interfaces have traditionally been designed to accommodate the information presentation on visual displays. Hence, special arrangements are required to make the technology accessible. This requires consideration of appropriate input and output mechanisms on the hardware side and a usable representation of information for applications and content (Shinohara and Tenenberg 2009).

Early on, there was little consideration of how alternative input or output mechanisms could effectively process information for the blind. In recent years, however, voluntary and legislated efforts have begun to address these needs. IT vendors such as Microsoft (2006) and Apple (2006) have integrated accessible facilities in operating systems, and third-party vendors made special accessibility hardware available to supplement standard IT configurations. Legislation and regulation in various jurisdictions required efforts to render systems accessible to disabled persons, including the blind (U.S. Department of Justice 2005). For example, Section 508 of the U.S. Code commits federal agencies to comply with standards intended to make Internet sites universally accessible, and the Americans with Disabilities Act requires that covered employers make efforts to insure that disabled employees are able to effectively access information systems (IT Accessibility and Workforce Division 2010).

While these efforts promise the potential to make systems, applications, and products more accessible and usable for blind users, they carry an implicit assumption that accommodating systems that were designed for use by the sighted, so that blind and vision-impaired people can use them, is sufficient, i.e., that the vision-impaired will not have their own needs and preferences for functionality and features. Blind and vision-disabled people demand much more. According to the National Federation of the Blind, an organization representing 50,000 blind and low-vision members in the U.S., “the blind are normal individuals who can compete on terms of equality” (National Federation of the Blind 2010) with the sighted. “The blind can do anything that the sighted can do and they can do it just as well, if they are given the chance” (Maurer 2010). These contemporary assertions continue a more than forty-year-old demand by Jacobus TenBroek (1966), a legal scholar and founder of the NFB, that the blind were possessed of a “right to live in the world,” just as sighted people do.

Accomplishing this task will require that the design of systems and applications go well beyond accommodating systems designed for the sighted so that they can be used by the blind, to incorporate the needs and preferences of the blind for functionality and purpose of new systems, particularly so that new systems can be designed to enhance the independence and mobility of the blind and to enhance opportunities for the blind to participate in every activity that the sighted are able to do. This will require enormous effort in requirements engineering (RE) and design for new systems. Ironically, little has been done to insure that RE processes are effectively accessible to the blind.

This task is important. There are approximately 161 million people in the world who are vision-impaired, according to the World Health Organization (2003), including 45 million who are blind. Furthermore, the number of blind people in the world is increasing, largely because of increased life expectancy and age-related causes for blindness, such as cataracts and macular degeneration. In addition, an unfortunate impact of contemporary warfare has resulted in

CONTRIBUTION
This paper makes several contributions to the requirements engineering and disability literatures:

First, it justifies the need for RE methods that accommodate the needs of users who are blind or vision-impaired. Hitherto, much research has focused on techniques and devices for ex post accommodation of products and systems for use by the blind, but not on procedures to accommodate the RE process so that blind users can participate in the early design stages.

Second, it develops an effective RE procedure, focusing on target population participation, data collection, analysis, and presentation of blind user requirements.

Third, it demonstrates the procedure with the development of requirements for applications and features that would benefit blind users. The demonstration shows that, when given the opportunity to participate, contributed preferences for features that would not likely have been contributed by sighted participants.

Fourth, it evaluates the efficacy of the method by referring back to design objectives, related to participant motivation, information processing constraints, complexity constraints, and communication constraints, that were suggested by the prior literature.
many new cases of vision impairment among young people, who might be expected to be beginning careers. According to Col. Donald Gagliano, Executive Director, Department of Veterans Affairs Vision Center of Excellence, (Gagliano 2010), 10 percent of U.S. veterans returning from Afghanistan have experienced a concussive event from an improvised explosive device and, of those, 80 percent experience some level of vision disorder. If this substantial population is to achieve its potential for productivity and happiness, its particular needs and preferences should be considered in the design of new systems.

Can we design RE procedures that are accessible and usable for the blind user? The blind represent a target population for RE that may require more than the obvious simple accommodation for lack of sight in order to accomplish effective participation in RE. We have identified four general problem areas, based on Davis (1982) and Browne (2002), motivation, information processing, complexity, and communication. We assert that an RE process to include blind persons should accommodate elements in these four areas to be effective.

In this study we design blind-user RE procedures that incorporate accessibility techniques, as well as techniques adapted from the standard repertoire of data collection, to accommodate the needs of the blind with respect to the four problem areas that we identified, to allow blind users and potential users able to effectively participate in the data gathering and validation parts of the RE process. We employ the design science research paradigm (Hevner et al. 2004; Peffers et al. 2008) to identify the problem and objectives of a solution, and to design a process to address the objectives. We demonstrate the use of this process in the context of RE for mobile services and features that would benefit blind users. Finally we evaluate the identified services and features in a follow-up survey of blind users.

This paper is organized as follows. In the next section, we review the present state of applicable knowledge. Then we detail the objectives of a solution to the problem. The following section briefly outlines the designed procedures. The next section demonstrates use of the procedures to develop the requirements for mobile service applications and features for blind users. The following section evaluates the requirements. The final section concludes the paper with a recap of what we accomplished and a brief agenda for future research.

RELATIONSHIP TO THE PRESENT STATE OF KNOWLEDGE IN THE FIELD

There are two major research and practice streams that are relevant to this project. One involves research and inventive engineering to produce products that will enhance independence and mobility for the blind. The other stream involves techniques and methods for requirements engineering, the state of that stream, and the implications for the feasibility and contribution of blind RE methodology.

Research and Practice to Enhance the Independence and Mobility of the Blind

The primary focus of academic and practitioner efforts toward accommodating the needs of blind people has been on the accessibility of the system user interface (e.g., Donker et al. 2002; Edwards 1989; Freire et al. 2007; Freitas and Kouroupetroglou 2008b; Gill 2005; Gillespie and O'Modhrain 1995; Glinert 1984; Takagi et al. 2004; Wagner et al. 2006). An information system is considered accessible to the blind when its user interface can accommodate the special needs of the blind, so that they can access the system in a manner that is similar to that of sighted people (Glinert 1984; Hoffman et al. 2005). The blind generally rely on alternative input and output mechanisms when accessing information systems.

Typically, these provide large scale imaging for low-vision users (Glinert 1984; Kline and Glinert 1995; Wagner et al. 2006), text-to-speech functionality (Freitas and Kouroupetroglou 2008a), or haptic interfaces. The listening and talking computer represents a convenient and effective way of accessing both content and functionality. For input, speech commands let the user control the system with his/her voice. Microsoft (2006) and Apple (2006) have included this feature in their respective operating systems; while third-party providers offer a wide range of additional speech recognition solutions. For information output, screen-reading software solutions transform textual into audible information. JAWS, created by Freedom Scientific, is commonly used by the blind to navigate the Windows operating system and the Internet (FreedomScientific 2006). Its purpose is to convert text to speech or to a refreshable Braille display. To interact with systems, blind users can rely on special Braille keyboards (HumanWare 2010) and displays. Braille keyboards are designed to write Braille characters and to navigate through a system. Alternately, a traditional QWERTY can be supplemented with accessibility-enriching software solutions, such as StickyKeys (Apple 2006; Microsoft 2006). Braille displays physically formed Braille characters that the user can “read” through touch.
There is strong evidence in the increasingly widespread use of information technology by the blind, spurred by the obvious value of products with accessibility features.\(^1\) Further, anecdotal responses to prototype applications suggest that the response to potential new mobile services, enabled by complex information systems and telecommunication technology, will be especially interesting as they can potentially enable new degrees of freedom that can lead to improved quality of life. For example, a user of Trekker, a PDA-based GPS add-on for the blind, describes her experience with her new mobile assistant:

*For me, the most positive aspect of my blindness has always been the dignity, safety and freedom of mobility working with a guide dog provides. But that was before Trekker … [which] allowed me to move halfway across the United States and in combination with my guide dog, discover and learn a whole new city, much more quickly and independently than I would have thought possible previously…* (HumanWareTrekker 2006).

Recent research efforts have sought to extend accessibility technology. For example, efforts to render touch screen technology accessible to the blind, difficult because of the lack of inherent tactile feedback from this interface, resulted in the multiple-touch gesture language that has subsequently been commercialized in the Apple iPhone interface for the non-sighted (Kane et al. 2008). Yu et al. (2001) reported on experiments with the PHANTOM\(^\circledR\) haptic device, intended to permit blind users to feel elements of graphical content through force feedback.

**The Applicability of RE Methods and Techniques for Use with the Blind**

Much has been accomplished in research and practice to accommodate applications and products that were developed for the sighted for use by the blind. Recent research papers suggest that there are as many as 100 methods and techniques for RE (Maguire and Bevan 2002; Mathiassen et al. 2007; Nuseibeh and Easterbrook 2000). Many involve small variations on several themes. Here we briefly review RE methods and techniques with a view toward considering their potential for use with the blind and then we discuss explicit efforts for RE involving the blind.

Traditional data-gathering methods, such as questionnaires and surveys, and interviews (see, e.g., Mathiassen et al. 2007) generally rely on large amounts of textual information, such as written questionnaires and surveys or the review of existing system documentation. Such methods can be adapted for use with blind participants, however, to the extent to which they are structured for use with heavy amounts of visual information, such as charts, tables, and graphics, intended to aid the collection of data from sighted participants, such adaption may be difficult.

Prototyping has been referred to by many researchers as a good way of getting feedback from end-users. Researchers have advocated the use of prototyping when end-users are not able to express their requirements well or when they need help to visualize new possibilities for systems (Davis 1982; Mathiassen et al. 1995). The limiting factor in prototyping is in its main strength: it is necessary to have a prototype, or mock-up, to demonstrate the features to end-users. This would require at first having insights of the needs of the users, and this can be especially difficult with innovative services or applications. Consequently, prototyping potentially plays a role for use with the blind, with the caveat that reliance on visual presentations must be eschewed. Blake and Tucker (2006) suggested starting with paper prototypes and then proceeding with a live person, instead of an automated application. Embossed paper prototypes have also been suggested (Miao et al. 2009).

Contextual methods make use of observation of use or process behavior within a contextual situation. These methods vary in their theoretical background and include, for example, ethnographic methods, as well as ethnomethodology and conversation analysis, both of which apply fine-grained analysis to identify patterns in conversation and interaction. Contextual design (Holtzblatt and Beyer 1993) is often mentioned when thinking of such methods. It heavily uses on-site observation and prototyping to come up with a design. Its obvious limitation is that it may not be a cost-effective methodology for developing feature-level preference data from a target population, particularly if the population members will represent a small portion of total RE subjects in a study or where there is no obvious in-use behavior to observe.

Cognitive methods were originally developed for knowledge acquisition purposes (Shaw and Gaines 1996). They include protocol analysis (in which an expert thinks aloud while performing a task), laddering (using probes to elicit the structure and content of subject knowledge), and card sorting (asking stakeholders to sort cards into themes). Browne et al. (2002; 2001) asserted that laddering enables analysts to elicit a rich set of requirements. Peffers et al. (2006) and Tuunanen et al. (2004) have observed its effectiveness for discovering and understanding participant

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\(^1\) For example, the National Convention of the National Federation of the Blind, in the US, is attended by nearly 3000 blind and vision-impaired participants annually and by dozens of firms that seek to provide technology solutions for access to information systems for this population.
reasoning, as well as preferences. Hollan et al. (2000) suggested extending the cognition boundary to include the task domain and combining ethnographic observation with controlled experimentation. Lazar et al. (2007) suggested using diaries to track user frustrations with a prototype application. Cognitive methods have substantial potential for adaption to support non-visual requirements gathering.

Model-driven methods start with specific models for the type of information to be gathered, and use these models to drive the elicitation process. Examples of model-driven approaches are goal-based methods (van Lamsweerde and Letier 2000), scenario-based methods (Haumer et al. 1998; Sutcliffe et al. 2005). These are problematic as RE methods for general use by the visually impaired because they typically require knowledge of the system domain area and of related work-practices. Users without basic skills in modeling languages, such as E-R diagrams or UML, find it difficult to grasp the meaning of the diagrams and the requirements information behind them. Furthermore, these methods generally rely on visual presentation of the modeling language.

A small number of researchers have explicitly addressed some portion of the problem of an RE method for the blind. Hong et al (2005) were concerned with the development of new applications that incorporated knowledge about the user context. Applications developed for the blind might be expected to be among them. They suggested a requirements model that incorporates context information. Smith-Jackson et al. (2003) suggested a framework for developing mobile applications for the disabled, including the blind, using preferences elicited from the target user population. In brief, their framework includes qualitative data collection to elicit preference data and a classical iterative prototyping activity to refine the requirements. These findings concur with our earlier work (Peffers et al. 2003; Tuunanen et al. 2004) that promotes using in-depth individual and group interviewing techniques for data gathering, where the target-user represents a different culture, such as the blind, relative to analysts, developers, and decision makers in the organization owning the development project. Krishna et al. (Oct. 2008) used focused group interviews to identify needs of blind persons to support their successful social interaction among members of a general population, particularly at the workplace. Together these efforts suggest an emergent interest in methodology for RE with blind participants. Their successes in obtaining partial solutions to the problem suggest that a more general solution may be feasible. To date, however, no formal research effort has addressed the problem of a more general solution that is formally defined and rigorously evaluated.

Researchers have recognized that the lack of explicit methodology for RE with blind participants is a serious problem. For example, Mankoff et al. (2005), concerned with the specific problem of Web page accessibility, noted that involving blind users in prototype testing is beyond the capability Web developers, but sighted users cannot satisfactorily pretend to be blind (Sánchez and Ellas 2007). Difficulties include finding suitable subjects and the accessibility of a testing location. “There is no immediately obvious or attainable solution for the problem. (Mankoff et al. 2005).”

Some elements of solutions have been suggested. To date, however, each of the efforts have focused either on a specific observed problem or been the result of ad hoc solutions in the course of working on an accessibility or other related research problem. No research effort, to our knowledge, has addressed the overall problem of developing requirements engineering methodology for use with the blind.

OBJECTIVES OF A SOLUTION

Classical research in systems development observed four major sources for many of the failures affecting the discovery of good systems requirements. According to Davis (1982) and Browne and Ramesh (2002), they include: the motivation and ability of RE participants to be effectively engaged in the process; human information processing constraints; the complexity of information system functionality and features; and communication among the parties to RE, including subject participants, analysts, designers, and managers. We use these four sources as a framework to consider how blindness affects the ability to effectively participate in RE, and we develop objectives for a solution in an RE process.

Motivation

Motivation to participate effectively in RE activities is a concern because unmotivated subjects may fail to participate or may not attend well enough to RE activities to provide good quality data. Motivation may be affected by organizational politics, cultural norms, personal incentives for participation, and contextual factors, such as a lack of trust in the confidentiality of responses in the process (Browne and Ramesh 2002).

For the blind, motivational considerations are important. Consequently, the recruitment of subjects is a major consideration in the RE effort. To participate in RE, a subject must make him/herself available to the activity. If a sufficient number and adequate distribution of blind participants cannot or will not show up, the results will be biased
against the preferences and needs of this population. Usually this means traveling to the participation site or otherwise arranging to appropriately communicate with the analysts. For the blind, traveling to a hitherto unvisited location, even if nearby, generally requires far more effort and planning than it does for sighted persons (Barlow et al. 2005; Franklin and Bourquin 2000; Sauerburger 1997). In addition, the added complexity of traffic patterns in recent decades may have made travel to some new places more difficult (Long et al. 2005; Sauerburger 2005) than they were in the past, when traffic patterns were more simple. Such travel may also be costly, time consuming, stressful, or even hazardous (Perla and O’Donnell 2004; Pfeiffer 1995).

A second, related motivational concern is trust. Blind subjects may feel themselves at situational disadvantage when interacting with sighted strangers and may require credible vetting to establish sufficient trust to avoid anxiety in the RE process (Beverley and Bath 2007; Fang et al. 2009).

Third, blind people require more time and attention to complete the everyday tasks associated with home life, work, school, and other activities that directly affect them and their families. They have less discretion to use their time and attention to participate in activities that don’t directly affect them (Perla and O’Donnell 2004) and may eschew participation if they don’t see it as convenient and important.

Put together, these motivational concerns suggest that an RE process that includes blind participants must be carefully designed to consider participant travel arrangements or alternatives to onsite participation, to establish trust in the process, and to provide appropriate incentives for participation.

**Objective:** An effective RE process for blind users would specifically address the needs of the participants for convenient and safe logistical arrangements, clearly established mechanisms to establish trust, and incentive for participation.

### Information Processing Constraints

Limitations on working memory affect the ability of participants to perform complex evaluation tasks during the RE process. Limitations on long-term memory affect the ability of participants to provide all of the relevant data about their needs and preferences. RE participants may often not recall system needs and preferences that have not been brought to their attention lately, particularly if they have worked around the needs in their work or daily lives or if they assume that their preferences cannot be met.

RE techniques typically rely heavily on visual materials, e.g., lists, scenarios, and organizational documents, as aids to short and long-term memory. The absence of support from these visual aids dramatically increases demands on memory for the blind RE participant. Most particularly, such demands affect the ability of the participant to engage in activities such as rank ordering lists of items, choosing from such lists, or manipulating items in complex relationships. Blind persons can, with attention and training, compensate, with working memory skills, for the lack of visual aids, but only to a very limited extent (Bliss et al. 2004). In addition, the absence of visual material support makes it difficult for blind participants to identify missing items from the data that they have provided to analysts from long-term memory.

**Objective:** An effective RE process for blind users would avoid excess demands on working and long-term memory for participants in order to enable participants to provide complete data about their preferences and needs, as well as to effectively evaluate competing ideas for functionality and features.

### Complexity Constraints

The inherent complexity of information systems is known to lead to high variability in the expressed preferences of RE participants. Participants often may not fully understand the organizational or technical possibilities of the system or application for which their preferences are being sought. This is particularly true where the participant is unfamiliar with either the organization or has little or no experience or conceptual understanding of the underlying technology.

For sighted RE participants the most common way to overcome this constraint is through visually oriented stimuli, such as presentations or prototypes. Blind participants are unable to use visual clues about the technology or from presentation materials regarding a product or system idea to draw inferences about processes, value, and intended use. Thus, for blind participants the need to eschew visual materials means that the stimuli necessary to aid in idea generation for functionality, information, and other features requires substantial adaptation.

**Objective:** An effective RE process for blind users would be designed to elicit needs and preferences for functionality and features from participants who are unfamiliar with underlying processes and technology, without the use of visual materials.
Communication Constraints

Communication among RE participants and other parties to the RE process, such as analysts, designers, and managers, is an acknowledged source of incomplete or misunderstood needs. Participants are likely to lack understanding of the professional and organizational language of the analyst, and they are unlikely to fully understand the objectives and values of the organization. In addition, they are likely to be members of underlying individual cultures that are different from those of the analyst, because of differences in nationality, socio-economic background, lifestyle, etc. As a result, the structure of their beliefs about how the world works, their values, and their goals may differ to the extent that the analyst may find it difficult to capture their preferences completely or to express them accurately.

For the RE process to succeed, the needs of the participants must be captured completely and expressed accurately, but also to be represented in ways that are understandable and useful for clients of the RE process, including managers and system designers.

For blind participants, the differences between blind and sighted persons’ perspectives must be added to the communication problems described above, i.e., blind persons have all of the cultural, educational, and situational variation of the sighted population, in addition to their blindness, which can be expected to affect their beliefs, values, and goals, as well as the structure of their knowledge (Sauerburger 1997).

Objective: An effective RE process for blind participants would capture and aggregate data in a manner that is structurally very flexible, and it would represent data in a manner that is useful and understandable for managers and designers.

DESIGN OF A SOLUTION

Here we briefly outline procedures for the designed RE process for use with blind participants, designed to meet the objectives described in “objectives” above. Requirements engineering involves a complex collection of processes. Here we focus on just four major RE elements: participant recruitment, data collection, analysis, and presentation. Here we describe how these elements are incorporated into RE activities. Figure 1 shows a graphical representation of the activities.

Pre-Study: Determine study scope and participant characteristics, recruit participants, and collect stimuli.

To motivate participation from the target population, recruit participants with an assertive, multilayered approach that includes communications through blind organizations and/or snowballing, each of which is intended to enhance trust by referral of the solicitation through known, trusted entities, i.e., acquaintances or known organizations. Screen participants for desired characteristics, including “lead user” attributes.

Lead users are a minority of savvy users who tend to use new technology early in its lifecycle and whose experience with technology can be exploited to predict future trends (von Hippel 1986). Lead users are expected to be less constrained by complexity and new technology than average users. They are more highly motivated to engage in ideation about new product attributes than average users, because they enjoy thinking about new technologies and trying out products that result from them. Models based on adoption of innovation theory use lead user adoptions, early in the product lifecycle, to predict eventual adoption rates for the larger target audience (Peffers and Dos Santos 1996).

It is worth noting that the participant sample that results from the snowballing procedure and the use of lead users will not be representative of the entire target population. This is not problematic because the purpose of this data collection is to acquire rich, meaningful data about product and system attributes that might be valuable for members of the target population, rather than to describe the views of the target population. Consequently, inferences that the data describes target population preferences should be entertained with care.

Use interview scheduling as an opportunity to collect stimuli by asking the prospective participants for ideas (Browne and Rogich 2001). The use of stimuli ideas in data collection is intended to reduce demands on long-term memory that result from lack of visual aids. Document and aggregate the collected ideas to get a stimuli list for the laddering interviews. The number of stimuli depends on the study, but often four or five is a good number (Peffers, et al. 2003) to avoid information processing constraints of participants. Simplify the collected stimuli for oral presentation and to accommodate working memory limitations of oral presentation, by reducing the number of items in the stimuli and the verbal complexity of their presentation.
The participant recruitment procedures address the motivation objective. The use of lead users addresses the complexity objective. The use of stimuli addresses the objectives for information processing and complexity constraints.

**Needs elicitation: Collect data from the participants and record as ladders.** Use one-on-one oral interviews to optimize convenience to participants. Structure the interviews and record the resulting data, using the laddering method (Browne and Rogich 2001). Laddering is based on personal construct theory (PCT) (Kelly 1955). Kelly found, through his experience as a school psychologist, that if he understood his clients’ models of how the world works, he could better understand their behavior. PCT is concerned with peoples’ models of the states of the universe, the consequences of those states, and impacts on their individual values. Laddering is a data collection and recording technique that captures states, consequences, and values, in this case preferences for new system attributes, expected outcomes from those attributes, and the expected affects on the participants’ values. The laddering technique is useful because it aids communication among stakeholders by collecting preferences and reasoning data, without any other structural constraints.

Starting with the participant’s choice of the most appealing stimuli (reducing complexity), ask “How would this work for you?” to elicit preferences for specific features. For each preference continue with “Why would that be important for you?” questions to elicit the steps in a ladder of consequences and values (Browne and Ramesh 2002; Kelly 1955). Continue with the participant’s second choice stimulus to repeat the process. Record the data in a manner that preserves the integrity of each ladder, e.g., as cells in a spreadsheet column, and make an audio-recording of the interview. Going through two stimuli will likely require 45-to-60-minute interview. After this, the participant starts to be tired (Peffers et al. 2003), and, therefore, it is better to either conclude the interview or consider continuing on another time if you have chosen to use more than two stimuli.

To record participant views on the importance of their ideas, ask each to prioritize his/her own ideas. In a two step rank-ordering process, to reduce working memory demands, ask the participant to identify and rank order the several most important of his/her feature ideas and then separately to rank order the remaining ones.

The use of one-on-one interviews addresses the motivation objective. The use of the laddering method collects preferences with rich reasoning data to support the communication objective. The two-step prioritization addresses the information processing constraint, while providing evaluation data.

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<td>13. Collect participant reasoning data about value ratings.</td>
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<td><strong>PRESENTATION</strong></td>
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**Figure 1. Requirements engineering procedure for use with users who are blind.**

**Model aggregation:** Cluster the interview ladders into themes and create thematic maps. Code the individual statements in the data as attributes, consequences, and values items. Determine a number of themes, ideally no more than seven to accommodate working memory limitations, that represent the data in the ladders and assign each ladder into one or more themes.
Create thematic maps, graphical network representations that depict the links among attribute, consequence, and value codes as they occurred in each ladder and are aggregated into themes. A thematic map represents a consensus model consisting of, from left to right, descriptions of desired system attributes, the reasoning and consequences behind them, and associated participant values. The thematic maps connect nodes with association (reasons why) links that may or may not be causal. The horizontal dimension in the maps represent an “attribute–consequences–value” dimension.

Arrange the thematic maps to show subthemes, i.e., major feature sets of the application. Subthemes will reduce information processing constraints. Continue with clusters of attributes, consequences, and values, within the subthemes. These maps provide a graphical picture of all ladders in subthemes.

The use of themes addresses the working memory constraint, while thematic mapping addresses the communication objective by retaining the structure of reasoning data for downstream information users, such as managers and system designers.

**Model evaluation: Determine the importance of themes and individual features.** The first step is to determine which themes represent the most desirable or important application bundles. To reduce complexity of the task and working memory demands, create brief summary descriptions that depict a descriptive label for each of the themes and a list of the included features. Present the participants with the summaries, asking them to rate the importance of each theme using a Likert-type scale.

Continue to the feature level by developing scenarios that briefly describe attributes and consequences for groups of features, so as to appeal to a user’s imagination about having several features available in a system. Depending on the complexity of each theme, scenarios should contain two or more features. Read the scenarios to participants and ask them to name the features that are most interesting or important to them and record the importance responses as Likert scales and identify the most important features for each participant.

Reduce communication constraints further by asking the participant to give reasons for preferences. For a participant’s most preferred features ask him/her, “Why is this feature important to you?” to elicit reasoning for the choices. This post-analysis feedback instrument will serve as a constructive critique or confirmation of the analysis phase. If necessary, the users’ critiques can be incorporated into the refinement of the suggestions.

Use of the labeled themes, along with use scenarios, supports the overcoming the complexity and working memory constraints. Collecting reasoning data in the evaluation supports accomplishing the communications objective.

**Presentation: Development of the business report.** Incorporate the collected data, analysis, and specific user comments into a business report written for the clients. This report should include an elaborate description of the most-valued systems and their features. Moreover, it should state the consequences and the values the systems address. This step supports the communications objective, i.e., it helps downstream information users to understand the reasoning behind stated preferences.

**DEMONSTRATION OF THE DESIGNED SOLUTION**

Here we demonstrate the use of the designed method in a case study in which we use it to develop requirements for mobile services for the blind. We carried out the study in New Zealand and Germany in 2006. We start with data gathering and continue with analysis, presentation, and results.

**Pre-Study**

Target participants for the study included blind lead users. We foreswore the use of participant incentive payments, thus insuring that recruiting participants would be challenging. Our objective was to recruit at least twenty participants, the minimum necessary to make the study results meaningful (Peffers et al. 2003; Tuunanen et al. 2006; Tuunanen et al. 2004). To recruit participants in New Zealand we employed communications channels of the Royal New Zealand Foundation of the Blind. We sent several hundred e-mailed invitations to the foundation’s lists, inviting list members to take a short screening survey. We posted an announcement on the foundation’s telephone oral newspaper service. In addition, we asked willing participants to nominate other likely participants and contacted them, either by e-mail or through the referring participant. After four weeks, these efforts yielded five participants.
We continued recruitment by making a presentation at a foundation-training center, where we explained our research objectives in the classroom. This yielded five more participants. Foundation staff contacted some people directly, yielding three more, and one staff member agreed to participate. In all, we recruited fourteen potential participants in New Zealand.

Next we turned our attention to Germany, where *Trierische Tonpost* publishes a monthly “spoken magazine” for 850 blind and vision-impaired subscribers across Germany. A solicitation in this medium yielded nine, for a total of twenty-three participants.

To screen for lead users, we asked a series of questions, derived from a screening device used elsewhere (Tuunanen et al. 2006), to assess the use of new technologies. Part 1 contained six statements about the use of mobile and assistive technologies. Part 2 posed two questions about mobile and adaptive technology the participants have used. The survey was available as an Internet questionnaire and by telephone. One participant was screened out of the study in this process.

This left us with twenty-two participants, for whom Table 1 shows sample demographic data. Note that the age distribution is more heavily weighted with people who are less than forty years old and the sample was male dominated.

<table>
<thead>
<tr>
<th>Age Distribution</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>18–29 years</td>
<td>39% Male 78%</td>
</tr>
<tr>
<td>30–39 years</td>
<td>22% Female 22%</td>
</tr>
<tr>
<td>40–49 years</td>
<td>28%</td>
</tr>
<tr>
<td>50+</td>
<td>11%</td>
</tr>
</tbody>
</table>

### Needs Elicitation and Evaluation

All participants who qualified for participation were telephoned to invite them to participate in individual interviews. At the end of each phone call, they were asked to give one idea for a potential system that could be of interest to them. Some participants contributed three or more ideas. After the first seven invitations, we developed a preliminary list of stimuli for use with the first interviews. This allowed us to start with the interviews before all participants had committed to taking part. The list was gradually refined with new ideas and clustered into four items that served to define the scope of the data collection and to stimulate ideation. The items were (1) a mobile navigation service, (2) mobile content, such as radio, TV, or music, (3) a mobile shopping service, and (4) a truly accessible mobile phone.

We conducted the interviews, lasting an average of 35 minutes each, in person or by telephone, using the laddering method (Browne and Rogich 2001). We audio-recorded each interview and took notes on an electronic spreadsheet.

Table 2 illustrates the resulting raw interview notes. Shown the stimuli ideas about new mobile services, the participant chose the two most interesting to him/her or volunteered his/her own ideas. Next we asked, “What would be an interesting feature of the service/product?” and recorded the response as an attribute, shown in Table 2 with capital A prefix. Then we asked a series of “Why would this be interesting to you?” questions, and recorded the responses labeled with a “C” (for consequence) prefix. We continued until the participant volunteered one or more basic values or goals, shown with a “V” prefix in Table 2. We repeated this process for the second-most interesting stimuli.

To wind up each interview, we asked the participant to evaluate the ideas that they had contributed. To avoid working memory overload, we first asked the participant to identify the three most interesting ideas in rank order. Then we collected a rank-ordered list of additional items that they thought interesting.

### Model Aggregation

The interpretive analysis process involved four steps. First, we determined seven “themes,” or concepts, that would cover all chains. Next, we assigned each chain to one of these themes. Next, within each theme, we grouped participants’ statements by attribute clusters, consequence clusters, and value clusters, to highlight clusters, or subthemes, within each theme. Finally, for each theme, we drew a value map, a graphical representation that shows preferences and reasoning of the aggregated chains that it contains.
Two researchers independently examined the data to develop conceptual themes that would incorporate all of the chains; one developing ten and the other seven. They reached a consensus on seven themes by discussion.

Next the two researchers independently assigned each of the chains to one of the themes. They initially agreed for 86 percent of the chains, a high level of agreement, compared to similar studies (Tuunanen et al. 2006; Tuunanen et al. 2004), and resolved differences through discussion, for six chains including them in two themes each and placing one chain in three themes. One chain was dropped from the analysis due to feasibility concerns.

<table>
<thead>
<tr>
<th>Table 2: Field Notes with Example Ladders</th>
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<tbody>
<tr>
<td>Interview</td>
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<tr>
<td>Type</td>
</tr>
<tr>
<td>Stimuli</td>
</tr>
<tr>
<td>Ladder ID</td>
</tr>
<tr>
<td>Start time</td>
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<tr>
<td>Rank</td>
</tr>
<tr>
<td>Feature</td>
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</table>

Participants expressed their preferences and reasoning in different languages. Consequently, to interpret the data within themes, we clustered the chains by attributes, consequences, and values, assigning a common label to each of similar attribute, consequence, and value statements. The names followed the language used by participants to the extent appropriate. By assigning these labels it would be easier to get a bird’s eye view of the themes and their features and to depict links among attributes, consequences, and values in the themes. By sorting by the labels, this allowed us to see clusters within the themes.

We copied each ladder into a spreadsheet and labeled it according to the theme to which it was assigned. Then we grouped the ladders into clusters, stepwise, by attributes, consequences, and values. Where ladders included more than one attribute, we copied them into more than one ladder, where necessary, to cluster.

Next, we arranged the codes theme-wise in a graphical representation, to form thematic maps, creating one map for each theme on partitioned sheets with areas for attributes (left), consequences (center), and values (right).

Figure 2 shows a thematic map for the theme “Shopping assistant.” At a glance, it can be seen that most system features (left) eventually lead to the value “independence” (far right). With the same granularity as the chains are noted in the electronic spreadsheet, they were now traceable in an easy-to-understand graphical format.

With the aggregated models of user preferences in hand we proceeded to getting post-analysis feedback from the users. In the initial interviews, we grounded user’s individual preferences for mobile services. In this phase, we gathered feedback on what every user thinks about the features all participants contributed.

The feedback was gathered in short phone interviews. All participants were called with the objective to have a short feedback interview. Three participants could not be reached by telephone. In total, we successfully contacted eighteen for the post-analysis feedback session. The three steps to elicit user feedback are further described below.

Selecting Most Important Themes. The initial challenge was to find a representation that gets the user familiar with each theme and its associated features. We did not want to overwhelm the users with descriptions that were too verbose. To limit complexity, we wrote a theme description that included a refined name of the theme, followed by a summarized enumeration of the related features. We read out the theme summaries one by one and clarified the specifications if necessary. After each summary we asked the participant to indicate, on a scale between 1 (not important) and 10 (very important) how important the particular theme was to him/her.
Selecting Most Important Features. We broke down each theme into written scenarios to summarize groups of features. The narratives aimed to introduce participants to features of which they might never have heard. Each scenario started off with “Imagine…,” then named the features and explained them when necessary. The scenarios also stated what one could accomplish with a particular feature or features. These constitute the consequences that manifest themselves when having the feature available. For example, one scenario read, “Imagine you had a rather bulky phone with, large, raised and well spaced-apart keys, with square-shaped number keys and differently shaped function keys, arrow keys instead of joysticks, more wheels and switches, and a dot on the 5. This would result in a more accurate input.” Participants provided importance ratings for the scenarios in a manner similar to that above for the themes.

Compile Rankings. Using the data from the feedback interviews, we used the Likert ratings for themes and feature groups, normalized for the number of items rated, to compute rank-order ratings for each theme and feature cluster.

Model Evaluation

We evaluated the results of requirements elicitation and analysis in two ways. First, we aimed to clarify which ideas proposed by individual participants were most valued by others. Second, we sought to verify whether the system suggestions derived from interpretive analyses, which were carried out by the researchers, accurately represented users’ needs. To evaluate the efficacy of the selection, ranking, and rating rounds, we here compare the outcomes of these consecutive rounds to each other.

During the original individual laddering interviews, we had asked the participants to rank order their top three ideas. This provided us with a first round of data, a portion of which is depicted in the left column of Table 3. The second column presents data collected in follow-up telephone interviews after the creation of the thematic maps. It presents a tally of Likert-type rating scales for the ideas that lie within the three top themes. The top three themes, out of seven, “navigation & routing,” “traffic & public transport assistant,” and “shopping assistant” accounted for 70 percent of the total of post-analysis rating scores. These ratings were computed during the feedback-gathering phase of the study.
The results show that the preferences most highly rated by individual participants in the original data collection, were also the most highly rated by all participants, following the intervening analysis. That the same themes where highly rated suggests some support for the aggregation and modeling of the analysts, i.e., that the preferences and reasoning were well-captured and interpreted. The rest of the themes followed this trend within the data. Note that comparisons of the values of the ratings across the two columns are not meaningful.

Table 4 presents more in-depth analysis of the results within the navigation and routing theme. Here there is more variation between pre- and post-analysis results, but we can see that the five top-ranking feature groups, out of twelve, are largely the same even though the order among them differs. These results also suggest that the analysis has well captured the meaning of the data provided by the participants. Here also, the actual numerical values are not comparable across columns.

**Presentation**

**Presenting Thematic Maps.** In Figure 3 we present the thematic map for the theme “Navigation and Routing Device” as it was presented in the final business report. It lays out the links among system features on the left, consequences in the middle, and personal values or goals on the far right. We summarize key features described in the business report here.

A “Navigation and Routing Device” would enable spatial guidance with a mobile device. It would be a personal city navigator for the blind that would come with GPS functionality and a route management facility as well as tracking services for guide dogs and family members. A ranking score accompanies the features on the left. The higher the value is, the more important the feature was rated. Within the “navigation and routing” theme, the four highest scoring features in descending order were the following.

- **Bookmark and manage routes:** This feature would enable the user to walk and record new pedestrian routes around the city, along with associated landmarks. Participants wished to “record” routes; i.e., they wished to press a button at the origin and, once again, at the destination to save a route. This feature also incorporates the option to reverse a saved route so that a return path is easy to manage. With such a route-management feature, a blind or vision-impaired person would have the confidence to take routes other than his/her standard ones.

- **City navigation guide:** This feature was ranked very high because it came very close to a complete personal navigator that participants wanted. It would incorporate navigation assistance, telling the user where and when to turn. In addition, it would announce the name of the street one is currently on, as well as the name of intersecting streets and house numbers. It would also inform the user about restaurants, cinemas, and theaters. Ideally, it would have public transportation assistance integrated.
• **Underground reception of service:** Participants reasoned that such a navigator would work well only if it was available anywhere, especially underground and large buildings. This would ensure the best possible reliability, and it would mean less need to ask around.

• **Show where peers are located:** The participants highly valued the usefulness of a mobile system that could track the position of peers, such as one’s children and spouse. The persons to be observed would carry a GPS device that transmits their current position to the observer’s mobile device or home computer. This service would ensure that blind parents knew where their children were located, one of many factors that would assure responsibility and thus equal participation in society.

**Emerging New Mobile Service—Virtual Voyager.** In the model evaluation section, all participants were made familiar with all seven themes to get feedback on them. A considerable portion of the participants stated that the themes “Navigation & Routing” and “Traffic & Public Transport Assistance” are highly related and that they would like to see them combined. The two themes together would allow blind people to explore unfamiliar areas. A German participant specifically stated that a mobile navigation device would make sense only if it had routing and tracking functionality combined with Europe-wide public transport and airport information. Overall, these two topic areas were rated first and third. Combining them to one system would certainly yield a service that would be highly valuable.

![Figure 3. Highlighted thematic map of “Navigation and Routing Device.”]

The theme “Shopping Assistant”, ranked second, caters for short-range navigation in stores. Such a mobile service would announce a shop that a user is passing, guide him/her to the correct aisle and identify a product on the shelf. A shopping assistant would fit to the wide-range navigation solution explained above. The name of a shop would be announced while a user is navigating through the streets. Moreover, all three themes would enable a more “independent lifestyle,” a value that was expressed over and over again when relating to features within these three categories. Therefore, we proposed in our business report a mobile service that would integrate all three themes: “Virtual Voyager.”

The conceptual model of the “Virtual Voyager” is illustrated in Figure 4. It emerged from the three top-rated themes as well as from the highest rated features within each theme. The themes and their features have been drawn from the theme maps of “Navigation and Routing Device,” “Shopping Assistant,” and “Traffic and Public Transport Assistant.” For the purposes of this conceptual model, the features were regrouped in an interpretive manner.
The first building block of the “Virtual Voyager” is a city navigation guide that navigates a blind person through cities and that takes care of routing and storing of routes. In addition, it integrates public transport information in the form of mobile timetables so that notifications about delays or variations in the schedule would be announced. Second, as part of a citywide navigation service, it would announce certain shops a person is passing, which relates to the next building block, shopping assistance. The third building block of the artifact is a personal safeguard assistant. It is able to warn of barriers on the footpath or elsewhere. It exchanges information with the routing feature to propose hazard-free routes. In addition, it can track the position of a family member or of a lost guide dog.

The fourth functional component of the conceptual model describes the technical specifications that were valued highest in relation to these topic areas. To start with, it should allow switching between car and vehicle modes. Next, it should be available anywhere, both underground and within large buildings. Third, it should be fairly easy to control, ideally with one hand so that the other hand can hold on to a leash or a cane. Lastly, the mobile device should release a certain sound signal when approaching particular points of interest.

**EVALUATION OF THE PROCEDURE**

Here is how we addressed each of the objectives developed above for a blind user RE procedure. This mapping of process features to objectives is summarized in Table 5.

Our objective with respect to motivation was to provide for convenient and safe logistical arrangements, clearly established mechanisms to establish trust, and incentive for participation. To better understand the affect of our methodology, we eschewed extrinsic motivation in favor of motivating participation on participants’ understanding of the public good of the research. To create trust as vetted strangers, we recruited through the recognized blind organizations in New Zealand and Germany, respectively. To minimize the inconvenience and anxiety of travel, we arranged for all interviewing to be conducted either by telephone or in person, at the convenience of the participant.

Our objective with respect to information processing was to avoid excess demands on working and long-term memory for participants. Use of stimuli developed from other participants works to pool long-term memory of participants to elicit more items. Individually interviewing participants on their two most preferred stimuli, using the laddering interviewing technique, minimized working memory demands by focusing on from one to a small number of concepts at a time. The two-step rank-ordering process for needs evaluation reduced the number of concepts considered at a time. In model evaluation, the talk-aloud scenarios chunk concepts into a smaller number of scenarios to create smaller working memory loads.

Our objective with respect to complexity was to elicit needs and preferences for functionality and features from participants who are unfamiliar with underlying processes and technology, without the use of visual materials. Selecting lead user members of the target population, i.e., members who are interested in exploring the use of new technologies, limits lack of understanding of the technologies in elicitation. In needs elicitation, the laddering technique breaks down participant constructs to consider one element at a time. In model aggregation structuring, the expressed preferences in attribute–consequence–values provides a very generalized structure for expressing participant preferences that doesn’t depend on the structure of the participant constructs. In model evaluation, the use of aggregated rank ordering for preferences is a simple, general concept easily understood by participants.
Our objective with respect to communication was to capture data in a manner that is structurally very flexible and that would represent results of analysis in a manner that is useful and understandable for managers and designers. The collection of stimuli from participants initiates the requirements elicitation with ideas that are expressed in terms of the participants’ knowledge. The laddering interviews allow participants to use their own knowledge structures to present reasoning data. The thematic clustering preserves these participant structures, while the model evaluation technique overlays this with a structure of priorities for use by managers. The use of the thematic maps, which present aggregated preferences in terms of attributes, consequences, and values, provides reasoning for the expressed preferences, which helps technical and managerial users of the analysis, in a manner that accommodates the participants’ own knowledge structures.

Overall, the procedure, described here and demonstrated with New Zealand and German blind participants, explicitly addresses all of the objectives that we developed above for a blind user RE process. The demonstration showed that it can be successfully used to develop preferences for applications and features for the target population. Indeed, the concepts for new applications developed in the demonstration appear at face value to be an interesting set of applications and features for services well targeted to the blind population and which do not already exist. This supports assertions in the introduction of this paper of the importance of including members of this population in RE activities, rather than merely accommodating their use ex post of applications that are designed for the general sighted population.

Since this is the first published RE procedure for blind users, there is not another method with which to compare its efficacy. Certainly we neither claim nor think that it represents a best possible method. We expect to pursue the development of RE methodology for use with the blind, and we would hope that others would do so also. It should be noted that none of the specific techniques or activities in this process was invented specifically for this use. All of the techniques used here have been used elsewhere. It is their combination to accomplish the objectives of this process and their adaptation for use with this target population that creates unique value.

The results of this procedure included ideas for new applications with features that would, if developed be very complex software and hardware projects. They were developed to level of specificity where they could, with additional business analysis, be the subject of project proposals. Obviously, the demonstration did not result in requirements specifications that could be used to move ahead to a project design phase. Extending our process to include all of the phases of requirements specifications would be valuable, although it might be argued that niche target population participation is most critical at the pre-project proposal stage, where ideas for new applications and features of particular importance to the population are incorporated into the initial project proposal.

<table>
<thead>
<tr>
<th>Method/Constraints</th>
<th>Motivation</th>
<th>Information processing</th>
<th>Complexity</th>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Study</td>
<td>Recruit subjects through trusted organizations</td>
<td>Lead-users as proxies for users</td>
<td>Stimuli collection for laddering</td>
<td></td>
</tr>
<tr>
<td>Needs Elicitation</td>
<td>Arrange interviews so as not to require travel—high convenience</td>
<td>Selecting attractive stimuli and laddering interviews limit demands on WM and LTM</td>
<td>Use of Laddering interviewing technique breaks down participant construct</td>
<td>Use of Laddering—participants use own constructs</td>
</tr>
<tr>
<td>Needs Evaluation</td>
<td>Initial evaluation at end of telephone interview</td>
<td>Two step rank ordering best features</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Aggregation</td>
<td></td>
<td>Use of attribute/feature—consequence—value—goal structure for data</td>
<td>Thematic clustering of requirements—participants’ own constructs</td>
<td></td>
</tr>
<tr>
<td>Model Evaluation</td>
<td>Telephone follow-up with initial participants</td>
<td>Talk-aloud scenarios of feature subthemes chunk items</td>
<td>Use aggregated rank order data of elicited requirements.</td>
<td>Provide numerical data for cross-comparison of features</td>
</tr>
<tr>
<td>Presentation</td>
<td></td>
<td></td>
<td>Thematic maps: reasoning with preferences to aid understanding</td>
<td></td>
</tr>
</tbody>
</table>
CONCLUSIONS

In this study we identified an important RE problem: the need to design RE methods for blind users, so as to be able to effectively determine requirements for systems targeted to these users, and we identified three objectives for a method to accomplish this, aggressive participant recruitment, non-visual data gathering, and accommodation to working memory limitations among participants. We designed a procedure to accomplish these objectives and demonstrated its use to develop the requirements for mobile services tailored to blind users. The demonstration includes a conceptual proposal for a system to be implemented. Finally, we evaluated the proposed method in terms of how we were able meet the objectives.

We see that the proposed requirements engineering method holds promise for use in research and practice to develop a variety of applications, services, products, and accommodations for use by blind people. In addition, our success in using a design science approach to develop this new method suggests that the same approach might be used to design RE methods tailored to other hard-to-reach populations, such as Islamic women or the learning disabled.

As the first paper to directly address the problem of designing RE methodology for the blind, this paper represents early research. This is a complex problem that one paper cannot fully solve. We have motivated study about the problem, developed a theoretical frame in which to study it, demonstrated the design of a solution, and shown that, when blind participants are given the chance to participate in RE activities, they have unique needs and preferences to express. Many other aspects of the problem remain to be addressed in subsequent studies. For example, this study was conducted at a high level of abstraction, to develop ideas for applications and features. Subsequent studies must also carry the problem to a much more fine-grained level. We carried the problem through the initial participant recruitment, data collection, analysis, and presentation. Subsequent research should carry the problem all of the way through the development process. This project concluded with a conceptual evaluation of the designed methodology. Subsequent research that continues through the entire RE process and beyond will be able to conduct much stronger evaluation.

Here we proposed a portfolio of techniques, none of which are individually novel. There is no intention here to suggest that they must be used in an all-or-nothing manner or that other techniques will not work as well, depending on the context and purpose of the study.

The use of lead users and the snowballing recruitment techniques necessarily result in a non-representative sample, i.e., the sample does not represent the population of blind users. The snowballing technique is intended as an effective behavior to identify members of a subpopulation that might otherwise be difficult to locate and, because one subject refers the analysts to the next, to vet the researcher for trust. The lead user concept is intended to identify members of a population who are more likely to be able to participate effectively in data collection, particularly when the subject of the data collection involves innovative products or technology. Lead user samples have been used effectively to anticipate the preferences of mass audiences. There cannot be any certainty, however, that the mass audience’s preferences will eventually mimic those of the lead users for any particular set of ideas, preferences, or product features. Indeed it seems likely that some portion of the population of blind persons may never be interested in some of the ideas expressed by the participants. If we were attempting to paint an unbiased picture of the preferences of the population, this would be worrisome. For the purpose of designing new systems and products, however, this is not a problem. No system will be attractive to all members of a population and one that is attractive to a substantial portion may create much value.

Finally, it may be obvious to the reader that none of the techniques proposed here are applicable only for use with the blind. This is a very positive attribute of the methodology. Instead of designing a methodology for the sighted and accommodating blind participants, we have designed one for the blind that is already fully usable with the sighted, without the need for any accessibility accommodation.
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