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ABSTRACT

Our motivation is the belief that blind students cannot participate effectively in Web-enhanced instruction due to challenges in non-visual Web interactions. We want to understand nature of accessibility and usability problems they face in WEI environments. Literature informs the Web lacks accessibility and usability, but does not explain what aspects of WEI interactions present difficulties for the blind. This is necessary to improve their WEI participation. Our user-centered, task-oriented approach relies on sound understanding of blind students' WEI experiences, supplemented by perspectives of instructors, developers and accessibility standards. We employ protocol analysis of blind participants' verbal reports, content analysis of instructor and developer interviews, and objective accessibility evaluation. Results explain where and why difficulties occur; their character; associated interface elements; coping mechanisms and possible solutions. Findings help instructors, developers and accessibility researchers better appreciate blind students' needs and challenges. It will help develop WEI environments that support non-visual WEI participation.

Keywords

Accessibility, Usability, Web-enhanced instruction, Blindness, Verbal Protocol Analysis.

INTRODUCTION

Web-enhanced Instruction (WEI) is a common practice for delivering academic programs where students accomplish learning tasks on-line using Web-based systems (Landry, et al. 2006). The central premise of this research is that blind students have difficulty participating effectively in WEI due to problems inherent in non-visual Web interaction. Approximately 37 million people around the world do not have the functional vision to read from a computer screen or operate a mouse (World Health Organization, 2004). They interact with the Web aurally based on speech output of a screen-reader software. Research shows that the Web lacks the accessibility and usability needed for non-visual Web interaction (Lazar, et al. 2007; Leuthold, et al. 2008). Accessibility allows users access to system functionality (Goodhue, 1986). Usability is the degree to which a system conforms to a user's cognitive perception about performing a task (Goodwin, 1987). The lack of web accessibility and usability is undesirable for all users; it creates additional problems for the blind (Correani, et al. 2004). Accessibility and usability problems in WEI environments prevent blind students from accomplishing academic goals effectively.

Extant literature lacks a sound understanding of the nature of problems blind users experience in Web interactions. The majority of studies adopt a techno-centric view, attributing the source of this problem to the graphical interface (Leuthold, et al. 2008). This techno-centric view is not informed by a blind user's perspective on the problem. Very scant research examines a blind user's Web experience (Theofanos & Redish, 2003; Lazar, et al. 2007). This does not provide a clear understanding of where and why blind users face difficulty in Web interactions. This understanding is critically needed for developing interventions and design modifications that will enable blind students function effectively in WEI environments. Our research develops this understanding.

We want to understand the nature of accessibility and usability problems that blind students face in performing common WEI tasks. Non-visual Web interaction has a set of unique challenges. These challenges are confounded by Web developers' focus on visual Web interaction as well as by WCAG's (Web Content Accessibility Guidelines) inability to address these challenges completely. Our research considers all these aspects to develop a holistic understanding of the problem. We will

adopt a user-centered, task-oriented approach where the focus of inquiry will be blind students' experience in completing WEI tasks. We will employ an integrated problem-solving framework and verbal protocol analysis to gain an in-depth understanding of difficulties experienced by blind participants. We will incorporate into this understanding the perspectives of (1) instructors of these students, (2) Web developers and (3) WCAG.

Results will provide a holistic understanding of accessibility and usability problems blind students face in WEI environments. This will explain what aspect of a WEI task is difficult for blind student; what is the character of this difficulty; what interface elements are associated with this difficulty; how instructors, web developers and WCAG view this difficulty; what work-around strategies and possible remedies are available. This basic knowledge will help instructors, Web developers and Web accessibility researchers better appreciate the needs and challenges of blind students in WEI. Web developers can use this knowledge to understand if their Web systems can be effectively used by blind students for academic purposes. Instructors will use this knowledge to determine if a WEI task is appropriately presented for blind students, in addition to being well-informed to mentor such students for effective WEI participation. The outcome of this study will comprise the foundational research needed to create a barrier-free learning environment for blind students in today's WEI-based education.

We organize the rest of the paper as follows. In the next section, we summarize our current understanding of the problems blind users face on the Web, leading to our research question. We then describe our novel approach and present a framework to guide our investigation of the research question. To implement this approach, we will employ a qualitative method. We discuss our research design in the subsequent section. We briefly explain what outcome we expect of this research. We conclude by outlining the streams of research we plan in future based on the outcome of this research.

LITERATURE REVIEW

Blind users interact with the Web through a screen-reader. Screen-readers recognize textual content on a Web page and read this to the user sequentially (Leuthold, et al. 2008). This mode of interaction has its unique set of problems. Based on analysis of the scant literature on blind users' Web experience, we summarize these problems as follows:

i. The sequential nature of interaction means at any given point, users perceive only a snippet of the content, losing all contextual information (Lazar, et al. 2007).
ii. Users cannot appreciate information embedded in graphical elements since screen-readers are designed to recognize only textual content (Leuthold, et al. 2008).
iii. Inability to quickly scan a page makes locating goal-relevant information difficult (Di Blas, et al, 2004).
iv. When Web pages have a complex layout, screen-reader's feedback becomes ambiguous (Lazar, et al. 2007). Screen-readers also mispronounce many words (Theofanos & Redish, 2003). These create comprehension problems for the blind.
v. The wide range of screen-reader functionality makes it difficult for users to remember and use appropriate functions for Web interaction (Theofanos & Redish, 2003).
vi. User's spend their cognitive resources in trying to understand the Web browser, the Web site and the screen reader (Theofanos & Redish, 2003). This contributes to a cognitive overload in non-visual Web interaction (Millar, 1994; Thinus-Blanc & Gaunet, 1997).

Literature does not provide a sound understanding about the nature of problems blind students face in interacting with WEI systems. These interactions are driven by the need to perform a task (e.g. assessment, assignment, class discussion). Current knowledge does not help us understand where and why a blind student experiences difficulty in performing a WEI task. An experiential understanding of the problem is needed to develop interactive techniques for effective use of a system (Foley, et al. 1984). Addressing blind students' accessibility and usability problems will first need a sound understanding of their difficulties in completing WEI tasks. Through this research, we will examine the question:

What is the nature of accessibility and usability problems blind students face in performing WEI tasks?

APPROACH

In this research, we adopt a cognitive, user-centered, task-oriented approach to develop a holistic understanding of problems blind students experience in WEI. A cognitive view helps us understand how blind students think about a problem, and how they conceptualize a solution. A user-centered view presents the problem in the perspective of blind students' experience in Web interaction. A task-oriented view explains what aspects of a WEI task are problematic for the blind. We will implement our approach through an in-depth examination of thoughts, perceptions, and actions of blind students in performing WEI

tasks. Performing a goal-oriented task proceeds in the same way as solving a problem (Newell & Simon, 1972). A problem-solving framework will help us examine what blind students think, perceive and act in WEI tasks. We have developed an integrated problem-solving framework by synthesizing research in cognitive science and HCI to conduct this examination. We next present this framework.

Newell and Simon (1972) proposed the problem solving theory that characterizes how people perform regular problem-solving tasks. Norman (1988) proposed the Seven-Staged Action model to explain problem-solving tasks using information systems. Both these models inform our research what blind students are likely to go through in performing WEI tasks. Norman's (1988) action model also helps us identify and understand users' difficulties in problem solving. According to Norman (1988), difficulties arise when users fail to determine (1) relationship between intended actions and system mechanisms, (2) functions of a control; (3) mapping between controls and functions; and (4) inadequate feedback for verifying outcomes of actions (Norman, 1988). These inconsistencies correspond to two types of gulfs (Norman, 1988):

a. Gulf of execution: This represents a mismatch between a user's intentions and system's allowable actions. Users have difficulty translating goals into actions.

b. Gulf of evaluation: This represents the mismatch between the system's physical representation and the user's ability to perceive and interpret it directly with respect to her expectation. This gulf is large if feedback is difficult to perceive, interpret and is inconsistent with user's expectation.

These gulfs explain the perceived inconsistencies between expected and observed system behavior (Bhattacherjee, 2001). In this research, we use the term *incongruence* to denote blind people's difficulty in completing Web-based tasks due to gulfs of execution or evaluation. We further use the term *dissonance* as a label for difficulties resulting from a gulf of execution, and *failure* as a label for difficulties resulting from a gulf of evaluation.

We used concepts drawn from problem solving theory (Newell & Simon, 1972) and the 7-staged action model (Norman, 1988) to propose an integrated problem solving framework that guides our research. This framework characterizes a blind student's interaction with WEI environment as:

1. Problem formulation: The user formulates the problem and selects a problem space that represents her understanding of a WEI task.
2. Method: She chooses a problem-solving method. This method comprises a sequence of actions rationally associated with attaining a solution, as formulated and seen in terms of problem formulation.
3. Expectation: She forms an expectation that by executing an action of the sequence, she will receive a specific response from the WEI environment.
4. Action: She executes the chosen method by interacting with the WEI environment. This typically proceeds through several stages. At each stage, the user performs an action and the system provides a response (Borgman, 1986). Since a blind user does not use a mouse, all actions involve keystrokes.
5. Perceive system state: She perceives response of the WEI environment to an action. A blind user relies on screen-reader's announcement to perceive any system response.
6. Interpretation: She evaluates the system response with respect to her expectation. This gives rise to two possibilities:
7. Dissonance: She fails to interpret the system response. This situation arises because of two reasons (Norman, 1988). First, she did not receive enough feedback about the system response. This prompts her to search for another method. Second, she received a feedback that was inconsistent with her expectation. This prompts her to reformulate the problem (Newell & Simon, 1972).
8. Consonance: She interprets the system response. This gives rise to two possibilities:
9. Failure: The goal remains unattained. This could result because of a gulf of execution. This will prompt the user to reformulate the problem.
10. Success: The goal is accomplished. She will move to the subsequent task or sub-task.

This framework will guide our examination of blind students' thought processes in WEI tasks, and help us trace their difficulties. In order to characterize these difficulties, we will use a set of accessibility and usability principles. The accessibility principles we choose represent design recommendations of WCAG. We choose usability principles proposed by renowned HCI scholars.

WCAG is the de facto standard on Web accessibility established by the World Wide Web Consortium (W3C) (Kelly, et al. 2005). Its current version (WCAG 2.0) became operational in December 2008 (http://www.w3.org/TR/WCAG20). This

includes a hierarchy of 4 guidelines and 18 checkpoints. The guidelines – perceivability, understandability, operability and robustness represent four principles of accessible Web design (Kelly, et al. 2005). In the context of non-visual Web interaction, these principles recommend:

1. Perceivable: A blind user can perceive a Web interface element;
2. Operable: A blind user can operate an interface Element;
3. Understandable: A blind user can understand all content and controls; and
4. Robust: The screen reader can interoperate with every interface element.

We adopt usability principles proposed by Nielsen (1993), Norman (1988), Shneiderman (2004). These principles include:

1. *Learnability*. First-time Web site users can quickly find information and use functionality (Nielsen, 1993).
2. *Efficiency*. Users can accomplish online tasks quickly, without much cognitive effort (Nielsen, 1993).
3. *Errors*. Users are prone to committing few errors and can recover from these quickly (Nielsen, 1993).
4. *Satisfaction*. Users are satisfied with how the website works (Nielsen, 1993).
5. *Memorability*. Returning users don't have to relearn how to use the Web site (Nielsen, 1993).
6. *Visibility*. Users can detect system behavior and alternatives for action by observing it (Norman, 1988).
7. *Good mappings*. Users can determine the relationships between actions and results, between the controls and their effects and between the system state and what is visible (Norman, 1988).
8. *Feedback*. Users receive full and continuous feedback about the results of actions (Norman, 1988).
9. *Consistency*. Sequence of action is consistent in similar situations; labeling, order and effects of user interface elements are consistent (Shneiderman & Plaisant, 2004).
10. *Working memory load*. Displays are kept simple, multiple page displays are consolidated and window-motion frequency is reduced (Shneiderman & Plaisant, 2004).

We will use these accessibility and usability principles to understand blind students' difficulties in WEI environments.

RESEARCH DESIGN

Our research design employs qualitative analysis to understand blind students' task-oriented problem solving and accessibility and usability problems in WEI. We supplement this with supportive understanding from instructors, Web developers and WCAG. The objective is to develop a holistic understanding of the nature of accessibility and usability problems blind students face in WEI environments. We employ verbal protocol analysis using our integrated problem-solving framework to examine blind students' thoughts and actions in WEI tasks and trace their accessibility and usability problems. This will provide a mapping of Web interface elements and the nature of problems these create. We will interview instructors who work with blind students and Web developers to understand their perspectives on these problems. We will conduct objective evaluation of Web pages used in WEI to understand WCAG's perspective on these problems. Synthesis of understanding from various perspectives will reveal a holistic understanding of accessibility and usability problems blind students face in Web interactions needed for WEI tasks.

METHOD

Our qualitative method employs verbal protocol analysis (VPA), open-ended interviews and objective evaluation of Web accessibility. We employ VPA to understand the problem from blind students' perspective. VPA is an effective technique to collect and analyze verbal data to examine human problem solving (Ericsson & Simon, 1984; Todd & Benbasat, 1987). In VPA, participants verbalize their thoughts on performing a task. These verbalizations can be either concurrent or retrospective to the task. Concurrent verbal protocols provide access to knowledge in short-term memory, while retrospective verbal protocols reveal knowledge in long-term memory (Ericsson & Simon, 1984). VPA is very appropriate for identifying usability problems in Web sites (Cotton & Gresty, 2006). It offers an effective and feasible method for our investigation of blind students' problem solving as well as accessibility and usability problems in WEI tasks. We will conduct a series of one-on-one blind-user studies where participants think aloud while working on a set of tasks.

The tasks we have chosen are representative of common WEI activities. Students perform these activities over Web-based CMS (Landry, et al. 2006). Using a CMS, we have designed the following set of tasks:

i. Access electronic course: Participants log into CMS account and locate courses they are enrolled in.
ii. Reading class announcements.

iii. Conducting Internet research. They search for online information on a topic. We will suggest three resources: Wikipedia.com, Answers.com and Google.com
iv. Completing assessment. They complete online assessments using three common question formats: multiple-choice, multiple-answer and essay-type.
v. Submitting assignment. They report work in a Word document and upload it on the CMS. They report work by typing into an input field in the CMS. The purpose is to identify challenges associated with different modes of assignment submission.
vi. Participating in class discussion. We want to assess experience using online discussion threads.

Using VPA for these tasks allows us to develop a deep understanding of blind students' difficulties in Web Interactions required for completing WEI tasks.

In addition, we employ open-ended interviews to understand the perspectives of blind students' instructors and Web developers. Interviews with instructors help us obtain an outsider's perspective on problems identified by blind students. Personal interviews with Web developers allow us to understand the Web design aspect of the problem. We employ objective evaluation of Web pages using accessibility checkers that evaluate the WCAG compliance of a web page. These provide information from various perspectives that allow us to develop a holistic understanding of blind students' problems.

EVIDENCE GATHERING

Our research design comprises four evidence gathering activities. The first activity generates the primary evidence based on the blind-user studies. The other three activities generate supplemental evidence based on perspectives of instructors, Web developers and WCAG. We will need three categories of research participants:

a. Blind students with a basic experience in using the Web
b. Technology instructors experienced in working with blind students
c. Web developers experienced in creating accessible Web systems.

We have access to blind students and technology instructors through institutions of special education across four states in the U.S. These institutions include North Carolina Division of Services for the Blind, Texas School for the Blind & Visually Impaired, Iowa Department for the Blind and Michigan Commission for the Blind. These institutions offer computer courses through technology instructors to train blind citizens in the use of the Web. These instructors have long-term experience working with blind students. We will conduct the blind-user studies and instructor interviews in the premises of their respective institutions. We have access to Web developers through a major software firm. These Web developers serve in usability teams responsible for incorporating WCAG into Web applications. We will interview these developers at the participating firm. We plan to recruit 6 to 8 blind students, 3 instructors and 3 developers as research participants.

Our first evidence gathering activity will involve a series of blind-user studies where participants will work on the set of tasks and concurrently verbalize task-relevant thoughts. To remove the reactivity of verbalizing on task performance, we will conduct practice sessions for participants on concurrent verbalizations before these studies. In each study, we will instruct participants to verbalize specific kinds of thoughts that are needed in this research. This includes five aspects of the task: Goal; Plan of action; Actions being executed; Outcome of action; and Basis of interpretation. We will make audio recordings of each participant's verbalizations and the speech output of the screen-reader.

The next set of activities will provide supplemental evidence based on perspectives of technology instructors, Web developers and WCAG.

Technology instructors: We will interview instructors to seek their views on: (a) difficulties experienced by blind students; (b) difficulties created by an interface element; and (c) work-around strategies. These insights will help us triangulate the findings of the blind-user studies. We will make audio recordings of these interviews.

Web Developers: We will interview developers to understand their perspective on the problems identified in the user studies. Presenting our findings about the problems, we will seek their opinion on: (a) difficulties experienced by blind students; (b) difficulties created by an interface element; (c) possible solutions; and (d) constraints in incorporating relevant WCAG recommendations into an interface element. We will make audio-recordings of these interviews.

WCAG: We will understand the aspect of problem concerned with Web accessibility standards by analyzing the Web pages used against WCAG recommendations. This analysis includes objective evaluation of Web interface elements for accessibility using an evaluation tool. An accessibility checker is an evaluation tool used for empirical evaluation of Web sites for WCAG compliance. Although WCAG 2.0 supersedes WCAG 1.0, the latter is still in use. We will use an

accessibility checker that analyzes using standards of WCAG 1.0 and WCAG 2.0. This will allow us to develop a comprehensive understanding of the problems with the design recommendations in both WCAG versions.

TRANSCRIPTION AND CODING

We will transcribe all the audio-recordings into three sets of rich qualitative evidence. The first set corresponds to evidence gathered from blind participants including their verbalizations, conversations with researchers and screen-reader's speech output. We will separate participants' verbalizations and decompose these into single units of thoughts or segments. We will categorize these segments using our coding scheme corresponding to stages of our integrated problem solving framework. We will include an additional category for miscellaneous segments. The second set of transcription corresponds to instructor interviews. We will code these transcripts into segments representing three kinds of evidence: difficulties of blind students, difficulties presented by interface elements and work-around strategies. The third set comprises transcripts of Web developer interviews which will be coded into four kinds of evidence: blind students' difficulties, difficulties presented by interface elements, constraints in WCAG implementation and possible solutions.

ANALYSIS

We will analyze coded verbalizations of blind participants to examine their thoughts and actions at each stage of a task. This will help us understand their problem solving approach and trace their difficulties to specific aspects of WEI tasks. Segments labeled as Dissonance or Failure represent difficulties experienced by blind participants. We will characterize each difficulty as accessibility and/or usability problem. We will identify interface elements associated with a difficulty by extracting information intrinsic to relevant segments. We will compare corresponding segments of different participants to understand different types of problems presented by an interface element. We will validate these findings by requesting participants for verification. We will perform content analysis of interviews with technology instructors and Web developers per established norms of qualitative methods. Analysis of instructor interviews will triangulate the problem from blind students' perspective. In addition, we expect this to identify work-around strategies to deal with a problem. We will analyze developer interviews to understand Web design aspects of the problem. We also expect this to identify possible design modifications as solution to a problem. These design modifications can be validated in a future research. Our empirical analysis of the Web pages used by blind participants will comprise a report that displays a page-wise assessment of accessibility problems with each interface element in terms of WCAG 1.0 and WCAG 2.0. We will perform a final analysis by integrating results of each kind of analysis to obtain a holistic understanding of blind students' accessibility and usability problems in WEI tasks.

EXPECTED RESULTS

The synthesized results comprise the holistic and foundational understanding of: where and why blind students face difficulties in WEI tasks; what is the character of the difficulty; what interface elements cause this difficulty; the kind of difficulties a specific element creates; how blind instructors, web developers and WCAG view the difficulty; what work-around strategies and possible solutions are available. The outcome is a multidimensional view of accessibility and usability problems of blind students defined at an atomic level.

This basic level understanding will help Web developers, instructors and Web accessibility researchers better appreciate the needs and challenges of blind students in Web interactions needed for participating in WEI. Web developers can use this knowledge to choose interface elements for designing accessible WEI systems (e.g. CMS). An outcome of this research will be a preliminary assessment of WCAG's efficacy. Verbal protocol analysis of blind participants' thoughts on perceivability, understandability and operability of interface elements will test WCAG's effectiveness in meeting blind users' accessibility needs. Future research can use this finding for comprehensive WCAG assessments. Instructors will find this knowledge helpful to understand if a WEI task is appropriately presented for blind students, and be adequately informed to mentor them for participating in WEI. Findings of our research will guide the development of interventions and design modifications needed to enable blind students overcome challenges in non-visual Web interaction, and participate effectively in WEI.

FUTURE RESEARCH

Successful completion of this dissertation will lay the foundation for our long-term research agenda to help the blind function effectively in Web environments. In a future study, we will examine the problem at a global level and in other contexts. We will obtain evidence from a larger number of participants. Findings of that study will add another dimension to the kind of understanding we develop here. Our future plan includes development and evaluation of two interventions to educate instructors and Web developers about non-visual Web interaction. A small scale pilot study we conducted earlier revealed that blind participants had difficulty completing online assessment due to several accessibility and usability problems. This

implies that test scores of blind students will be indicative of not just academic skill, but also of the presentation of the assessment task. We plan for an intervention to train instructors of blind students about their special needs and challenges in WEI tasks. The purpose is to enable these instructors better accommodate the challenges of blind students while creating on-line academic tasks.

Research shows that Web developers' lack of awareness about needs and challenges of target users gives rise to problems in Web interaction. Research also informs that most Web developers are totally ignorant about non-visual Web interaction. If Web developers are made aware of the kind of problems blind people face in using their Web sites, they will use interactive techniques suitable for non-visual Web interaction. We want to develop an intervention to educate Web developers about experience of blind students in WEI.

Web Accessibility Initiative (WAI) operationalized WCAG 2.0 in December 2008. It's efficacy in addressing accessibility problems of various groups of disabled users has not been assessed. Some usability experts have expressed reservations about its efficacy in meeting needs of blind users. In a future research, we want to assess WCAG's efficacy based on a textual and functional analysis. Findings of this project will be useful in such an assessment. If WCAG fails the assessment, we will identify missing and outstanding requirements for improving its efficacy for blind users. This will assume the form of an improved set of guidelines for Web accessibility and usability. We will create a Wiki to seek feedback from Web developers and experts serving in the WAI on these guidelines. We will explore ways in which our guidelines can be incorporated into the future amendment of WCAG.

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