BABU, RAKESH, Ph.D. Developing an Understanding of the Nature of Accessibility and Usability Problems Blind Students Face in Web-Enhanced Instruction Environments. (2011)
Directed by Dr. Rahul Singh. 234 pp.

The central premise of this research is that blind and visually impaired (BVI) people cannot use the Internet effectively due to accessibility and usability problems. Use of the Internet is indispensable in today's education system that relies on Web-enhanced instruction (WEI). Therefore, BVI students cannot participate effectively in WEI. Extant literature recognizes that non-visual Web interaction is inherently challenging. However, it does not explain where, how and why BVI students face accessibility and usability problems in performing academic tasks in WEI. This knowledge is necessary to adequately inform the development of interventions that improve the functional and academic outcomes of BVI students in WEI.

The purpose of this doctoral research is to understand the nature of accessibility and usability problems BVI students face in WEI environments. It adopts a novel user-centered, task-oriented, cognitive approach to develop an in-depth, contextually-situated, observational and experiential knowledge of these problems. The context of WEI experience under investigation is an online exam over a typical course management system. Research design is a qualitative field study that involves a multimethod evaluation of the WEI environment. The core component of this multimethod evaluation is BVI students' assessment of the WEI environment. This is triangulated through assessments made by WCAG (Web Content Accessibility Guidelines) and Web developers. The BVI student assessment employs an integrated problem solving model,

in combination with verbal protocol analysis, to identify and understand where, how and why BVI students face a problem in completing the exam. The WCAG assessment employs automated accessibility testing and WCAG textual analysis to identify interface objects that violate accessibility standards and characterizes a problem. The Web developer assessment involves open-ended interviews to identify the source of a problem.

Results show that the WEI environment consisted of innumerable interface objects that violated WCAG's standards on Web accessibility and usability. BVI participants faced many accessibility and usability problems that posed significant challenges completing the online exam. These problems fall into six major problem types as described below:

1. Confusion while navigating across WEI environment due to its frame-based page structure without unique frame names;
2. Susceptibility to submitting incomplete work when a new question page does not provide location and contextual information;
3. Difficulty understanding how to submit work when the selection controls for multiple option questions lack a consistent keyboard navigation procedure;
4. Inability to negotiate security information pop-up when the WEI environment uses an alert dialogue box;
5. Ambiguity in essay-type question page that lack meaningful labels for interface objects, including text area and text formatting toolbar;

6. Vulnerability of losing work when Backspace behaves as browser's Back button inside text area.

This doctoral research contributes in three ways. It fills the knowledge gap about the nature of problems BVI students face in Web interactions for academic tasks. This kind of knowledge is necessary to determine accessibility and usability requirements for WEI. Another contribution is a set of mental model representations that explicate the thought processes of BVI students. Such representations are useful in developing user instruction and design of more accessible and usable Web sites. A third contribution is a user-centered, task-based, cognitive and multi-method approach to evaluate Web accessibility and usability.

DEVELOPING AN UNDERSTANDING OF THE NATURE

OF ACCESSIBILITY AND USABILITY PROBLEMS

BLIND STUDENTS FACE IN WEB-ENHANCED

INSTRUCTION ENVIRONMENTS

BY

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A Dissertation Submitted to
The Faculty of The Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
2011

Approved by

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APPROVAL PAGE

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ACKNOWLEDGEMENTS

I wish to thank my doctoral advisor Dr. Rahul Singh and other members of the dissertation committee for their help and guidance throughout this doctoral study. I thank the National Science Foundation for funding this doctoral research. A special thanks to Dr. Betty Tullar - Program Officer of the Perception-Action-Cognition program of NSF. Thanks to the Graduate School at UNCG for its support to this doctoral study. I wish to thank the North Carolina Division of Services for the Blind (DSB) and UNCG's Office of Disability Services for their support in the form of reading services and assistive technology needed for this research. I wish to thank DSB and the Texas School for the BVI for allowing me access to their BVI students and computer labs needed to conduct this research. I thank Infosys Technologies Ltd and Braille Without Borders for allowing me access to their Web developers.

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CHAPTER I

INTRODUCTION

Imagine the following scenario:

A student sits in front of a computer to take an online exam for a class. Though the computer is on, the screen is dark. A closer observation shows that this student has her headphones on. She rarely looks in the direction of the computer screen. This student is blind. She is listening to a Web site through a text-to-speech program called screen-reader. What she hears is not a complete narration of the information on a Web page; it is merely a translation of on-screen text into synthetic speech. There are no graphics in this rendition of the Internet. There are no cues to assist with successful interaction, other than those embedded in the text. For all intents and purposes, this Internet is a continuous audio stream, which lacks logical sections or segments.

Such is the experience of a blind or visually impaired (BVI) student as she interacts with the most powerful tool of the information society - the Web.

The purpose of this doctoral research is to develop an in-depth, contextually-situated, observational and experiential knowledge of accessibility and usability problems BVI students face in interacting with the Web to accomplish academic tasks. I organize this chapter in the following way. Section 1 explains the motivation and research problem. Section 2 discusses existing research on this topic and identifies the knowledge gap. Section 3 outlines the research question that guides this doctoral study. Section 4 describes a novel approach to answer this question. Section 5 describes the methodology and research design used to implement this approach. Section 6 discusses the results and analysis. Section 7 explains the contributions and implications of this doctoral research. Section 8 concludes this chapter by outlining the dissertation organization.

1.1 Motivation and Problem

Web-enhanced Instruction (WEI) is a common practice to deliver academic programs where students accomplish coursework by interacting with Web-based systems such as course management systems (CMS), digital libraries and online informational resources (Landry, et al. 2006). The central premise of this doctoral research is that blind and visually impaired (BVI) students cannot participate effectively in WEI due to inherent challenges in non-visual interaction (NVI). Much academic and institutional research supports this premise (Babu & Singh, 2009; Lazar et al., 2007; American Foundation for the Blind, 2008). The Web is designed primarily for visual interaction (Bradbard and Peters, 2008). Users see information presented on Web pages and provide mouse or keyboard inputs. This sight-centered design creates significant accessibility and usability challenges in NVI (Babu, et al. 2010; Babu and Singh, 2009; Leuthold, et al., 2008; Lazar, et al., 2007). More than 314 million people around the world lack the functional vision necessary to see information presented on a computer screen or operate a mouse (World Health Organization, 2009). They interact with the Web by listening to speech output from screen-reading assistive technology. Accessibility allows users access to system functionality (Goodhue, 1986). Usability is how well the system fits with user's notion of performing a system-based task (Goodwin, 1987) . Although lack of accessibility and usability is undesirable in any condition, it creates additional challenges in NVI (Leuthold, et al., 2008). BVI users are half as likely to complete online tasks as their sighted counterparts (Correani, et al. 2004). Considering that online tasks are integral parts of course activities, BVI students are at a significant disadvantage in WEI. Addressing accessibility and usability problems in WEI environment can improve the functional and academic outcomes for BVI students in the information society.

1.2 Extant Research and Knowledge Gap

Extant literature recognizes that Web interaction is challenging for the BVI but does not clearly explain the nature of problems they face. BVI students 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). My literature analysis informs that this non-visual interaction has its unique set of constraints. I summarize these constraints 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 images, color, and lay-out 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). Users are forced to hear information repeated across pages, such as Web site headers and navigational links on every page. This contributes to information overload (Chandrashekar, 2010).

iv. Reliance on Keyboard input method means users cannot negotiate many Web sites that support mouse-only interactions (Chandrashekar, 2010).

v. 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 BVI.

vi. The wide range of screen-reader functionality makes it difficult for users to remember and use appropriate functions for Web interaction (Theofanos & Redish, 2003).

vii. 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).

Constraints in NVI slow down Web interaction for BVI users and contribute to a great deal of frustration (Lazar, et al., 2007). Their frustration is compounded by the fact that visual cues on web pages that aid navigation and interpretation are not directly available. Their Web experience is also influenced by how well they can use their screen reader to negotiate web pages (Chandrashekar, 2010). Challenges of BVI users on the Web is confounded by lack of support for NVI due to ignorance of developers and designers about special needs of BVI users (Lazar, et al., 2003). Design standards on Web accessibility and usability (e.g. Web Content Accessibility Guidelines) are available

(Kelly, et al., 2005). However, compliance with such standards does not ensure a barrier-free Web experience for the BVI (Mankoff, et al., 2005; Clark, 2006; di Blas, et al., 2004).

Existing research addresses problems in non-visual Web interaction through technical solutions (Takagi, et al., 2004; Tonn-Eichstädt, 2006; Lunn, et al., 2009; Hailpern, et al., 2009; Mikovec, et al., 2009; Yu, et al. 2006; Mahmud, 2007). These solutions try to achieve standardization, better interface design and improve screen-reading technology. Yet, Web accessibility and usability remain challenging for the BVI (Babu and Singh, 2009; Leuthold, et al. 2008; Lazar, et al. 2007; Hailpern, et al., 2009; Mikovec, et al., 2009). A critical limitation in existing literature is a sound understanding of the nature of problems BVI users face in Web interactions. These interactions are driven by the need to perform a task. In WEI, students go on-line for taking an exam, completing an assignment, participating in class discussion and doing Internet research . Existing literature does not help us understand where, how and why a blind student faces difficulty completing a WEI task. An observational and experiential knowledge of user's difficulties in Web interaction tasks is needed to accurately assess the accessibility and usability problems in Web-based systems (Foley, et al. 1984). Existing research approaches are not adequate to develop such observational and experiential knowledge of a BVI student's Web interaction challenges. We need new research approaches to develop an in-depth, contextually-situated, observational and experiential knowledge of accessibility and usability problems BVI students face in WEI interactions. Without this, efforts to improve WEI accessibility and usability for the BVI will remain ineffective.

This dissertation explains a new research approach to develop the kind of understanding necessary to fill the literature gap.

1.3 Research Question

What is the nature of accessibility and usability problems BVI students face in WEI environments?

1.4 Approach

I adopt a cognitive, user-centered, task-oriented approach founded on research in human-computer interaction (Norman, 1988; Norman, 1983; Young, 1983), problem-solving (Newell and Simon, 1972) and mental model (Johnson-Laird, 1980; Johnson-Laird, 1989; Johnson-Laird et al., 1992). Accessibility and usability problems result from a discrepancy between expected and observed outcomes of user actions in an online task. The cognitive view explains how a problem manifests in the mind of blind students. The user-centered view presents the problem with respect to needs and challenges of BVI students in WEI interactions. The task-oriented view situates the problem in the context of the student's goal of WEI interaction.

Founded on Norman's (1988) Action Model, this approach conceives a WEI interaction problem as BVI students failure 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. These inconsistencies correspond to two types of gulfs (Norman, 1988):

a. Gulf of execution: This represents a mismatch between a student's intentions and the WEI system's allowable actions. Students have difficulty translating goals into actions.

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

These gulfs explain the perceived inconsistencies between expected and observed system behavior (Bhattacherjee, 2001). In this doctoral research, I use the term incongruence to denote BVI students' difficulty in completing WEI tasks due to gulfs of execution or evaluation. I 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.

My approach requires a close examination of perceptions, actions and cognitions of BVI students in completing online tasks. I developed an integrated problem-solving framework to guide this examination. It characterizes a BVI student's interaction with WEI environment as:

1. ***Problem Formulation:*** The student formulates the problem (goal) 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 BVI students do not use a mouse, all actions involve keystrokes.

5. ***Perceive System State:*** She perceives response of the WEI environment to an action. BVI students rely on screen-reader's announcement to perceive the state of the system.

6. ***Interpretation:*** She evaluates the system response with respect to her expectation. This gives rise to two possibilities:

   i. ***Dissonance:*** She fails to interpret the system response. This situation arises under two conditions (Norman, 1988):

      a. ***Failure:*** She did not receive enough feedback to interpret system state. This prompts her to search for another method.

      b. ***Inconsistency:*** She received a feedback that was inconsistent with her expectation. This prompts her to reformulate the problem (Newell & Simon, 1972).

   ii. ***Consonance:*** She interprets the system response. This gives rise to two possibilities:

a. ***Failure:*** The goal remains unattained. This could result because of a gulf of execution. This prompts the student to reformulate the problem.

b. ***Success:*** The goal is accomplished. She will move to the subsequent task or sub-task.

This framework guided my examination of perceptions, actions, and cognitions of BVI students in completing WEI tasks, and helped in tracing their difficulties.

1.5 Methodology and Research Design

I performed a task-based, multi-method evaluation of the WEI environment for a holistic understanding of the accessibility and usability problems BVI students face in WEI environments. The basic tenet of this multi-method evaluation is that WEI accessibility and usability for non-visual interaction is the interplay between three entities - the BVI student, WCAG, and the Web developer. Figure 1.1 schematically represents my multi-method evaluation approach to WEI accessibility and usability for NVI.

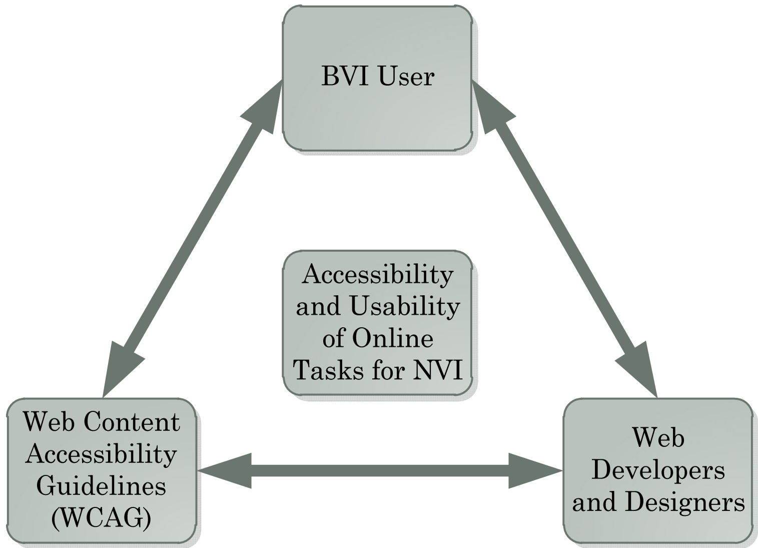


Figure 1.1. Multi-method evaluation of WEI accessibility and usability in NVI.

The multi-method evaluation approach guided me in assessing the accessibility and usability of the WEI environment from the perspectives of BVI students, WCAG design principles, and Web developers. My unit of analysis was a WEI activity. I chose an online exam over a course management system (CMS) as a typical and common activity that students perform in WEI environment.

My research design was a qualitative field study comprising three assessments of the WEI environment

Assessment I:	BVI Student Assessment of WEI environment;
Assessment II:	WCAG Assessment of WEI environment; and
Assessment III:	Web Developer Assessment of WEI Environment.

My research participants included (1) 6 BVI students from the North Carolina Rehabilitation Center for the Blind and the Texas School for the Blind and Visually Impaired; and (2) 5 Web developers affiliated with Infosys Technologies Ltd. And Braille without Borders. I employed verbal protocol analysis for the BVI student assessment. I employed a combination of textual analysis and automated testing for WCAG assessment. I employed interview analysis for Web developer assessment. I then synthesized the results of the BVI student assessment with the results of the WCAG and Web developer assessments.

1.6 Results

My analysis provided a broad yet deep understanding of accessibility and usability challenges BVI participants faced in interacting with the WEI environment. Specifically, it explained that the WEI environment consisted of thousands of interface objects (e.g. images, tables, anchors and scripts) whose design did not comply with WCAG's standards for Web accessibility and usability. BVI participants faced significant challenges completing the online task. I observed six major accessibility and usability problems in their WEI interaction

7. They got confused and feel disoriented in WEI environment when navigating across pages with frame-based structure with no frame labels.

8. They were susceptible to submitting incomplete work in WEI environment when a new question page does not provide location and contextual information.

9. They had difficulty understanding how to submit their work in WEI environment when the selection controls for multiple option questions lack a consistent keyboard navigation procedure.

10. They got stuck in WEI environment when it uses an alert dialogue box to present security information.

11. They experienced significant ambiguity in WEI environment when an essay-type question page did not use meaningful labels for (a) graphic pointing to the input area; (b) input area itself; and (c) text formatting tools.

12. They were vulnerable to losing their work in WEI environment when Backspace behaved like the browser's Back button inside the text area.

All six findings amount to accessibility and usability problems in the WEI environment that negatively impact BVI students ability to accomplish academic tasks effectively and in time. Poor accessibility and usability defeats the purpose of CMS as a mechanism to evaluate WEI learning outcomes. The extent to which the task environment is accessible and usable becomes a determinant of test scores for BVI students. Considering the widespread use of WEI as a practice to deliver academic programs in colleges and universities, BVI students cannot enjoy equal learning opportunities in today's education system. My findings have implications for the design of Web resources used for purposes beyond Web-enhanced instruction.

1.7 Contribution and Implications

This doctoral research contributes in three ways. It fills the knowledge gap about the nature of problems BVI students face in Web interactions for academic tasks. This kind of knowledge is necessary to determine accessibility and usability requirements for WEI applications.

Another contribution is a set of mental model representations that explicate the thought processes of BVI students under conditions of dissonance. These representations outline the knowledge structures and cognitive processes that are responsible for challenges in non-visual Web interaction. They reveal what BVI users observe and experience during Web interaction. This finding has two broad implications. First, it helps in the accurate assessment of the gulf between BVI users and the Web. This gulf makes non-visual Web interaction inherently challenging. Second, it informs that Web accessibility and usability problems have a cognitive component that originates from a user's misconceptions about Web interaction. The structure of mental models represents new knowledge about special needs and challenges in non-visual Web interaction. This knowledge will be useful to improve the efficacy of existing accessibility and usability standards and screen-reading AT. Inferential knowledge derived from these mental models will inform the development of learning models on effective NVI. These mental models will inform Web developers and designers about special needs and challenges of BVI users, and guide them in building Web applications that support NVI.

A third contribution is a user-centered, task-based, cognitive and multi-method approach to evaluate Web accessibility and usability. It helps identify design errors in a Web-based system, the consequent challenges for BVI users in completing an online task, the root cause of these challenges, and feasible design modifications to potentially address these challenges. This represents a more complete, practical and solution-oriented approach to Web accessibility and usability evaluation. It explains (a) where, how and why BVI students face problems completing WEI tasks; (b) how each problem manifests in their minds; (c) responsible interface elements; (d) character of each problem as per accessibility and usability principles; and (e) feasible design modifications that can potentially address the problem. The multi-method evaluation technique is feasible to understand accessibility and usability problems in other types of Web applications and for other user groups with special needs.

This doctoral research emphasizes the need for a holistic view of BVI users' Web interaction problems as the basis of any accessibility and usability solution. These problems have both a cognitive and a technical dimension. They are task-specific and depend on the purpose for which a Web site is used. Research in mental model and problem solving informs that these problems can be reduced or eliminated if the BVI acquire accurate mental models for Web interactions. Accuracy of mental models improves through learning and with practice. Many BVI users (power users) develop creative and ingenuous strategies to overcome challenges presented by the sight-centered design of technology. We can use knowledge about their mental models for Web interactions to develop solutions (e.g. learning models and learning systems) on effective

Web interactions for the BVI and sighted users who employ non-visual interaction. Findings of this doctoral research will inform the development of such accessibility and usability solutions.

1.8 Dissertation Organization

In this chapter, I explained that the purpose of this research is to develop an understanding of the nature of accessibility and usability problems blind and visually impaired (BVI) students face in Web-enhanced instruction (WEI). Chapter II discusses the results of my literature review. It identifies the literature gap about an accurate and in-depth understanding of this problem, and explains the inadequacies in existing research approaches to develop this understanding. Chapter III describes my novel approach, the theoretical foundation and my integrated problem-solving framework. It explains how this approach and framework helped me develop an in-depth, contextually-situated, observational and experiential knowledge of the problem. Chapter IV describes my multi-method evaluation technique and outlines the research design using which I implemented my novel approach to understand the problem. Chapter VI discusses the results and analysis of the multi-method evaluation of the WEI environment. Chapter VI concludes this dissertation with a discussion of research contributions, implications, limitations and future research.

CHAPTER II

LITERATURE REVIEW

The blind and visually impaired (BVI) comprise an atypical user population that interacts with computers and the Internet in entirely different ways than sighted users. Existing literature recognizes that the Web lacks the accessibility and usability needed in non-visual interaction; it does not clarify the nature of problems this presents to the BVI. In this chapter, I discuss the results of my literature review, define the problem and identify the research question. In section 1, I present some statistics to highlight the magnitude of the problem. In section 2, I identify the population for this research. In section 3, I explain the unique Web interaction technique of this population. In section 4, I provide a working definition of Web-enhanced instruction and its importance for educational outcomes for this population. In section 5, I provide working definitions of accessibility and usability, and explain their differences. In section 6, I discuss existing design standards on Web accessibility and usability for this population. In section 7, I explain what my literature review informs about the Web experience of this population. In section 8, I conclude by identifying the research problem and research question.

2.1 Prevalence of Vision Impairment

Around the world, there are more than 314 million people who are blind or visually impaired (World Health Organization, 2009). In the U.S., the BVI population exceeds 25 million (American Foundation for the Blind, 2008). Table 2.1 shows the distribution of the BVI adult population in terms of age, education attainment, and geography.

Table 2.1. Distribution of BVI adult population in the U.S. (Adapted from National Health Interview Survey of 2009)

Year	2006	2007	2008
Population	21.2 million	22.4 million	25.2 million
Age Range (in years)			
18 to 44	6.0 million	7.6 million	8.0 million
45 to 64	9.0 million	9.3 million	10.7 million
65 to 74	*2.6 million	2.5 million	2.8 million
75 and older	3.6 million	3.0 million	3.7 million
Education			
Less than a high school diploma	4.5 million	4.4 million	5.0 million
High school diploma or GED	6.0 million	6.3 million	6.3 million

Some college	5.4 million	5.6 million	6.5 million
Bachelors Degree or higher	3.6 million	4.0 million	4.8 million
Regional Distribution			
Northeast	2.9 million	3.2 million	3.8 million
Midwest	5.5 million	5.6 million	5.9 million
South	8.5 million	8.3 million	10.2 million
West	4.3 million	5.2 million	5.2 million

In Table 2.2, I provide some statistics about the number of BVI children and youth (below 18 years) and their distribution in terms of affiliated institutions .

Table 2.2. Population of BVI children and youth in the U.S. (Adapted from the 2009 Annual Report of the American Printinghouse for the Blind, available at http://www.aph.org/about/ar2009.html).

Population (Approx)	59,355
Registered By	
Departments of Education	49,442 (83%)
Residential schools for blind	5,238 (9%)
Rehabilitation Programs	3,027 (5%)
Multiple Disability Programs	1,648 (3%)

The figures in Table 2.1 and Table 2.2 are indicative of the magnitude of the problem my doctoral research focuses on.

2.2 The Blind and Visually Impaired

In this doctoral research, I use the phrase “Blind and Visually Impaired” and its acronym “BVI” when referring to people who lack the functional vision to see information presented on a computer screen or operate a mouse. They predominantly rely on text-to-speech assistive technology called screen-readers to interact with computers and the Internet. Text-to-Braille assistive technology is available but used by a small fraction of BVI population (Lazar et al., 2007). A screen-reader identifies and interprets textual content on the computer screen and presents this aurally through a synthetic voice (Di Blas et al., 2004). This doctoral research is concerned with the Web interaction of BVI students who rely on screen-readers.

2.3. Non-Visual Interaction

For BVI students, interacting with the Web is a listening activity. Screen-readers announce text content of a Web page from top left to bottom right (Leuthold et al., 2008). This non-visual interaction is characterized by sequential access to information, as opposed to direct access for sighted interaction. BVI students provide input exclusively through the keyboard, with continual guidance from the screen-reader’s typing echo. Although screen-reader functionality includes innumerable key commands for various operations (Harper et al., 2006), most users know or use only a handful of these (Theofanos and Redish, 2003). Non-visual interaction employs a unique information access strategy. Therefore, BVI students have accessibility and usability needs distinct from typical sighted students in Web interaction(Bornemann-Jeske, 1996).

2.4 Web-Enhanced Instruction

Literature uses concepts such as Web-based education, e-learning, blended learning, online education, technology-mediated learning, and virtual learning when refering to education delivered on-line with varying degrees of student-teacher interaction (McCormick, 2000). In this doctoral research, I refer to all these concepts collectively as Web-enhanced instruction (WEI). WEI refers to the practice of delivering academic programs that extensively uses Web-based resources to supplement classroom learning. (Landry, Griffeth, and Hartman, 2006). Web-based resources that WEI typically uses include course management systems (CMS), digital libraries and online information resources (Picoli, et al., 2004). In this doctoral research, I refer to all these Web-based resources collectively as WEI environment. Students accomplish academic activities such as reading course material, completing assignments, taking exams, conducting Internet research, participating in class discussions, and working on group projects in WEI environments. The prevalence of WEI is evident from the fact that in 2004, more than 2 million students in the U.S. received education through this mode of instruction (Meissonier, Houzé, Benbya, and Belbaly 2006).

Researchers believe that students with disabilities (including the BVI) benefit from access to the Web more than the sighted (Taylor, 2000; Anderson-Inman, Knox-Quinn, & Szymnski, 1999; DO-IT, 2002; Hasselbring & Glaser, 2000). These students can lead a successful adult life by engaging in productive online activities (National Council on Disability and Social Security Administration, 2001; Kim-Rupnow and Burgstahler, 2004). Presently, BVI students lag behind academically (McNeil, 2000; National Council on Disability, 2000; National Organization on Disability, 1998). They can maximize their educational outcomes through effective use of the Web (Kim-Rupnow and Burgstahler, 2003). Effective use of the Web requires accessibility and usability (Babu & Singh, 2009).

2.5 Accessibility and Usability

Accessibility and usability are two related but distinct concepts. Accessibility allows users access to system functionality (Goodhue, 1986). For users with disabilities, accessibility is treated as a technical construct that allows ATs, such as screen-readers, the necessary access to interface elements of a system (Leuthold et al., 2008). Usability refers to how well a system conforms to users' conceptualization of performing a task (Goodwin, 1987). It is a cognitive construct that depends on the task the user performs. A system that is not accessible is not usable; however an accessible system does not guarantee usability (Di Blas et al., 2004). Accessibility Problems prevent access to features and functionality of a Web site. Usability problems prevent the use of these features and functionality. To better explain this difference, I use the “Fox and Stork” anecdote represented by Figure 2.1.

Figure 2.1. The Fox and Stork Anecdote to differentiate accessibility and usability problems.

Figure 2.1 shows that both the fox and the stork face problems eating their food due to poorly designed serving vessels. The fox faces an accessibility problem as he cannot get to the food served in the jug. The stork faces a usability problem as she cannot eat the food in spite of having access to it as it is served on a platter. The situations of the fox and the stork are comparable to a user's accessibility and usability problems in systems interaction. Effective user-system interaction requires both technical accessibility and cognitive usability (Norman, 1988). In this doctoral research, I separate accessibility from usability.

2.6 Standards on Web Accessibility and Usability

The Web Content Accessibility Guidelines (WCAG) is the de facto standard on Web accessibility and usability for the BVI. It comprises a set of design principles established by the World Wide Web Consortium (W3C) Web Accessibility Initiative (WAI) in 1999. Since then, recommendations of WCAG 1.0, updated to WCAG 2.0 in December 2008 (**http://trace.wisc.edu/news/archives/000255.php**), represent the primary source of guidance for developers and designers on Web accessibility and usability (Kelly, et al. 2005). Several governments have incorporated WCAG recommendations into laws on Web accessibility (e.g. Section 508 of the U.S. Federal government) (Leuthold, 2008).

The current version of WCAG guidelines (WCAG 2.0 – http://www.w3c.org/tr/wcag20/) includes a hierarchy of 4 guidelines and 18 success criteria. The four guidelines correspond to four principles of Web accessibility – *perceivability, operability, understandability, and robustness*. The 18 success criteria are considered normative, and include definitions, benefits, and examples. In Table 2.3, I summarize the main ideas of the four guidelines, along with the corresponding success factors.

Table 2.3: WCAG 2.0 Guidelines and Checkpoints. Adapted from W3C (http://www.w3.org/TR/WCAG20/#guidelines).

Guideline	**Success Criteria**
Perceivable	1. All non-text content that can be expressed in words should have a text equivalent of the function or information that the non-text content was intended to convey. 2. Synchronized media equivalents must be provided for time-dependent presentations. 3. Information/substance and structure must be separable from presentation. 4. All characters and words in the content should be unambiguously decodable. 5. Structure must be made perceivable to more people through presentation(s), positioning, and labels. 6. Foreground content must be easily differentiable from background for both auditory and visual default presentations.
Operable	1. All functionality must be operable at a minimum through a keyboard or a keyboard interface.

	2. Users should be able to control any time limits on their reading, interaction, or responses unless control is not possible due to nature of real time events or competition. 3. User should be able to avoid experiencing screen flicker. 4. Structure and/or alternate navigation mechanisms must be added to facilitate orientation and movement in content. 5. Methods must be provided to minimize error and provide graceful recovery.
Understandable	1. Language of content must be programmatically determined. 2. Definition of abbreviations and acronyms must be unambiguously determined. 3. Content must be written to be no more complex than is necessary and/or supplemented with simpler forms of the content. 4. Layout and behavior of content must be consistent or predictable, but not identical.
Robust	1. Technologies must be used according to specification. 2. Technologies that are relied upon by the content must be declared and widely available.

	3. Technologies used for presentation and user interface must support accessibility, or provide alternate versions of content that support accessibility.

My literature analysis informs that WCAG compliance is necessary but not sufficient for effective Web accessibility and usability for the BVI. Many experts believe WCAG recommendations do not represent accessibility and usability needs of the BVI accurately (Di Blas, et al. 2004; Clark, 2006; Kelly, et al. 2007). For instance, recommendations on perceivability prescribe modifying graphical interface to facilitate screen reader access (Leuthold, et al. 2008). This will be ineffective as content readability for the blind requires aural presentation strategy (Di Blas, et al. 2004). Recommendations on understandability ignore design principles and semantics that are critical for understanding content (Di Blas, et al. 2004). These do not address complexity of content layout or navigation patterns that cause disorientation for the BVI (Kelly, et al. 2005). Recommendations on robustness do not address accessibility due to enhancement in screen-reading technology (Di Blas, et al. 2004).

Acknowledging its value, along with its limitations, I believe WCAG compliance is a good starting point in achieving Web accessibility and usability for the BVI. For this doctoral research, I conceptualize the four WCAG guidelines in the context of a BVI user’s Web interaction as follows:

1. Perceivable: It is possible for the BVI user to perceive all Web content.

2. Operable. It is possible for a BVI user to operate all interface Elements.
3. Understandable: It is possible for a BVI user to understand all content and controls.
4. Robust: It is possible for the screen reader to interoperate with every aspect of the Web.

2.7 Web Accessibility and Usability for the BVI: A Reality Check

Extant research recognizes that the Web lacks the accessibility and usability needed by BVI users (Hailpern, et al., 2009; American Foundation for the BVI, 2008; Leuthold et al., 2008; Lazar et al., 2007). Research shows that 80% of Web sites do not meet basic accessibility requirements (Loiacono and McCoy, 2004; Sullivan and Matson, 2000; Klein et al., 2003). Web sites that meet with these accessibility requirements still present access barriers for the BVI (Correani et al. 2004; Petrie et al., 2004). What's worse, Web accessibility and usability has declined recently as measured by evaluation tools (Leuthold et al., 2008). Although lack of accessibility and usability is undesirable for all, it creates additional problems for the BVI (Di Blas, 2004). These users are half as likely to complete online tasks as their sighted counterparts (Correani et al., 2004).

Current research (Takagi, 2004; Tonn-Eichstädt, 2006; Lunn et al., 2009; Mikovec et al., 2009) focuses on accessibility problems in non-visual interaction without considering the usability problems of the BVI. A common perception is that Web accessibility and usability problems of BVI users result from the graphical user interface (GUI) (Mynatt and Weber, 1994; Alty and Rigas, 1998; Franklin and Roberts, 2003; Brewster, 2003; Jacko et al., 2003; Zajicek et al., 2004; Yu et al. 2006; Harper et al., 2006; Mahmud, 2007). The contention is that screen-readers do not recognize graphics, and therefore fail to convey information embedded in graphical elements to a BVI user (Leuthold et al., 2008). These studies assume that the BVI are typical users, except they perceive information non-visually. They focus on how to improve interface design (accessibility) without addressing critical elements of user cognition for the task being performed (usability). In spite of much extant research, guidelines and laws, web accessibility and usability remain challenging for the BVI (Hailpern et al., 2009; Mikovec et al., 2009). It is important to consider both the technical accessibility and the cognitive usability of Web interaction while addressing BVI users' problems. Without understanding Web experiences of BVI users , we cannot accurately understand the nature of their accessibility and usability problems, and therefore cannot develop effective solutions.

The scant research on Web experiences of BVI users informs that non-visual Web interaction is constrained in several ways. I identify the following constraints in non-visual Web interaction based on analysis of this literature:

a. The sequential nature of Web interaction means that at any given point, the user perceives only a snippet of the content, losing all contextual information (Lazar et al., 2007).

b. Inability to quickly scan a page means that the user has trouble locating goal-relevant information on the Web (Di Blas, et al, 2004). For example, input fields are not apparent to them on a Web page (Theofanos and Redish, 2003).

c. When Web pages have a complex layout, the screen-reader's feedback becomes ambiguous (Lazar et al., 2007). Screen-readers also mispronounce many words (Theofanos and Redish, 2003). These shortcomings make it difficult for the user to understand the information being conveyed.

d. The wide range of screen-reader functionality makes it difficult for a user to remember and use the appropriate commands and functions during Web interaction (Theofanos and Redish, 2003).

e. Cognitive resources are split three ways; the user is trying to understand the web browser, the web site, and the screen-reader (Theofanos and Redish, 2003) simultaneously. This contributes to cognitive overload during Web interaction (Millar, 1994; Thinus-Blanc and Gaunet, 1997).

2.8 Research Problem and Research Question

Literature reveals only glimpses of accessibility and usability problems in non-visual Web interaction. It does not explain where, how and why BVI students face difficulty in Web interactions in WEI. Web interaction involves three types of basic processes: perception, cognition, and action. Problems arise when Web design forces the user to spend extra physical and mental effort in these processes (Folley, et al., 1984). An accurate assessment of system accessibility and usability requires an understanding of perceptions, actions and cognitions of users under a challenging situation (Norman, 2001). Existing literature does not provide insight into a BVI user's perception, action and cognition in Web interaction necessary to assess the nuanced nature of the problem. In addition, the few studies with a user-centered focus (e.g. Theofanos and Redish, 2003; Lazar et al., 2007) are founded on user-reported problems. Research shows that user-reporting reveals only a fraction of the problems observed. Users generally report a positive online experience even when they fail to accomplish their goals (Nielsen, 2001). This is particularly true for BVI users since they are accustomed to lack of Web accessibility (Gerber, 2002). When faced with a usability problem, people normally blame their own lack of proficiency (Norman, 1988). These unique characteristics of BVI users render the overall findings of existing research questionable. This points to a need to understand their perceptions, actions, and cognitions during web interaction. This requires a close examination of the user-system interaction process (Zhang, et al., 1999). Therefore, the question arises:

> *What is the nature of accessibility and usability problems BVI students face in WEI environments?*

CHAPTER III

APPROACH AND THEORETICAL FOUNDATION

Chapter I explained that the purpose of this research is to develop an understanding of the nature of accessibility and usability problems blind and visually impaired (BVI) students face in Web-enhanced instruction (WEI). Chapter II identified a critical gap in existing literature about an accurate and in-depth understanding of this problem, and explained the inadequacies in existing research approaches to develop this understanding. This doctoral research adopts a novel user-centered, task-oriented, cognitive approach to develop an in-depth, contextually-situated, observational and experiential knowledge of the problem. The user-centered view explains a problem in terms of the difficulty faced by a BVI student in WEI interaction. The task-oriented view situates this problem in the context of her goal of WEI interaction. The cognitive view explains how this problem manifests in her mind. This approach demands an in-depth examination of her perceptions, actions, and cognitions in completing WEI tasks. I developed an integrated problem-solving framework by synthesizing research in Information Systems, Cognitive Science and Human-Computer Interaction to conduct this examination. This chapter discusses my novel approach, the theoretical foundation, and the integrated problem-solving framework that guided my doctoral research. In section 1, I describe my novel user-centered, task-oriented, cognitive approach. In section 2, I provide a detailed discussion of my theoretical foundation that synthesizes research in Information Systems, Cognitive

Science and Human-Computer Interaction. In section 3, I develop the integrated problem-solving framework.

3.1 Approach

I adopted a novel, user-centered, task-oriented, cognitive approach to understand the nature of accessibility and usability problems BVI students face in WEI environments. In Subsection 1.1, I explain the value of my cognitive approach. In Subsection 1.2, I explain the importance of a user-centered approach. In Subsection 1.3, I discuss the need for the task-oriented approach.

3.1.1 Cognitive Approach

My literature review informed that Web accessibility and usability for non-visual interaction involves three main entities – the BVI user, WCAG (Web Content Accessibility Guidelines) and the Web developer/ designer. For BVI users, Web interaction is a listening activity mediated by a screen-reader. They have accessibility and usability needs distinct from typical sighted users. WCAG is the de facto standards on Web accessibility and usability; it governs how a Web site accommodate special needs of BVI users. Web developers and designers use WCAG recommendations to design an accessible and usable Web site for BVI users. Therefore, I conceptualize Web accessibility and usability as a tripartite arrangement. Figure 3.1 represents this tripartite notion of Web accessibility and usability.

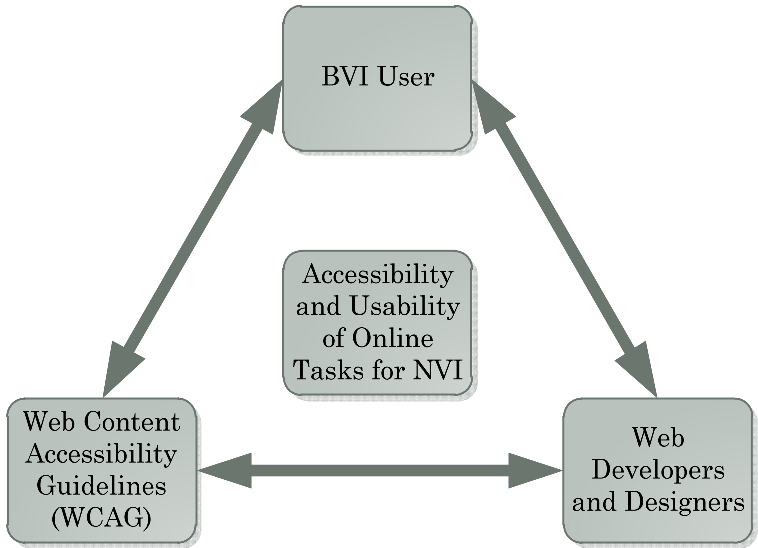


Figure 3.1. Tripartite notion of Web accessibility and usability.

According to this notion, Web accessibility and usability is a cognitive construct that emerges from the shared understanding about the special needs of non-visual Web interaction. Accessibility and usability problems occur due to a discrepancy between the BVI user's understanding of how a Web site works in non-visual Web interaction, and how this Web site behaves in reality. Web interaction involves three activities– perception, action and cognition. Therefore, an accurate assessment of BVI user's problem requires understanding their cognition, perception, and action as they deal with difficult situation.

3.1.2 User-Centered Approach

Existing research approaches accessibility and usability problems in non-visual Web interaction predominantly with a techno-centric view. It assumes that the BVI are typical Web users except they perceive information non-visually. It perceives the problem lies in interface elements that are inaccessible through screen-reading technology, without paying adequate attention to the consequent challenges faced by BVI users. It tries to address this problem through new and innovative interface design and better screen-reading technology. In some ways, it forces the user to change her interaction strategy that fits the Web site . This contrasts a user-centered approach that emphasizes on optimizing the interface around the way users can, want, or need to work (Greenbaum & Kyng, 1991; Schuler & Namioka, 1993). User-centered design considers cognitive factors such as problem-solving, perception, memory, and learning in user-system interaction (Katz-Haas, 1998). This approach tries to understand the difficulties experienced by BVI users in Web interaction and not assume it. Such an approach is necessary for an accurate understanding of the problem. In this doctoral research, I adopt a user-centered approach to understand the nature of accessibility and usability problems BVI students face in WEI environments.

3.1.3 Task-Oriented Approach

Web-based systems are designed to serve a purpose (e.g. academic, commercial, social, informational). This purpose is realized when users achieve their goals by interacting with it. On the other hand, Web interactions are most often goal-oriented; users visit a

Web site to accomplish their tasks. This is especially true in WEI where students interact with Web-based systems (e.g. course management systems, digital libraries, etc.) to accomplish an academic task. A measure of the success of the Web-based system is how well users perform the online task to achieve its purpose. Accessibility and usability problems prevent users from effectively performing online tasks; users fail to achieve their goals; the Web-based system does not serve its purpose. A practical approach to assess accessibility and usability problems in WEI is to understand the Web interaction challenges of a BVI student as she tries to accomplish an academic task. This represents a more complete and contextually-situated understanding of the problem. Such an understanding is necessary to adequately inform research efforts to improve the functional and academic outcomes for BVI students in WEI.

To summarize, I adopted a novel, cognitive, user-centered, and task-oriented approach to develop an in-depth, contextually-situated, observational and experiential knowledge of accessibility and usability problems BVI students face in WEI. The implementation of this approach required a close examination of the perceptions, actions and cognitions of BVI students in Web interactions with academic goals.

3.2 Theoretical Foundation

A goal-driven activity on the Web, such as taking an online exam, is typically associated with problems (Nadkarni & Gupta, 2007). A problem is an unexpected situation that hinders goal accomplishment (Arlin, 1989). The process of goal accomplishment involves a sequence of actions (Jonassen, 1997). The sequence of actions performed using a Web-based system for a goal represents an online task. Accessibility allows access to all feature and functionality of a Web-based system (Goodhue, 1988). Usability is how well this Web-based system fits with the user's conceptualization of performing an online task (Goodwin, 1987). Accessibility and usability problems in this Web-based system present challenges at different stages of task accomplishment. Examining the process through which a user performs a task helps us understand the nature of their problems (Cotton & Gresty, 2006). In this doctoral research, I examine the process through which BVI students perform an online task in WEI environments.

According to Newell and Simon (1972) the process of performing a task is the same as the process of problem-solving. A problem-solving model captures the complete interaction between the user and the Web-based system (Hersh, et al. 1996), including her perception, action and cognition (Folley, et al., 1984) . In order to examine the perceptions, actions, and cognitions of BVI students in WEI interactions, I needed to understand their problem-solving models for WEI tasks. Problem solving through the use of a system begins by internally representing the problem, and selecting a problem space. The next step involves choosing a method from a repertory in this problem space. The method, though not an optimal one due to bounded rationality, is good enough to reach a solution consistent with mental model of the problem situation. Implementation of the method proceeds through several stages, each associated with a mental model, and corresponding set of actions. Information about consequence of action on system state is used to update the mental model. When this information is inconsistent with expectation, additional cognitive effort is spent in processing it. This hampers the accuracy of resultant mental model, negatively affecting performance. Inconsistencies between expected and observed outcomes gives rise to dissonance that alters future cognition and behavior. The task environment is reframed by the problem solver. Iterations of such dissonance and reframing transform a novice problem solver into an expert.

I organize the rest of Section 2 as follows. In Section 2.1, I explain how tasks and goals are essential aspects of problem-solving. In section 2.2, I underscore the need to formulate the problem, and the objective of the solution according to the problem solving theory (Newell & Simon, 1972). In section 2.3, I explain how problem solving involves decision making at each step, and discuss people's decision making behavior using the theory of bounded rationality. In Section 2.4, I explain how people conceptualize a problem using the theory of mental model (Johnson-Laird, 1989). In section 2.5, I explain how users of Information Systems problem-solve using Seven-Staged Action Model (Norman, 1988). In section 2.6, I explain what users go through when they observe inconsistent system behavior using Cognitive Load Theory (Sweller, 1988). In Section 2.7, I explain the impact of cognitive load on the outcome of a problem-solving effort. In Section 2.8, I explain how people react to inconsistencies using Cognitive Dissonance Theory (Festenger, 1957). In Section 2.9, I conclude by explaining how dissonance results in learning based on the concept of Framing.

3.2.1 Tasks, Goals, and Problems

According to the Cambridge International Dictionary (1995), a task is an activity involving some level of difficulty. It is typically characterized by an identifiable outcome – a goal or an end (Hoffman and Novak 1995). It involves a series of actions to solve a problem (Cooper, 1996; Chandrasekaran, 1990). A goal is defined as an intended outcome that requires action to satisfy needs (Goldratt & Cox, 1988). It is abstract, formed by the human mind through a process of questions and internal reflection (Cooper, 1996). It could simply be a desired situation, such as stacking three blocks on top of each other in a specific order to form a tower (Newell, 1969). Therefore, a task is an observable sequence of steps performed with some difficulty to reach a desired situation – the goal. In this research, I use this definition to understand how BVI students identify their goals to formulate a problem.

Problems and solutions share the same relationship as tasks and goals. A problem is defined as an unknown that results from any situation in which an individual seeks to fulfill a need or accomplish a goal (Jonassen, 1997). A solution represents the goal the individual aims to accomplish (Newell, 1969). A problem may either have a single, known solution, or several acceptable solutions. Problems evoke in an individual a need to search for a solution in order to eliminate discrepancies (Arlin, 1989). Thus, problem-solving involves a similar process as performing a task.

The environment surrounding the task, goal, or problem that motivates the individual to find a solution is termed the task environment. This controls the behavior of the individual during problem solving (Newell & Simon, 1972). In this research, I attempt to understand BVI students' experience with online tasks from a problem-solving perspective.

3.2.2 Theory of Problem-Solving

To better understand BVI students' interaction with the Web as a problem solving process, it is important to understand three key concepts – state, operator, and problem space. A state refers to a data structure that defines possible stages of progress in moving from a problem to a solution (Newell, 1969). In human computer interaction, data structure includes users' actions and system responses (Borgman, 1986). An operator is a procedure that may be used for moving from one state to another by performing some action (Newell & Simon, 1972). In this research, I use the above definitions to understand the different stages BVI students pass through, and corresponding processes they employ to progress towards goal attainment.

A problem space is the fundamental organizational unit of all goal-oriented activity carried out by human beings (Newell, 1980). This problem space (or problem schema comprises a collection of states and operators available for achieving a goal, including the knowledge of initial state and goal state (Wood, 1983). It represents the given situation, and various possibilities for transforming this situation (Newell & Simon, 1972). I use this definition to understand the notions of BVI students about different (1) stages they must go through, and (2) corresponding procedures they must follow to complete a learning activity.

Within a problem space, a problem is solved by starting at some initial (problem) state, transforming that state through the application of operators until a state is reached that is recognized as being a desired (goal) state (Newell, 1969). This activity of selecting and applying operators constitutes the process of problem solving (Newell & Simon, 1972). This process requires a series of actions, carefully selected from a repertoire of available actions that progressively transform the problem state into the goal state (Heylighen 1988). Different actions impact the state differently. What action a problem-solver takes depends on his problem formulation, and understanding about initial state and goal state (Newell, 1969). Newell and Simon (1972) list the following stages during problem solving:

1. The problem solver initially forms an internal representation of the external environment using a process called input translation. At the same time, he selects a problem space. The problem solving then proceeds in the framework of the internal representation. This representation could render problem solutions obvious, obscure, or even unattainable.

2. Once a problem is represented internally, the problem solver responds by selecting a particular problem solving method. A method is a process that bears some rational relation to attaining a problem solution, as formulated and seen in terms of the internal representation.

3. The problem solver executes the selected method. At any time, the method may be terminated as the outcome of processes incorporated in it, or processes that monitor its application.

4. On terminating the method, the problem solver has three options: (a) he attempts another method, (b) he selects a different internal representation and reformulates the problem, or (c) he abandons the attempt to solve the problem.

5. While executing a method, new problems (or sub-goals) may arise. The problem solver may also have the option of setting aside a new subgoal, continuing instead with another branch of the original method.

I use this definition of a problem-solving process to understand how BVI students formulate the problem, how they select and apply a method, under what situation do they terminate a method, and what they do when the problem is too complex. Suppose a BVI student's task is to complete an online assignment. The student begins by internally representing the online assignment environment. He simultaneously selects a problem space that represents various stages in assignment completion, and a number of methods for transforming one stage of this assignment into another. He solves the problem entirely within the bounds of his internal representation. Next, he selects one method consistent with his internal representation, and then implements it by physically interacting with the online assignment environment. At anytime, he may terminate the method. If this happens, he has three options:

(1) Apply another method;

(2) Reformulate the problem; or

(3) Abandon the attempt altogether.

During execution, the student may feel the need to decompose the overall problem into sub-problems, and solve one after the other.

How a problem solver approaches a problem, and how much effort he expends in solving the problem is a function of his repertory of problem representations in his problem space (Sweller, 1988). Novices, due to a lack of experience, have a limited range of problem schemas. In other words, their understanding of problem situation is weak, and recognition of problem state is vague. Their search of the problem space will therefore be extensive, exploring different methods before the goal is achieved (Sweller, 1988). A most common search strategy novices adopt is means-end analysis (Newell, 1969). Here, the problem-solver employs a series of strategies including (1) selecting differences between goal and current states, (2) selecting operators that reduce the chosen differences, and (3) either applying these operators, or creating subproblems to transform the current states into states where the operators apply. This may require chaining backward from aspects of the goal state to find relevant operators, and determine useful sub-goals. With practice, problem solvers construct richer problem schemas that can be applied in a more proceduralized or automatized manner. Such problem schemas are more effective in recognizing the pattern of a problem situation. Their behaviors appear controlled and devoid of search (Newell, 1969). They employ forward chaining strategy that leads directly to the goal state (Larkin et al., 1980). This knowledge will help us understand why a BVI student struggles to perform a task, and how experience impacts their problem-solving skills.

Problem solving involves decision making at every step. This begins with deciding on problem formulation, choosing problem space, selecting methods to implement, calling off the method, and sub-goalling. Deciding on which method to select is probably the most challenging since there can be several methods that may lead to the goal state. Deciding on the problem space and method are critical for goal accomplishment. The theory of problem solving does not account for this aspect of human behavior. To better understand BVI students' decision-making behavior interacting with the Web, I rely on theory of bounded rationality (Simon, 1955 and 1956).

3.2.3 Theory of Bounded Rationality

In the simplest terms, decision making involves "selecting among possible actions" (Gilhooly, 1988). Early decision making research predominantly focused on proposing mathematical algorithms to predict optimal decision making (Tyszka, 1989). Simon (1955, 1956) rejected the idea of optimal choice, proposing the theory of "bounded rationality." He argued that due to time constraints and cognitive limitations, it is not possible for humans to consider all existing decision outcomes and then make fully reasoned and purely rational choices. He suggested that humans operate rationally within practical boundaries, or within the limits of bounded rationality (Simon, 1955). Therefore, time constraints and cognitive limitations restrict problem-solvers from evaluating all possible options before deciding on the best one. The concept of bounded rationality guided this doctoral research better understand the decision-making behavior of BVI students in various stages of problem solving in WEI environments.

Human beings are moderately good at deductive logic, and make moderate use of it (Simon, 1955). However, they are very good at recognizing or matching patterns—behaviors that result in obvious benefits (Agosto, 2001). When they find themselves in complicated situations, they look for patterns, and use these to construct temporary mental models to work with (Arthur, 1994). This way, they simplify the problem at hand. They carry out localized deductions based on their current mental model and act on these (Arthur, 1994; Simon, 1956). As feedback from the environment comes in, they evaluate the effectiveness of these mental models. They discard those that fail to perform, and replace these as needed with new ones (Arthur, 1994). In other words, when they cannot fully reason or lack full definition of the problem, they use simple models to fill the gaps in their understanding. Such behaviors are inductive in nature. Thus, in the absence of complete reasoning or accurate understanding of problems, they use pattern-matching to simplify the problem. This implies BVI students will simplify complex problems if they can induce a pattern of a problem from prior experience.

A second type of behavior relevant in this context is "satisficing". Simon (1955) explains that due to limited information processing capacity, people often choose decision outcomes that are good enough for their purposes, but not necessarily the optimal ones. Satisficing involves "setting an acceptable level or aspiration level as a final criterion and simply taking the first acceptable option" (Newell & Simon, 1972). Satisficing acts as a “stop rule” (Simon, 1979) — once an acceptable alternative is found, the decision maker concludes the decision process. Nonetheless, satisficing does not limit the decision maker to one deciding factor:

“When the criterion of problem solution or action has more than one dimension, there is the matter of calculating the relative merits of several alternatives, one of which may be preferred along one dimension, another along another . The satisficing rule stipulates that search stops when a solution has been found that is good enough along all dimensions.” (Simon, 1979)

Thus, a strategy BVI students may adopt in WEI environment includes (1) set an acceptable criterion, (2) choose the first acceptable option, and (3) call off their exploration of methods during problem solving.

Several scholars have examined this kind of behavior involving the use of Web-based information systems. Bilal (1998) explored students’ use of a Web search engine designed specifically for youth. She observed that her subjects tended to examine briefly the first few results before performing new searches, rather than examining every hit in detail. This is a satisficing behavior that enables users to deal with prohibitively large amounts of information (Agosto, 2001). Hirsh (1999) found that school students tended to skim resources when deciding on their relevance to their objective. This represents another satisficing strategy that reduces the amount of information necessary for making site selections. Bilal (2000) investigated cognitive, affective, and physical behaviors of high-school students as they used a search engine. She found that the subjects preferred keyword searching to browsing. This represents another satisficing behavior stemming out of the need to reduce the pool of sites from which they must decide.

When users find themselves in a complicated task environment, they will reduce the complexity by adopting strategies like pattern matching and satisficing to accomplish their goals. For example, during the search of the problem space, they are likely to do two things. First, they will identify similar problems experienced in the past (mental model with similar pattern) that were solved successfully to guide their current problem solving task. This process is likely to be guided by satisficing principle – call off the search before all possibilities are explored. Of these, they choose the one that is the easiest. This choice may not be the optimal one I would normally expect.

I now focus the discussion on a specific aspect of problem solving – internal representation (or problem schema) – that is the key to problem solving. In cognitive psychology, internal representation is better known as mental model (Ericson & Simon, 1980). The following section is devoted to this topic.

3.2.4 Mental Models

The concept of mental model was first introduced by Kenneth Craik (1943). Using the term "internal automata", he defines these as representations of reality that help people anticipate events. He asserts that: "We translate external events into internal models and reason by manipulating these symbolic representations. We can translate the resulting symbols back into actions or recognize a correspondence between them and external events." (Kraik, 1943). People translate a problem into a mental model to comprehend the task environment, and use these models to guide their actions during problem solving. I use this conceptualization to understand what is the role of mental models during BVI students' problem solving.

Contemporary scholars define mental models as active and dynamic cognitive constructs that organize thoughts and beliefs of objects, events and ideas that help us interpret the world (Norman, 1987; Johnson-Laird, 1983; Mayer, 1992). Mental models have particular significance in problem solving. These assist our understanding of problem situations, and predict consequences of chosen actions (Marchionini & Shneiderman, 1988). These represent a block of knowledge comprising two parts - knowledge structures and cognitive processes. Knowledge structures represent knowledge in memory, including linguistic representations and structural models (Johnson-Laird, 1993). Cognitive processes allow us to manipulate and modify the knowledge stored in these structures (Merrill, 2000). These form the basis of our understanding, and provide the tools for problem solving in a given domain (Zhang, 2008). Thus, mental models comprise knowledge structures and cognitive processes relevant to the problem situation. This conceptualization of mental models guided me in identifying components of a mental model that are crucial in problem solving.

We may hold different mental models of the same system depending on the context of use. Each model has a structure corresponding to the structure of the situation (Johnson-Laird, 1992). Young (1983) explains the contextual nature of mental models using the example of an electronic calculater. He asserts that depending on the purpose of use - (1) performing basic arithmetic operations, (2) performing specialized high-level tasks, or (3) diagnosing malfunctions – we may possess three different mental model of the calculater.

Accordingly, mental models of BVI students will be contextual in nature – relevant to the learning task being performed. We construct mental models of a situation based on:

a. Our observation (aided by knowledge);

b. Other's description;

c. Analogous mental models acquired earlier. (Johnson-Laird, 1993; Marchionini & Shneiderman, 1988)

An important characteristic of human mind is its ability to recognize patterns (Simon, 1955). We often construct mental models based on implicit or explicit analogies (Gentner and Gentner, 1983; Kempton, 1986). This behavior is especially helpful in solving novel problems (Otter and Johnson, 2000). In a novel task environment, we first search my problem space for a mental model of an analogous task successfully performed earlier. We borrow its higher order structures and processes to build a workable mental model of the current situation. (Johnson-Laird, 1980). This implies in a novel task environment, BVI students will rely on analogous experiences to construct a mental model of the current situation.

Newell (1987) argues that mental models can be treated as state representations within a problem space. Thus when someone solves a problem, he applies a series of operations to transform a model of the initial state of affairs through a succession of models representing intermediate states until the goal is reached. This formulation is useful in characterizing the sequence of conscious states that an individual is aware of in solving a problem (Newell, 1989).

Newell’s (1989) conceptualization of problem solving in terms of mental models is consistent with Johnson-Laird’s (1992) process of human reasoning. Human reasoning involves three semantic procedures (Johnson-Laird, 1983): (1) constructing a mental model of the problem situation taking into account relevant knowledge, both generic and specific; (2) formulating a novel solution based on this mental model; (3) searching alternative mental models that refute the supposed solution. If there is no alternative model, the solution stands valid. If there is such a model, the problem solver returns to the second step, and attempts to reformulate a solution consistent with all models constructed thus far (Johnson-Laird, 1992). When existence of an alternative model is not apparent, the solution is accepted tentatively or expressed with some probablistic qualification (Kahneman and Tversky 1982). In the light of subsequent information, this tentative solution may be revised. This search for alternative models explains how BVI students may represent a large number of possible situations through a single model.

Research in human-computer interaction has long recognized the importance of mental models in organizing knowledge about (1) how a system works; (2) its component parts; (3) processes and their interactions; and (4) how one component influences another (Hanisch et al., 1991; Fein, et al. 1993). We store this knowledge in long-term memory as the basis of our expertise in controlling and understanding the system (Johnson-Laird, 1989; Conant, 1970; Gentner & Stevens, 1983).

In a typical interaction with a system, the user begins with a priori mental model of a system based on reading about it or watching others interact with it (Rook and Donnell, 1993). As the interaction begins, the user develops a rough, workable mental model, continuely evaluating relevance of incoming information (Relmann and Chi, 1989). Any new information is associated with previously acquired knowledge (BRANDT & UDEN, 2003). As experience grows, this mental model matures into a sophisticated one (Norman, 1988). Thus, mental models of BVI students for interacting with the WEI environment will improve as they gain experience.

Mental models provide explanations of specific user behaviors, such as choice of method and nature of errors (Young, 1983). To explore the effects of mental models on users' behavior of using Excel spreadsheets, Sasse (1997) asked two groups of users with different mental models to describe and use Excel. The comparison group described the system at a conceptual level, whereas the main group gave a purely procedural introduction to the system. The two groups also showed different behaviors; subjects in the main group tended to trade off physical efforts against cognitive efforts by specifying their own formulae instead of using system built-ins. Therefore, mental models dictate what methods problem-solvers apply to accomplish a goal. This implies BVI students choice of method during problem solving will depend on the quality of mental model they acquire about the WEI environment.

Mental models are very helpful in understanding performance using information systems (Young, 1983). Borgman (1986) observed two groups of undergraduate students searching a library online catalog. One group received training of system's conceptual model, while the other received training on how to search the system. The model group performed better in complex tasks. Dimitroff (1990) reported students with more complete mental models made fewer errors and found more items while searching an online catalog. This means with an accurate mental model, users will perform complex online tasks effectively. This implies BVI students can effectively use a WEI environment if they have an accurate mental model about it.

Although problem-solving theory provides an excellent framework for understanding people's behavior in a task environment, it was not intended for computer-based tasks. During the 1980s, when computers became widely available, human-computer interaction (HCI) emerged as an independent discipline. As user-centered systems design gained importance, scholars felt the need for modeling users' thought processes (mental models of a system) (Goschnick & Sterling, 1996). This need resulted in the Seven-Stage Action Model that explains a user's behavior while interacting with computer-based systems.

3.2.5 Seven-Stage Action Model

The seven stage action model explains the activities a user proceeds through while problem-solving with a system (Norman, 1988). The model includes both cognitive and physical activities (Zhang , et al. 1999). According to Norman, a user initiates the task by forming a goal. Here a "goal" is a step towards accomplishing a task. For example, if the task is to fill out an on-line credit card application form, then a goal can be to fill out the name field, or to fill out the date-of-birth field. A user needs to map such a goal to an action on the computer, execute the action, perceive and understand the feedback from the system, and examine if anything has gone wrong (Norman, 1988).

While performing the task, a user considers four different things: the goal, what is done to the world, the world itself, and the check of the world. The action itself has two major aspects: execution and evaluation (Norman, 1988). Execution begins with transforming the goal into an intention to act. The intention must be translated into a set of internal commands, a plan of action that satisfies the intention. The action sequence is still a mental event. Then this action sequence is executed on the system. Evaluation has three stages. First, the user perceives what happened to the system. He then tries to make sense of this in light of his expectations. He finally compares between what happened with what he wanted. The model is broadly divided into three parts and seven stages as follows (Norman, 1988):

A. Goal formation stage

1. Goal formation.

B. Execution stage

2. Translation of goals into a set of (unordered) tasks required to achieve the goal.

3. Sequencing the tasks to create a plan of action.

4. Executing the plan of action.

C. Evaluation stage

5. Perceiving the results after having executed the action sequence.

6. Interpreting the actual outcomes based on the expected outcomes.

7. Comparing what happened with what the user wished to happen.

This understanding of seven stages of action, coupled with the process of problem solving, guided my research to develop a complete understanding the interaction behavior of BVI students in WEI environments.

Norman points out that these seven stages form an approximate model, not a complete psychological theory. In particular, the stages are almost certainly not discrete entities. Most behavior does not require going through all stages in sequence, and most activities will not be satisfied by single actions. There must be numerous sequences, and the whole activity may last hours or even days. There is a continual feedback loop, in which the results of one activity are used to direct further activities, in which goals lead to sub goals, intentions lead to sub intentions. Real tasks are usually more complicated. The original goal may be ill-formed, vague, or imprecisely specified. There may be activities in which goals are forgotten, discarded, or reformulated. The process may be started at any point, responding to the events of the world (data-driven behavior) rather than to think out plans and goals (Norman, 1988). Actions may be executed before they are fully developed. An event in the world may trigger an interpretation and a resulting response. In spite of this lack of structure, this behavior is consistent with the action model (Norman, 1988). Thus the action model does not impose any structure on people's behavior during problem solving with a system. This understanding informs this research that BVI students may not proceed with problem-solving in a prescribed sequence of actions.

The most insightful aspect of the seven-stage action model is that it identifies the scope of problems during user-system interaction. Norman (1988) remarks that majority of my routine tasks are problematic. He asserts that neither a lack of understanding of goals or tasks, nor deep, subtle complexities are responsible for such problems. It is primarily because the people 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 outcome of actions (Norman, 1988). In other words, the difficulty is solely because they fail to map (1) intentions to interpretations, and (2) physical actions to system states. These inconsistencies, that result in major problems for the user, correspond to two types of gulfs:

a. Gulf of execution arises if the system does not provide actions that correspond to the intentions of the user. One measure of this gulf is how well the system allows the person to do the intended actions directly, without extra effort.

b. Gulf of evaluation arises when the system does not provide a physical representation that the user fails to directly perceive or directly interpret in terms of his intentions and expectations. It reflects the amount of effort that the person must exert to interpret the physical state of the system and to determine how well the expectations and intentions have been met. This gulf is small if feedback on system state is easily available, interpretable, and is consistent with user’s mental model of the system.

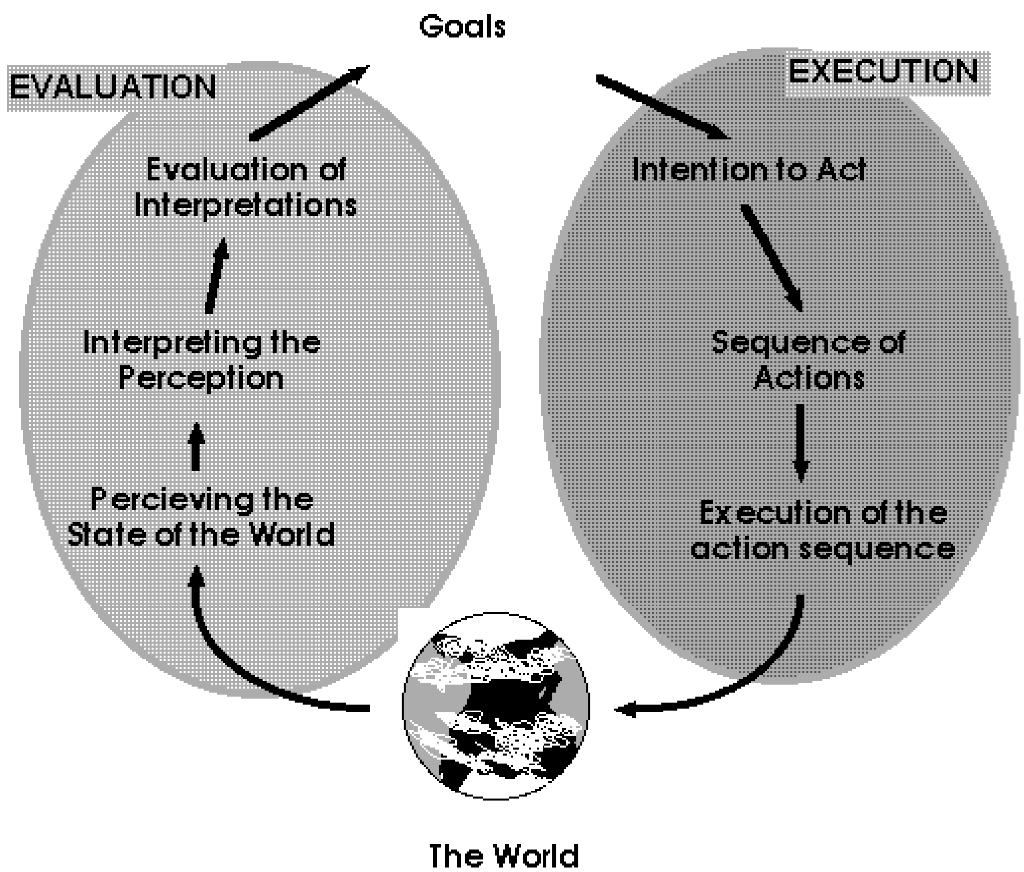


Figure 3.2. Gulfs of execution and evaluation.

The gulfs of execution and evaluation demand extra mental effort from the user, and are the primary reasons why people find system usage a difficult task. I use this knowledge to trace the sources of problems BVI students face during problem solving in online environments.

The additional cognitive effort expended due to the gulfs of execution and evaluation is very much a possibility when BVI students interact with the Web (Lazar, 2007) . When

BVI students find themselves on a website that has a huge amount of information, or presents information that is hard to interpret with respect to their goal, they experience information overload (Sweller, 1988). Neither the problem solving theory, nor Norman's action model account for the problem-solver's behavior under these conditions. I now introduce a theory that explains this phenomena – cognitive load theory.

3.2.6 Cognitive Load Theory

Cognitive load theory, developed by John Sweller (1988), proposes that information presentation has an impact on learning. Cognitive load is the amount of "mental energy" required to process a given amount of information (Sweller & Cooper, 1984). It is directly proportional to the quantity of information. When this quantity of information exceeds the information processing the mind's capacity, it negatively impacts comprehension (Saade & Otrakji, 2007). Thus, BVI students experience cognitive overload in online environments with a huge amount of unstructured information, that hampers learning.

Cognitive load theory assumes a limited working memory and a virtually unlimited long-term memory. Its prime concern is the ease of processing information in the working memory. Schemas (or mental models) categorize information by the pattern of use. These are acquired over time with exposure to the task environment. These are automated as rules, and stored in the long-term memory for future use. During problem solving, the limited-capacity working memory must act on these schemas in their entirety as a block of incredibly detailed and complex body of information. Therefore, CLT emphasizes on structuring information to assist the learner to quickly develop schemas and automated rules. The schema can act as a single element in working memory and will impose minimal working memory demands, especially if it is automated. Once constructed, this schema can act as an interacting element in higher order schemas.” The result is enhancement of knowledge acquisition and performance. (Sweller, van Merrienboer, and Paas, 1998). In short, information overload can be reduced by structuring information presented on a web site. This understanding of cognitive load informs my research about the consequence of information presentation on learning for BVI students in WEI environments.

In the context of Web-based systems,every effort additional to learning reduces the mental resources available for comprehension. These efforts may primarily stem from orientation, navigation and user-interface adjustment (Thuering, Hannemann, & Haake, 1995). This effort is even greater for BVI students who cannot rely on their visual perception to acquire information (Ang, et al. 2007). This negatively impacts their comprehension and learning effectiveness. Therefore, BVI students will expend extra effort in navigating, orientating, and processing information through non-visual channels. This hampers learning effectiveness.

Working memory load may be affected either by the intrinsic nature of the information (intrinsic cognitive load), by the manner in which the information is presented, or the activities required of students (extraneous cognitive load), or by the effort required to construct schemas (germane cognitive load). Instructional interventions are capable of altering extraneous and germane cognitive loads, but not intrinsic cognitive load.

(Sweller, Chandler, Tierney and Cooper, 1990). To summarize, when the WEI environment presents learning content in a structured way, and designed to assist learners construct accurate mental model of the information, cognitive load can be reduced. This implies cognitive burden on BVI students can be reduced through appropriate design of the WEI environment, thereby enhancing their learning effectiveness.

I now focus on two inter-related theories that deal with congruence between the user and the system, and its impact on performance.

3.2.7 Task-Technology Fit and Cognitive Fit

The theory of task-technology fit suggests that in order to perform a specific task effectively, users need systems functionalities that support (1) task requirements, and (2) individual abilities (Goodhue & Thompson, 1995). Fit refers to the congruence of a system and a task, that is, the extent to which a particular task can be performed effectively and efficiently using a particular system (Staples & Seddon, 2004). When people use a system to complete a task, they perform various types of operations, like opening a file, activating a link, entering query parameters, or selecting a radio button. Fit is affected by the number and complexity of these operations (Staples & Seddon, 2004). Some researchers have examined the effect of fit on performance. Card, Moran, and Newell (1980 and 1983) examined keystroke-level models of expert users' task performance, finding that performance using the same system varied with the task, while performance of the same task varied across systems. The variance of performance was dependent on fit. Wilson and Addo (1998) studied computer-displayed graphs. They found that people are more efficient in completing tasks when there is a good fit between the problem and the set of graphs. Spence and Tsai (1997) consider the relationship between cognitive style and processes under multiple task environments, concluding that cognitive processes vary according to task characteristics. All these studies clearly suggest that congruence between task and technology leads to performance benefits. This implies, to function effectively in WEI environments, BVI students will need the WEI system to fit their objectives, and their special needs.

Adopting a broader view, the theory of cognitive fit (CFT) (Vessey, 1991) suggests that in addition to task-technology fit, the user must use appropriate processes (developing appropriate mental models) to achieve desired effects. Consistent with information processing theory, CFT proposes that human problem solvers will seek ways to reduce their problem solving effort, since they are limited information processors (Newell and Simon 1972). One of the ways to reduce processing effort is to facilitate the problem-solving processes for completing the task. This can be achieved by matching the problem representation to the task, an approach that is known as cognitive fit (Vessey 1991). This implies, the WEI environment must assist BVI students construct an accurate mental model by presenting the learning content in a format consistent with their problem-solving process.

Clarifying this view, Vessey and Galletta (1994) explain that processes act on information in (1) the problem representation and (2) the problem-solving task, to produce the mental representation; and (3) the mental representation, to produce the problem solution. In this context, it is a subset of the total problem space (Newell and Simon 1972). The mental representation is formulated using the characteristics of both the problem representation and the task. Specifically, it is derived from the interaction of processes that act on the information in the problem representation and the problem-solving task.

When the types of information emphasized in the problem-solving elements (problem representation and task) match, the problem solver can use processes (and formulate a mental representation) that also emphasize the same type of information. Consequently, the processes the problem solver uses to both act on the problem representation and the task will match. The resultant consistent mental representation will facilitate the problem-solving process (Vessey, 1991). Hence, cognitive fit leads to an effective and efficient problem solution. This implies cognitive fit is critical to function effectively in online academic environments for BVI students.

When a mismatch occurs between problem representation and task, cognitive fit will not result, since similar processes cannot be used to both act on the problem representation and solve the problem. Because problem solvers induce their mental representations from materials presented to them (Perrig and Kintsch 1985), they will either formulate a mental representation based on the problem representation (in which case they will need to transform it to derive a solution to the problem), or they will formulate a mental representation based on the task (in which case they will need to transform the data derived from the problem representation into a mental representation suitable for task solution). In either case, performance will be worse than if the problem solver had been supplied a problem representation emphasizing the type of information that best supported task solution. (Vessey & Galletta, 1994). Thus, when a task is presented in a format that is inconsistent with the problem-solving process of a user, the user will experience extra cognitive load. This implies that when online educational material is presented in a format that does not suit the problem-solving processes employed by BVI students, they will experience cognitive overload and their learning will suffer.

A mismatch between system functionalities and users' abilities results in gulf of execution that results in failure to perform an action. The mismatch between users' expected feedback and the actual feedback from the system results in gulf of evaluation (Norman, 1988). The user observes a discrepancy between his cognition of how the system works, and the actual behavior of the system. This discrepancy results in a phenomena called "cognitive dissonance" (Festinger, 1957), that has implications for user's current and future cognition and behavior. I now introduce cognitive dissonance theory to understand how people behave following dissonance.

3.2.8 Cognitive Dissonance Theory

Festinger (1957) developed cognitive dissonance theory (CDT) explaining how people's cognition and/or behavior changes resulting from an observed discrepancy between their existing cognition and reality (Festinger, 1957). Cognition includes beliefs, affect, opinion, values, and knowledge about the environment (Festinger, 1957). Behavior refers to actions initiated in response to this cognition and/or personal evaluation of that behavior (Festinger 1957). When attitudes and behaviors are inconsistent with one another, psychological discomfort results. Dissonance increases with the importance and impact of the decision, along with the difficulty of reversing it. Discomfort about making the wrong choice of car is bigger than when choosing a lamp. This discomfort motivates us to change our behavior or attitude so that dissonance is reduced (Aronson, 1969). The maximum possible dissonance is equal to the resistance to change of the less "resistant cognition". Therefore, once dissonance exceeds the threshold to overcome the resistance of a particular cognition, we change or eliminate that cognition (Festinger, 1957). Such dissonance is reduced either by

- Changing action.
- Eliminating dissonant cognitions.
- Adding consonant cognitions.

If an action has been completed and cannot be undone, then the after-the-fact dissonance compels us to change our beliefs. If beliefs are moved, then the dissonance appears during decision-making, forcing us to take actions we would not have taken normally (Festinger, 1957).

To state this differently, people begin with a mental model of a given problem situation. They take some actions to solve this problem. When they observe inconsistent outcomes of their actions, they feel dissonant. This dissonance motivates them to search for alternative cognitive processes (plan of action). They choose one, and execute it. If this doesn’t result in consonant outcomes, they modify the knowledge structure (reformulate the problem). The ultimate goal is to reduce dissonance between their mental model and reality. In my research, I use this knowledge to understand how BVI students cope dissonance during problem solving in online environments. To understand this type of behavior, and its consequence on learning, I rely on the phenomena of framing (Tversky & Kahneman, 1981).

3.2.9 Frames

Frames are a combination of unquestionable beliefs, values, attitudes, and mental models that we use to perceive a situation (Watzlawick, Weakland, & Fisch, 1976). Kahneman and Tversky (1974) defined a decision frame as ‘the decision-maker’s conception of the act, outcomes and contingencies associated with a particular choice.’ It is effectively a “tinted spectacle” through which we view reality. It significantly effects how we infer meaning and hence understand a situation (Tversky & Kahneman, 1981). Thus, a frame (comprising mental models, beliefs, attitudes, and values) dictates our understanding of a problem situation. This knowledge will guide my research in adopting a holistic view of BVI students needs in online academic environments.

The frame that a decision-maker adopts is controlled partly by the formulation of the problem and partly by the norms, habits, and personal characteristics of the decision-maker (Tversky & Kahneman, 1981). Tversky and Kahneman (1981) note that I may frame a given problem in more than one ways. They compare alternative frames for a given problem to alternative perspectives on a visual scene. Citing the example of relationship between relative height of two neighboring mountains perceived from different vantage points, these scholars remark that “because of imperfections of human perception and decision, changes of perspective often reverse the relative apparent size of objects and the relative desirability of options" (Tversky & Kahneman, 1981). I may discover that the relative attractiveness of options varies when the same decision problem is framed in different ways. Such a discovery will normally lead us to reconsider the original preferences, even when there is no simple way to resolve the inconsistency. The susceptibility to perspective effects is of special concern in the domain of decision-making because of the absence of objective standards such as the true height of mountains. Thus, I may hold several frames about a problem with varying degrees of relevance, and consider one that seems most relevant for problem solving.

Any change in the frame (known as reframed) changes the inferred meaning. Reframing involves (1) changing the conceptual and/or emotional setting or viewpoint in relation to which a situation is experienced, (2) placing it in another frame which fits the 'facts' of the same concrete situation equally well or even better, and thereby (3) changing its entire meaning (Watzlawick, Weakland & Fisch, 1974). This means when people observe discrepancies between their problem frame and reality, they will reframe it to eliminate dissonance.

Reframing has particular significance in my research. When BVI students experience dissonance while performing an online task, they reframe the task environment to accommodate new realities. Reframing will facilitate future problem solving attempts. In other words, dissonance followed by reframing represent a process of learning that will make BVI students adept in performing online academic tasks.

In this doctoral research, I attempt to understand the nature of accessibility and usability problems BVI students face in WEI environments using a problem-solving model. When a student is presented with a problem, she will first internalize the problem situation, and select a problem space. She will choose one method out of a repertory from her problem space. This choice is typically guided by pattern matching and satisficing rule. The chosen method, though not optimal, is good enough to reach a supposed solution. She will then implement this method by interacting with the WEI environment (Web-based learning system). This involves several stages, each associated with a set of actions. She evaluates her mental model at each stage, updating it with new information coming from the online task environment. In the event of a gulf of execution or gulf of evaluation, the mental model constructed lacks consistency with reality. She spends extra cognitive effort dealing with this situation. The inconsistent mental model prevents her from executing her actions effectively. This inconsistency between cognition and reality gives rise to dissonance. This dissonance prompts her to chose one of three alternatives: (1) choose another method, (2) reformulate the problem, or (3) call off the attempt. She consequently reframes the problem situation that modifies her future cognitions and course of actions for the the WEI task. With this understanding, I wanted to examine the challenges BVI students face at individual stages of problem-solving.

3.3 Integrated Problem-Solving Framework

I synthesized extant theories in Information Systems, Cognitive Science and Human-Computer Interaction to develop an integrated problem-solving model. This model integrates multiple views pertinent to problem-solving in online environments. Newell and Simon (1972) view explains that problem solving begins with the user formulating the problem and selecting the problem space. The user then chooses a method from her problem space appropriate for goal attainment. She then executes this method – one action at a time. At any moment, she may realize the enormity of the goal, and decompose it into sub-goals. At any moment, she may stop executing her method to choose another method, reformulate her problem, or abandon her attempt. According to Norman's (1988) view, user-system interaction comprises seven stages. The user begins with identifying her goal. To accomplish this goal, she forms an intention. In order to transform this intention into action, she develops a plan of action or steps to be taken. She then executes this plan of action through computer operations. Sometimes, the system may not allow an action. This is termed "gulf of execution." For every action allowed by the system, the user attempts to perceive the response of the system. She then evaluates the perceived system state with respect to her goal. Sometimes, she fails to perceive or interpret the system state. This situation is termed "gulf of evaluation". If she successfully interprets this state, she decides if she achieved the goal or not. Problems occur due to the gulfs of execution or evaluation. In addition to the above two views, I examined Johnson-Laird's (1992) view on Human Reasonning, Simon's (1955 view on Bounded Rationality, Vessey's (1991) view of Cognitive Fit, Festinger's (1957) view on Cognitive Dissonance, and Tversky and Kahneman's (1981) view on frames. Synthesis of these viewpoints helped me develop an integrated problem-solving framework that I used for analyzing a BVI student's Web interactions in WEI. Table 3.1 represents this integrated problem-solving framework.

Table 3.1. Integrated Problem Solving Framework

1.	Problem Formulation: The user identifies the goal of her Web interaction and forms an intention to achieve the goal.	
2.	Method: She identifies a plan of action to carry out her intention	
3.	Expectation: She forms an expectation that by executing a planned action, she will receive a specific response from the Web-based system	
4.	Action: She executes the chosen method by interacting with the Web resource. The execution typically proceeds through several steps. At each step, the user performs an action and the system provides a response [Borgman, 1986]. BVI users' actions are key commands only.	
5.	Perceive system state: The user perceives system response to an action. BVI users perceive system response through screen-reader's announcement.	
6.	Interpretation: The user evaluates the system response with respect to her expectation. Two possibilities arise:	
	1.	Dissonance: She fails to interpret the system response. This situation arises because of two reasons (Norman, 1988). First, the user 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 and Simon, 1972].	
2.	Consonance: The user interprets the system response. Two possibilities arise:	
	1.	Failure: The goal remains unattained. This failure can be a result of a gulf of execution. The user will reformulate the problem.
	2.	Success: The goal is accomplished. The user will move to the subsequent task or sub-task.

This framework characterizes a problem using Norman's [1988] notion of the gulfs of execution and evaluation between an information system and the BVI user.

> ***Gulf of execution:*** represents the discrepancy between a user's intentions and the system's allowable actions. Users face difficulty translating goals into actions.

> ***Gulf of evaluation:*** represents the discrepancy between system state and the user's ability to perceive and understand this state directly with respect to expectations. This gulf is large if feedback is difficult to perceive, understand, and is inconsistent with user's expectation [Norman, 1988].

These gulfs explain the perceived inconsistencies between expected and observed system behavior [Bhattacherjee, 2001]. Accordingly, I conceptualize accessibility and usability problems as the difficulties resulting from discrepancies between the expected and observed outcomes of user actions in performing Web-based tasks. I use the term "dissonance" to represent difficulties resulting from gulf of evaluation and "failure" to represent difficulties due to gulf of execution.

3.4 Chapter Summary

In this chapter, I explained the novel user-centered, task-oriented, cognitive approach to Web accessibility and usability that helped me develop an in-depth, contextually-situated, observational and experiential knowledge of the problems BVI students experience in Web interactions with academic objectives. I adopted a user-centered view as it explains a problem in terms of the difficulty faced by a BVI student in WEI interaction. I adopted the task-oriented view as it situates this problem in the context of her goal of WEI interaction. I adopted the cognitive view as it explains how this problem manifests in her mind. I explained that to implement this approach, I needed to examine BVI students' perceptions, actions, and cognitions in completing WEI tasks. I discussed several viewpoints relevant to problem-solving in WEI environments that informed my examination. I concluded by presenting my integrated problem-solving framework that I developed by synthesizing research in Information Systems, Cognitive Science and Human-Computer Interaction to conduct this examination. This framework, in combination with the verbal protocol analysis technique, proved very effective in tracing and explaining a BVI student's accessibility and usability problems in WEI environments.

CHAPTER IV

METHODOLOGY AND RESEARCH DESIGN

Chapter I explained that the purpose of this research is to develop an understanding of the nature of accessibility and usability problems blind and visually impaired (BVI) students face in Web-enhanced instruction (WEI). Chapter II identified a critical gap in existing literature about an accurate and in-depth understanding of this problem, and explained the inadequacies in existing research approaches to develop this understanding. Chapter III explained the novel user-centered, task-oriented and cognitive approach adopted in this research to develop an in-depth, contextually-situated, observational and experiential knowledge of the problem. I chose a qualitative research method to implement this novel approach. This chapter will explain why a qualitative method is appropriate for this research and describe the research design for implementing this qualitative approach to develop an in-depth, contextually-situated, observational and experiential understanding of the nature of accessibility and usability problems BVI students face in WEI.

4.1 Why a Qualitative Methodology?

A research method is a strategy of inquiry which moves from the underlying philosophical assumptions to research design and data collection (Myers, 2004). In this section, I explore a qualitative method most feasible for implementing my user-centered, task-oriented, cognitive approach to the problem. In Subsection 1.1, I discuss the two broad categories of research methods: quantitative and qualitative, and explain why qualitative methods are more suitable for my purpose. In Subsection 1.2, I describe verbal protocol analysis, a qualitative method most suitable for examining problem-solving process.

4.1.1 Quantitative versus Qualitative Methods

Research methods can be broadly classified as qualitative and quantitative. From a quantitative perspective, phenomena can be explained by interpreting numeric representations of concepts and their relationship. On the other hand, qualitative approach is based on the assumption that a phenomenon can be explained based on how people make sense of it. In this section, I present some unique features of each approach and explain why qualitative methods are appropriate for this research.

Quantitative methods are based on the assumption that the world has an objective reality, which can be captured and translated into testable hypotheses, usually in the form of statistical or other numerical analyses (Kaplan and Duchon, 1988). The two cornerstones of quantitative methods are numerical data and positivist philosophy (Jenkins, 1985). Numbers come to represent values and levels of theoretical constructs and concepts. Interpretation of these numbers is viewed as strong scientific evidence of a phenomenon. This emphasis on numerical analysis is also fundamental to positivism that believes all theories can be falsified (Straub, Gefen and Boudreau, 2004). Quantitative methods well accepted in social sciences include surveys, laboratory experiments, econometrics, and mathematical modeling (Straub, et al. 2004). The two cornerstones of quantitative approach, including numeric data and positivism, do not apply to this dissertation's research domain. The process by which people solve a problem cannot be represented numerically. Neither do I have extant theories about online experience of BVI users that can be falsified. In addition, quantitative techniques, such as surveys, are not appropriate to ascertain responses that delve deeper into a user's experience. Accordingly, quantitative methods are not useful at this exploratory stage in my research.

Qualitative researchers view the world as a social construction that will demonstrate large variance depending on the observer and the interpreter of the phenomenon (Lee, 1991). Reality is typically viewed as highly subjective that can be accessed through language, consciousness and shared meanings (Lee, 1991). Qualitative methods are conducive for understanding people and the environment within which they live (Kaplan and Maxwell, 1994). These are feasible for developing an in-depth understanding of human behavior and the reasons that govern this behavior. Qualitative data sources include direct observation, participant observation, in-depth interviews, and documents and texts (Myers 1997). According to Kaplan and Maxwell (1994), the objective of understanding a phenomenon from the perspective of a subject and his environment is most feasible with a qualitative approach. Qualitative methods are suitable for my research. I can develop an in-depth understanding of the problem solving behavior of BVI students, and the reasons that govern this behavior. By observing their interaction with the Web, and listening to their description of this experience, I can understand their problem and its context. Direct observation and in-depth interviews can provide suitable environments of data collection for my research.

It is important to understand that qualitative and quantitative methods can be complementary to each other. As Nelson et al (2000) explain, qualitative methods are most appropriate in a new area of research, with little or no domain-specific theories. They make analysis of unstructured data sets possible through extraction of key concepts and relationships underlying the phenomenon (Nelson, et al 2000). Once theories emerge from the data, they are transformed into constructs and hypotheses. It is then validated using established quantitative methods (Nelson, et al. 2000). Since the online experience of BVI users is a relatively unexplored area, there are no theories to explain how BVI students work in WEI environments. This doctoral research is exploratory in nature. A qualitative method offers a feasible technique to investigate the research question.

Miles & Huberman (1994) provide an excellent comparison of quantitative versus qualitative methods. I adapt Table 4.1 from the Miles & Huberman (1994) study to demonstrate the appropriateness of qualitative methods in this research.

Table 4.1. Comparative view of qualitative versus quantitative methods [Adapted from Miles & Huberman (1994, p. 40)].

Dimension	**Qualitative Method**	**Quantitative Method**	**Current Research**
Aim	To provide a complete and detailed description	To classify features, count them, and construct statistical	The aim of my research is to develop a complete and in-depth understanding of problems of BVI

	about a phenomenon	model to explain an observed phenomenon	students in WEI.
Expected Results	Researcher has a rough idea of what to expect	Researcher has a clear idea of what to expect	Literature on Web experiences of BVI users is very scant. I embarked on this doctoral research with a vague idea of problems BVI students face in WEI.
Phase of Research Project	Appropriate for exploratory phase	Appropriate in developed phases	Existing knowledge on BVI students' Web experiences is inadequate. This research develops an understanding of their WEI interaction problems. As the nature of my study is exploratory, qualitative methods become most appropriate.
Design of the Study	The design emerges as the study unfolds	All aspects of the study are carefully designed before data is collected	The nature of this research required collection of evidence of the problem primarily from the perspectives of BVI students, and triangulate it with evidence from

			the perspectives of Web developers and WCAG. Design of the subsequent stages of data collection depended on completion of the primary stage.
Instrument for Data Collection	Researcher is the data gathering instrument	Researcher uses tools, such as questionnaires to collect numerical data	I wanted to understand the problem solving processes of BVI students in WEI environment. This requireed an in-depth investigation necessitating second and third order responses. This could not be achieved through quantitative methods. I wanted to capture and encode mental models of BVI students. This could not be accomplished based on numeric data. This required observing subjects interact with the system, and interpreting their description about it (Young, 1983).
Form of	Verbal or graphical	Numeric data	I used BVI students' verbalization

Data	data		as evidence of their problem solving process.
Subjectivity vs. Objectivity	Emphasis is on people's interpretation of a phenomenon	Emphasis is on precise measurement & analysis of target concepts.	My user-centered, cognitive approach requires that I understand the problem from the perspective of a BVI student. Therefore, subjects' interpretation of a situation becomes important.
Nature of Data	Qualitative data is richer. It takes longer to analyze. Results are less generalizable	Quantitative data is faster to analyze. It is appropriate for testing hypotheses. It does not capture contextual details	I wanted to trace the thought processes of BVI students as they performed a WEI task. I needed contextual information to better understand their problems. A rich set of qualitative data can reveal what goes on in the mind of a participant during problem solving. It captures the complete interaction between the user and the Web.
Involvement of Researcher	Subjective involvement in the subject matter	Objective separation from subject matter	It helps us understand the problem better through subjective involvement with users as they

			perform WEI tasks.

To summarize, a qualitative method is more appropriate to understand the nature of accessibility and usability problems of BVI students in WEI environments. It enabled me to conduct an in-depth investigation of the problem (Lee, 1991). I was able to obtain second and third order responses from my participants (Myers, 2004). It helped me better understand the experience of a BVI student based on her interpretation of the situation (Miles & Huberman, 1994). Accordingly, I was able to develop an in-depth, contextually-situated, observational and experiential knowledge of the accessibility and usability problems BVI students face in WEI environment.

4.1.2 Problem-Solving Methodologies

I implemented my task-oriented, user-centered, cognitive approach by examining the problem-solving process of BVI students in WEI environments. A task represents a problem. Therefore, the process involved in performing a task is problem solving. This allowed me apply the problem-solving theory to analyze the process and trace problems to a specific stage in completing the task. I needed a methodology appropriate for investigating problem solving with an information system. In this subsection, I briefly discuss the use of problem solving theory in IS research. I then identify a method that is most appropriate for my study – verbal protocol analysis. I explain how this method fits well with my research objective.

Human problem solving has been of interest to many scholars in information systems and allied disciplines (Kuusela & Paul, 2000; Glass, Vessey, & Conger, 1993; Vessey & Conger, 1993; Vitalari, 1985; Carroll & Payne, 1977). This understanding is essential to design effective systems (Todd & Benbasat, 1987). An examination of the problem solving process reveals when and why users have difficulty using a system (Sprague, 1980). By examining BVI students' problem-solving process in Web interactions, I identified where, how and why these students face difficulties in performing WEI tasks.

One of the most appropriate techniques for examining the problem solving process is verbal protocol analysis (VPA) (Ericsson & Simon, 1984; Todd & Benbasat, 1987; Newell & Simon, 1972). Scholars have employed this qualitative technique for investigating problem solving in tasks such as e-learning (Cotton & Gresty, 2006; systems design (Vitalari, 1980; Glass, et al. 1992; Vessey & Conger, 1993). In VPA, subjects respond orally to the investigators probe of the internal states to gain information about the course and mechanisms of cognitive processes (Ericsson & Simon, 1980). Through a careful task analysis, a space of possible encodings representing the information relevant to the task is defined a priori. The protocols are then encoded by identifying the category that expresses the same information as the verbalization (Todd & Benbasat, 1987; Ericson & Simon, 1984). The researcher can trace the exact sequence of actions of a problem solver, including strategies employed, inferences drawn from information, and accessing memory by recognition (Ericsson & Simon, 1980). I employ VPA to trace the problem solving process of BVI students in performing online tasks in WEI environments. I choose this method for the following advantages:

1. It provides a very systematic process of data collection. Results based on this kind of data have high validity (Ericsson and Simon, 1996).
2. It is feasible for understanding how subjects approach a task, how they feel about the task environment, and how and when usability problems occur (Benbunan-Fich, 2001; Cotton & Gresty, 2006).
3. It provides the richest set of data (Russo, 1978) and information value per data point (Simon, 1990).

Presenting a theory about VPA, Ericsson and Simon (1984) assert my assumptions to explain the relationship between the processes of problem-solving and verbal reporting:

1. The subject's behavior can be viewed as a search through a problem space, accumulating knowledge (not always correct) about the problem situation as he proceeds. This gradual, step-by-step accumulation of knowledge can be represented by a problem behavior graph, the kth node of which represents the subject's knowledge after k steps of search.
2. Each step in the search involves the application of an operator, selected from a relatively small set of task-relevant operators, to knowledge held by the subject in the short-term memory (STM). Application of the operator brings new knowledge into STM, moving the subject to a new state in the problem space.

3. The verbalizations of the subject correspond to some part of the information he is currently holding in STM, and usually to information that has recently been acquired.

4. The information in STM, and reported by the subject, consists primarily of knowledge required as inputs to the operators, new knowledge produced by operators, and symbols representing active goals and sub-goals that are driving the activity. A goal may take the form of an intention to apply an operator; in which case the protocol may contain explicit evidence for the application of operators.

The first two assumptions are weak postulates about the problem-solving process. The other two assumptions summarize the postulates about verbalization (Ericsson & Simon, 1984). This implies, by employing verbal protocol analysis, I can capture blind students' entire problem-solving process based on what they verbalize.

Verbal protocol analysis can be employed in several ways depending on the research objective (Bouwman, 1983). The types of verbal protocols include:

1. ***Concurrent:*** When the objective is to access information heeded during problem solving, the subject is asked to think aloud while performing the task. This type of verbalization is called concurrent verbal protocol (Todd & Benbasat, 1987). These provide direct access to information in the subject's short-term memory, and indirect access to internal stages of a cognitive process (Ericsson & Simon, 1996).

2. ***Retrospective:*** When the researcher is interested in any information that is relevant to the task, the subject is asked to verbalize the process for a task already attempted. This type of verbalization is termed as retrospective verbal protocols (Todd & Benbasat, 1987). These provide access to information that has been internalized in the long term memory (Ericsson & Simon, 1987).

3. ***Structured-probing:*** When the objective is to examine particular aspects of problem solving, subjects are instructed to verbalize keeping in mind a set of structured questions. Such verbalizations are termed structured-probing protocols (Todd & Benbasat, 1987). Structured-probing results in a more concise protocol which is suitable to analysis and easily comparable across subjects (Bouwman, 1983).

4. ***Neutral-probing:*** When the investigator does not focus on a specific aspect of the problem solving process, he instructs the subject to just describe the process without any structure (Ericsson & Simon, 1993). These verbalizations are termed neutral-probing protocols (Todd & Benbasat, 1987).

For my research, I collect both concurrent and retrospective protocols. Concurrent protocols help us map problems to individual stages in the process of completing a task. Retrospective protocols reveal information from long-term memory that is relevant to the task. The goal is to capture a larger set of information relevant for problem solving. Structured-probing allows us to collect protocols relevant to specific stages in blind students' problem solving.

As an analytical technique, verbal protocol analysis comprises a number of stages, generating successively more detailed representations of the problem solving process (Bouwman, 1983). The process begins by providing structure to the verbal data obtained. This data is usually in the form of continuous string of words, exclamations, and incomplete sentences. Next, a space of possible encodings representing the information relevant to the task is defined based on a careful task analysis. The protocols are then encoded by identifying the category that expresses the same information as the verbalization (Todd & Benbasat, 1987; Ericson & Simon, 1984). This way, a chaotic collection of verbalizations is translated into a more accessible representation of the problem solving process (Bouwman, 1983). I will use an encoding scheme to categorize the protocols. I discuss about this coding scheme in next subsection. By analyzing blind students encoded verbalizations, I can trace their exact sequence of actions including their strategies, inferences, and how they recognize patterns.

To summarize, a problem solving methodology helps us understand the nature of problems blind students face in online environments. It helps us identify when and why problems occur during the process of performing a task in WEI. To examine the problem solving process, verbal protocol analysis offers an appropriate technique. I collect verbal protocols by asking blind subjects to narrate how they perform a task. This can either be concurrent or retrospective. My research objective is best served if I collect both concurrent and retrospective protocols using structured-probing instructions. The concurrent protocols reveal the problem solving process as demanded by my task-oriented approach. The retrospective protocols reveal a wider range of blind students' mental models to satisfy the requirements of my user-centered, cognitive approach. Through structured-probing, I can obtain protocols that reveal the sequence of stages of an online task. I begin the analysis by structuring the verbal protocols with an encoding scheme. The encoded protocols reveal the exact sequence of actions including strategies, inferences, and recognition of pattern in a situation by blind subjects. This helps us capture and encode mental model of my blind subjects.

4.2 Research Design

The purpose of my doctoral research is to develop an understanding of the nature of accessibility and usability problems blind and visually impaired (BVI) students face in Web-enhanced instruction (WEI) environment. For this purpose, I adopt a novel user-centered, task-oriented, cognitive approach to the problem. The user-centered view guided me in understanding the problem from the perspective of BVI students – their special needs and challenges in WEI interactions. I was able to develop a more complete and experiential understanding of this problem. The task-oriented view guided me in understanding a problem and the difficulties it presents for BVI students in completing WEI activities. I was able to develop a more practical and contextually situated understanding of this problem. The cognitive view guided me in understanding a problem and its manifestation in the minds of BVI students. I was able to develop an in-depth and observational understanding of this problem. Thus, the user-centered, task-oriented, cognitive approach provided an accurate and in-depth understanding of accessibility and usability problems BVI students face in WEI. I implemented my user-centered, task-oriented, cognitive approach through a multi-method evaluation of the WEI environment for accessibility and usability in non-visual interaction (NVI).

4.2.1 Multi-Method Evaluation Approach

My literature review informed that the accessibility and usability of a Web site for BVI students involves three main entities – the BVI user, WCAG, and Web developer. BVI users rely exclusively on non-visual interaction techniques to use Web-based systems. Their unique Web interaction needs are communicated to Web designers and developers through WCAG. Web designers and developers use WCAG's recommendations to make their Web sites accessible and usable for NVI. When Web sites fail to accommodate these special needs, accessibility and usability problems arise for BVI users. To accurately understand the nature of accessibility and usability problems for BVI students in WEI environment, we must understand the perspectives of WCAG, the BVI user and the Web developer. I used a multi-method approach for a holistic understanding of the accessibility and usability problems BVI students face in WEI environments. The basic tenet of this multi-method evaluation is that WEI accessibility and usability in NVI is the interplay between three entities - the BVI student, the Web Content Accessibility Guidelines (WCAG), and the Web developer. Figure 4.1 schematically represents my multi-method evaluation approach to WEI accessibility and usability in NVI.

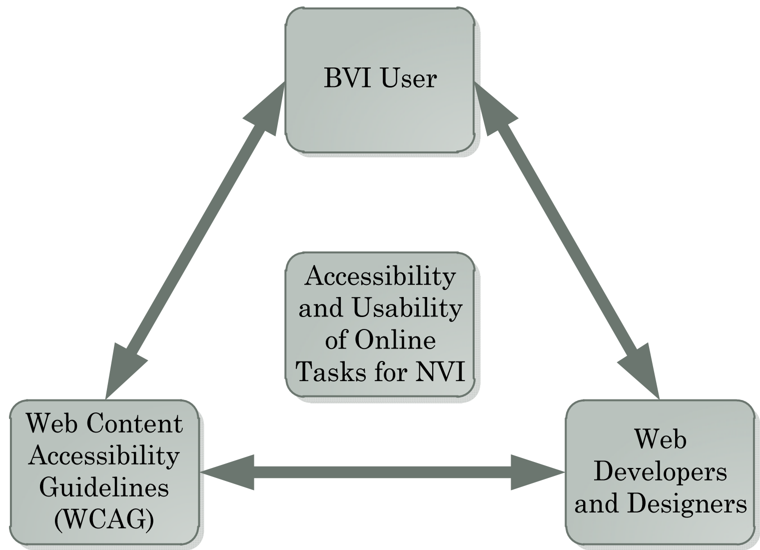


Figure 4.1. Multi-method evaluation of WEI accessibility and usability in NVI.

The multi-method evaluation approach guided me in assessing the accessibility and usability of the WEI environment from the perspectives of BVI students, WCAG design principles, and Web developers. I employed verbal protocol analysis for the BVI student assessment. I employed a combination of textual analysis and automated testing for WCAG assessment. I employed interview analysis for Web developer assessment. I then synthesized the results of the BVI student assessment with the results of the WCAG and Web developer assessments.

4.2.2 Unit of Analysis

My research design was a qualitative field study that included three assessments of the WEI environment, each based on the perspective of an entity (e.g. BVI student, WCAG or Web developer). The unit of analysis across the three assessments was a WEI activity. I chose an online exam over a course management system (CMS) as a typical and common activity that students perform in WEI environment. The online exam included a multiple-choice question, a multiple-answer question and an essay-type question. These represent the three most common formats of presenting questions in online exams, as well as in Web-based surveys, online job applications and online college applications. In addition, they represent the standard forms of information input for web forms. The CMS I used in my study was the Blackboard learning system - the most popular CMS used by academic institutions that had implemented WEI (Landry, et al., 2006). While the context of the study was an online exam over a particular CMS, the accessibility and usability challenges that BVI students encountered here are conceivably common to other forms of entering information on the web. The online exam included 15 distinct activities spread over 6 pages of the CMS. I identify the 15 activities of the online exam in Figure 4.2, and describe each of them subsequently.

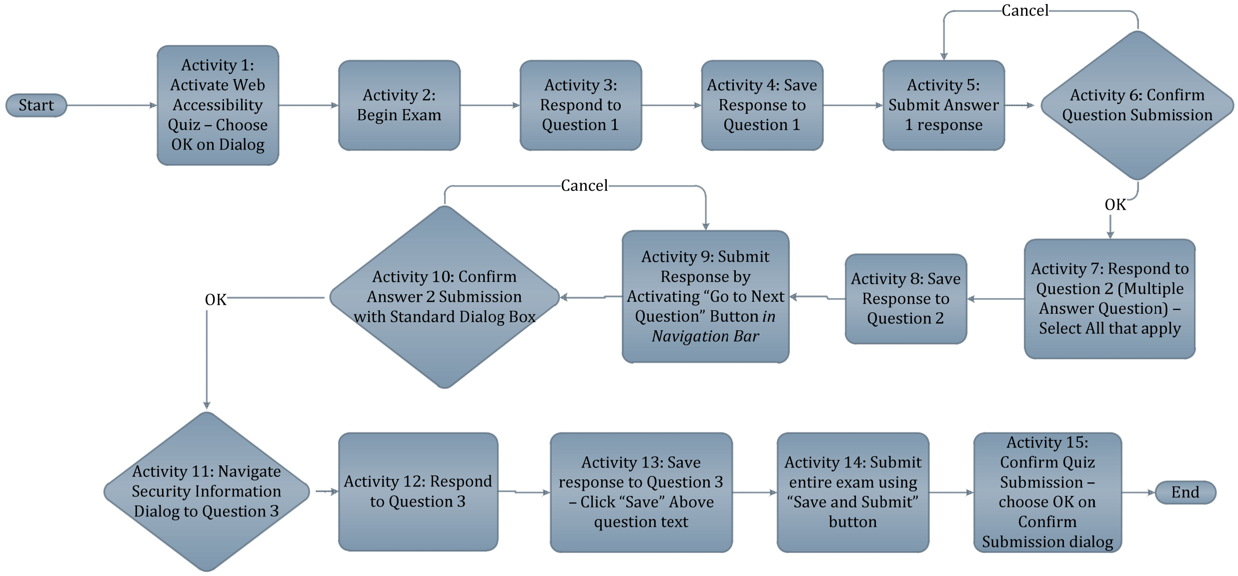


Figure 4.2: WEI activity used for the investigation.

Activity 1. Activate the link "Web Accessibility Quiz" to bring up the exam. The Web Accessibility Quiz link opened a page with the message "Click OK to begin the quiz," and a button labeled "OK" as the only command choice on the page.

Activity 2. Begin the exam by choosing OK, which brought up question 1 page with a multiple-choice question. The page presented a set of instructions, possible number of points, a link named "Save", Question 1 text, four radio button options and the navigation bar.

Activity 3. Respond to Question 1. Figure 3 shows a screenshot of the page that supports this activity. Participants responded to the question by selecting a radio button corresponding to one of the four options.

Activity 4. Save the response by activating the link “Save” available above the question text.

Activity 5. Submit response by activating the “Go to Next Question” button in the navigation bar. A “Confirm Question Submission” box opened which is a standard dialog box with an “OK” and a “CANCEL” button.

Activity 6. Confirm Answer 1 submission by activating the “OK” button. Selecting OK brought up question 2 page that displayed instructions, possible number of points, a link named "Save", Question 2 text with four options, and the navigation bar. Question 2 was in the multiple-answer format.

Activity 7. Respond to Question 2 by selecting checkboxes corresponding to all options that apply.

Activity 8. Save the response by activating the link “Save” available above the question text.

Activity 9. Submit the response by activating the “Go to Next Question button” in the navigation bar.

Activity 10. Confirm Answer 2 submission by activating “OK” button in a “Confirm Question Submission” dialogue pop-up - a standard dialog box with “OK” and “Cancel” options. Choosing “OK” brought up a “Security Information” dialogue box. It contained a security warning message, a “Yes” button and a “No” button.

Activity 11. Get past security warning message by choosing “Yes” and move to question 3 page. This page includes five relevant components: (1) instructions on completing the quiz; (2) possible number of points; (3) link "Save"; (4) question 3 text; (5) several text formatting controls; (6) input area; (7) additional controls leading to the navigation bar; (8) navigation bar with a “Save and Submit” button instead of the usual “Go to Next Question” button.

Activity 12. Respond to Question 3 by locating the input area and typing in the answer.

Activity 13. Save the response by activating the link “Save” available above the question text.

Activity 14. Submit the entire exam by activating the “Save and Submit” button.

Activity 15. Confirm exam submission by choosing “OK” on the “Confirm Submission” dialogue box. The last page loads that displays a message confirming submission and grade information.

4.2.3 Components of Multi-Method Evaluation

My multi-method evaluation of the online exam comprised three assessments:

Assessment I: BVI Student Assessment of WEI environment;

Assessment II: WCAG Assessment of WEI environment; and

Assessment III: Web Developer Assessment of WEI Environment.

In the following, I describe each of these assessments in detail.

4.2.3.A. Assessment I: BVI Student Assessment of WEI Environment

The BVI student assessment of the WEI environment was the most important component of the multi-method evaluation of WEI accessibility and usability. I expected this to provide an in-depth observational and experiential knowledge of WEI accessibility and usability problems in non-visual interaction. Results of this assessment formed the basis for the multi-method evaluation, and guided the WCAG and Web developer assessments. I carried out this assessment using two methods – an observation study and a focus group interview. In the following, I discuss details of this BVI student assessment that includes:

a. Description of the sites where I conducted this assessment – institutions of special education for the BVI;
b. Description of my BVI participants, including their demographic details;
c. Description of the materials I used for this assessment –protocols for the observation study and focus group interview; and
d. Description of the procedure, including the techniques for gathering and analyzing the qualitative evidence.

Sites: The success of the BVI student assessment was dependent on finding and recruiting students who were blind or visually impaired who relied exclusively on a screen-reader to interact with computers. I was aware that majority of BVI students (approx. 86%) receive education in their local school districts (American Printinghouse for the Blind, 2007). However, I also realized these students are spread thinly across many school systems (Ohio Department of Education, 2009). This presented a significant recruitment challenge for my BVI student assessment. To work around this challenge, I decided to focus on institutions of special education for the Blind (ISEB) where BVI students are clustered together. Every state in the country has a government run ISEB (http://www.medicalonline.com/disabled/schools/blindlist.htm) that provide educational, vocational, and rehabilitation training to these students. Technology instructors at these ISEBs are specially trained to teach BVI students how to use computers and the Internet with screen readers. I approached administrators of several ISEBs spread across multiple states to seek cooperation for my research. Four ISEBs that promised cooperation included the North Carolina Division of Services for the Blind (NC-DSB) Rehabilitation Center, the Texas School for the Blind and Visually Impaired (TSBVI), the Michigan Commission for the Blind Training Center (MCB/TC) and the Iowa Department for the Blind Training Center (IDB/TC). I visited these ISEBs to establish initial contacts with school administrators, instructors and BVI students, and study the feasibility of conducting the BVI student assessment. Based on schedule and other considerations, I selected two of these ISEBs for conducting my BVI student assessments, namely TSBVI and NC-DSB Rehabilitation Center

TSBVI serves as a special public school in the continuum of statewide placements for BVI students between the ages of 6 and 21. Located in Austin, the TSBVI believes that every blind person in Texas must have educational services equal to services provided to sighted students. The TSBVI trains BVI students develop skills necessary to lead vocationally, personally, and socially satisfying and productive lives.

The NC-DSB Rehabilitation Center provides BVI citizens of North Carolina with educational, vocational and rehabilitation skills to help them reach their goals of independence and employment. DSB helps a person without vision in three important ways: (1) facilitate transition from high school to college or university, (2) lead an independent adult life, and (3) prepare for, find, and retain a job. DSB provides technology training to BVI individuals to develop the skills needed to productively use computers and Internet through assistive technologies to achieve independent living, educational and vocational goals. Students work on personal and work goals developed jointly by them and the rehabilitation staff. Classes are small, and students receive individualized attention.

TSBVI offers regular high school education while NC-RCB offers supplementary educational and vocational training. These institutions provided us access to our participants as well as access to their computer labs for conducting the study. Technology instructors at both institutions train the BVI in using screen-readers, computers and the Web. These instructors helped in recruiting the participants. They explained the study’s objective to their class and asked for volunteers. Each volunteer participated in the BVI student assessment session independently in my presence. I conducted one-on-one sessions that were scheduled after school hours.

Participants: I recruited six BVI volunteers as participants (Mean Age = 23 years) with five males (83%) and one female (17%). All participants lacked the sight necessary to interact with computers visually. They used computers through screen-reader assistive technology. A typical participant used the Web for electronic mail and information gathering for over 5 years. She had never used a CMS or attempted an online exam. Four of the participants were enrolled at TSBVI while two were at the NC-DSB Rehabilitation Center at the time of the assessment. TSBVI participants were all school seniors. NC-RCB participants included a college freshman and a government employee.

Materials: Materials for the BVI student assessment included an instruction sheet in electronic format, a test course in the CMS, the online exam inside this course, and an interview protocol. Instructions directed participants to log on to their CMS accounts, visit the "E Learning Course" – a course I designed for my research, and find additional instructions under Announcements. The instruction in the "Announcements" section directed participants to the Assignments section, which includes instructions on completing the online exam called "Web Accessibility Quiz" described in figure 2. The interview protocol included follow-up questions about the experience completing the online exam intended to prompt participants reflect back on their perceptions, actions and cognitions.

Procedure: The objective of the BVI student assessment was to trace a BVI student's problem-solving of WEI interaction. Here, I wish to clarify that problem-solving represents the process of interacting with the WEI environment for a specific goal. Existing research in Cognitive Science and Human Computer Interaction explains that verbal protocol analysis (VPA) is an effective and feasible technique to understand human problem-solving and problems in system-user interaction (Todd & Benbasat, 1987; Newell & Simon, 1972). In VPA, participants respond orally to the investigators probe of the internal states to gain information about the course and mechanisms of cognitive processes (Ericsson & Simon, 1980). Through a careful task analysis, the investigator first defines a space of possible encodings representing the information relevant to the task. He then encodes the protocols by identifying the category that expresses the same information as the verbalization (Todd & Benbasat, 1987; Ericson & Simon, 1984). The investigator traces the exact sequence of a user's actions, including the strategies she employs, the inferences she draws from information, and accessing memory by recognition (Ericsson & Simon, 1980). The core component of my BVI student assessment procedure was tracing a BVI student's the problem solving in online exam employing VPA.

I chose verbal protocol analysis for the following advantages:

i. It provides a very systematic process of data collection. Results based on this kind of data have high validity (Ericsson and Simon, 1996).

ii. It is feasible for understanding how people approach a task, how they feel about the task environment, and how and when they encounter accessibility and usability problems (Benbunan-Fich, 2001; Cotton & Gresty, 2006).

iii. It provides the richest set of data (Russo, 1978) and information value per data point (Simon, 1990).

Verbal protocol analysis does not provide an interface-element-wise analysis of a web site. Nor is it suitable to understand feasible design modifications necessary to help the BVI accomplish online tasks. My multi-method approach of combining VPA with the WCAG-based assessment and developers' assessment forms an effective technique to generate the holistic understanding required to answer my research question.

Data Collection: The BVI student assessment required two kinds of verbal protocols of WEI interactions - concurrent and retrospective protocols. I needed concurrent protocols to map the student's difficulty to a specific aspect of a WEI activity. I needed retrospective protocols to examine their long-term memory for task-relevant information. My goal was to capture a larger pool of evidence about a BVI student's WEI interaction challenges. I collected the two kinds of verbal protocols using two methods. These methods include:

Method 1: Think-aloud method of direct observation to collect concurrent verbal reports;

Method 2: Focus group interview to collect retrospective verbal protocols.

I describe each of these methods in further detail below.

Method I. Think Aloud Method of Direct Observation – BVI participants concurrently verbalize their thoughts while completing the online exam.

In Method 1, participants worked on the online exam and concurrently verbalized whatever they were thinking [Ericsson and Simon, 1984; Todd and Benbasat, 1987]. Concurrent verbal protocols contain evidence of participants' information processing employed in performing tasks [Ericsson and Simon, 1984]. Ericsson and Simon [1993] found that concurrent verbalizations do not alter participants' behavior in tasks and are non-reactive. This technique is effective to develop an in-depth understanding of human problem-solving [Newell and Simon, 1972]. This method is feasible to trace accessibility and usability problems in Web-based IS [Cotton and Gresty, 2006]. My prior research [Babu and Singh, 2009] demonstrated the utility of this technique in developing an in-depth, user-centric understanding of a BVI user's accessibility and usability problems in Web interaction tasks.

Ericsson and Simon (1980) explained that the researcher must provide explicit instructions to verbalize that are consistent with the research objective. My research objective is to examine a participant's the problem solving process and determine her mental model. Accordingly, I chose to provide participants instructions on how to verbalize. This ensured I got a concise set of protocols that was easy to analyze and comparable across participants. I asked participants to verbalize six aspects of the task they performed. These were:

1. ***Goal:*** How they formulated a task. Participants stated this as the goal they had in mind or their intent to achieve this goal;
2. ***Plan of action:*** How they thought they could achieve the goal. Participants stated this as a sequence of steps they would take to reach their goal;

3. ***Actions:*** Each action being executed. Participants stated this as a keyboard command (e.g. Control + C) or the operations (e.g. Copy);

4. ***Goal Achieved?:*** Whether the goal was accomplished or not. Participants stated this as interpretation of the response from the WEI environment;

5. ***Basis of Conclusion:*** How did they know that they achieved the goal or not. Participants stated this in terms of what feedback they received from the WEI environment through the screen-reader; and

6. ***Next Step:*** What they intended to do subsequently.

Literature informs that concurrent verbalization can interfere with the task the user is attempting (Ericsson & Simon, 1980). Simon (1990) suggests this interference reduces considerably when participants practice talking aloud while performing a task. He explains that practice teaches how to encode heeded information into memory while talking about it. As a result, verbalizing becomes overt, without additional demands on processing time or capacity (Ericson & Simon, 1993). To ensure the methodology was clear to participants and give them practice thinking aloud, I conducted a familiarization session. In this session, I described the objective of the assessment to participants. I told them what they are expected to do in the study - work on the task while thinking aloud, and demonstrated the thinking aloud technique for a representative online task. I also described the structure and function of the WEI environment. I gave them login credentials for the CMS, and asked them to log-on to their accounts. I then let them practice thinking aloud while completing a representative Web interaction task. Thus, I ensured that my participants understood the methodology. I audio-recorded verbalizations and ensured that their audio quality was appropriate for transcription and analysis of the verbal protocols collected.

Method 1 comprised a 45 minute session for each participant. In each session, the participant read the instruction sheet, logged on to CMS and found the e-Learning course and additional instructions under Announcements. These instructions guided her to the Assignments page with links to the exam page. Instructions prompted her to verbalize after arriving in the Assignments section. If I observed that she paused for more than 60 seconds while working on any activity, I urged her to resume and continue verbalizing. Aside from these intermittent nudges, I intervened only when she requested assistance. I helped her get out of the roadblock without explaining the strategy employed. Thus, I avoided influencing her cognition and behavior on encountering a similar roadblock in a subsequent activity. I captured participant verbalizations, screen-reader speech and my conversation with participant through audio-recordings.

Method II. Focus Group Interview – BVI participants reflect back on WEI experiences.

Method 2 comprised a focus group discussion where participants reflected back on their WEI experiences. The purpose was to collect retrospective verbal protocols of a WEI activity that participants attempted in Method 1. Such retrospective protocols provide access to a participant's long-term memory of the task (Ericsson & Simon, 1993). Such protocols represent complete and well-organized thoughts of the task (Todd & Benbasat, 1987). They reveal task-relevant information that the participant may have ignored for problem-solving (Bouwman, 1978). My objective was to discover effective mental models that remained unused by a participant. This is expected to happen due to bounded rationality (Simon, 1955).

My choice of focus group interview over other technique was guided by the following advantages:

1. It allows gathering responses from several participants at one time (Nielsen, 1993);
2. It provides participants a permissive and nonthreatening environment to explain their perceptions (Krueger, 1988).
3. The dynamic discussion Reveals information typically not obtained in one-on-one interview (Pilsung, et al. 2006).
4. It allows for in-depth probing (Nielsen, 1994)

Nielsen (1993) provides extensive guidance on conducting focus group interviews. I conducted my focus group interviews following these guidelines. I commenced each session by explaining my study's objective to participants. I then explained the interview protocol – that they will respond to my questions one by one, and that I will audio-record their responses.

The protocol for the focus group interview included following questions:

1. In your mind, what is an online course?
2. What comes to mind when you hear about taking an online exam
3. What were some roadblocks you faced as you attempted the online exam?
4. How did you get out of the roadblock you faced?

I audio-recorded the focus group discussion in its entirety using audio recording software.

The output of the data collection phase of the BVI student assessment included two sets of audio-recordings – one for the observation studies and one for the focus group interviews. The audio-recordings from the observation studies contained concurrent verbal protocols. The average duration of a participant’s audio-recorded concurrent verbalization was approximately 150 minutes. The audio-recordings of the focus group discussions contained retrospective verbal protocols. The average duration of a participant’s audio-recorded retrospective verbalizations was 25 minutes. These together comprised a rich set of qualitative evidence of the assessment of the WEI environment for NVI accessibility and usability made by BVI students.

Data Analysis: I commenced the data analysis for the BVI student assessment with the transcription of the two sets of audio-recordings that the two methods yielded. I created these transcripts using Microsoft Word. A participant’s audio-recorded verbalization translated into approximately 43 pages of transcribed concurrent verbal protocols and approximately 4 pages of transcribed retrospective verbal protocols. Transcripts of the concurrent verbal protocols included five categories of evidence:

a. Participant concurrent verbalizations ;
b. Screen-reader’s announcement;
c. Screen-reader’s typing echo;
d. My conversation with participant; and
e. Any other audible evidence of participant’s WEI interaction.

Transcripts of the retrospective verbal protocols included participant’s responses on specific topics.

The next step of the analysis was segmentation of the transcripts. A segment is an individual unit of thought, often fragments of sentences (Ericsson & Simon, 1993). In the case of the BVI student assessment, two critical sources of evidence include a participant’s verbalization and the screen-reader’s announcement. Therefore, my segments were not merely units of thoughts; they included screen-reader feedback. I decomposed the transcripts into segments. Each segment represented a single unit of perception, action or cognition of the participant. Some segments were verbalized by participants, while others were announced by the screen-reader. I numbered these segments sequentially that helped me determine the context of an event.

Todd and Benbasat (1987) recommend developing a coding scheme to categorize the segments in structured protocols. I derived a coding scheme based on my integrated problem solving framework. This framework is founded on the theory of problem solving (Newell & Simon, 1972), 7-stage action model (Norman, 1988), theory of bounded rationality (Simon, 1955), and theory of mental model (Johnson-Laird, 1983). Categories of my coding scheme include:

I. ***Problem Formulation:*** Segments representing a goal or an intention. I combined these two together into one category since both represent participant's interpretation of the instruction for an activity. This is consistent with Norman's (1988) observation about the flexible nature of his model, as well as Newell and Simon's (1972) problem solving theory.

II. ***Method:*** Segments representing a plan of action. These include statements about an action (e.g. activate a link), or identifying a key command (e.g. hit enter on the link). Sometimes a participant verbalized her method before executing an action, and other times while doing so.

III. ***Expectation:*** Segments representing expected consequences of an action. This is founded in the theory of human reasoning (Johnson-Laird, 1992). According to this theory, people form an expectation about the consequence of an action. My contention is that the student forms an expectation about the behavior of the WEI environment in response to her action.

IV. ***Action:*** Segments representing execution of a method by interacting with the system. This includes statements about individual key commands. Sometimes, this was verbalized by the participant, while other times the screen-reader's typing echo revealed it.

V. ***Perception:*** Segments representing the response of the WEI environment communicated through the screen-reader. This category of segments included participant verbalizations as well as screen-reader announcements.

VI. ***Interpretation:*** Segments revealing what sense the participant makes of the screen-reader feedback. I subcategorized this as consonance and dissonance. Dissonance can either be a total failure to interpret system response due to no feedback; or inconsistencies that result from incomplete feedback from the system. Each form of dissonance indicates gulf of evaluation (Norman, 1988).

VII. ***Goal accomplishment:*** Segments representing participant's judgment about the outcome. I separated segments characterized as failure from segments characterized as success. Failure to accomplish goal indicates gulf of execution (Norman, 1988).

The novelty of this coding scheme is that it accounts for the choice behavior exhibited by participants at various stages of problem solving. I used this coding scheme to categorize each segment. I examined coded verbalizations, along with the speech output of screen-reader, to understand where and why BVI participants faced a roadblock while completing the online exam. My primary focus was on examining segments suggestive of dissonance or failure. Segments in other categories provided contextual information, and helped me gain a holistic understanding of a problem. Speech output of the screen-reader provided valuable clues to what actions participants took that they did not verbalize. This technique proved useful in capturing the complete interaction process and tracing additional problems participants experienced.

I identified segments that represented a Web interaction challenge that hampered a participant's ability to complete the task effectively. I labeled such segments as Problem. I identified problems that correspond to a situation where things were not apparent to the participant – confusion due to inadequate system feedback. I labeled this category of problems as Inconsistency. I identified problems corresponding to a situation where things did not work for the participant – an action did not yield expected outcome. I labeled this category of problems as Failure. This characterization of problems as inconsistency and failure is theoretically grounded in seminal human-computer interaction research. According to this stream of research, problems in systems interaction result from two kinds of gulfs between the system and the user [Norman, 1988]. Gulf of execution represents the discrepancy between a user's intentions and the system's allowable actions. Users face difficulty translating goals into actions. Gulf of evaluation represents the discrepancy between system state and the user's ability to perceive and understand this state directly with respect to expectations. This gulf is large if feedback is difficult to perceive, understand, and is inconsistent with user's expectation. My notions of Inconsistency and Failure correspond to gulf of evaluation and gulf of execution. Thus, I expected to understand what kind of gulf between the student and the WEI environment was responsible for a problem. I also expected to identify conditions where a specific action of the participant resulted in an unexpected outcome. According to me, this is an operationalization of a problem. This is consistent with the Action Model (Norman, 1988) that explains that problems arise due to discrepancies between expected and observed outcomes of user actions in systems interaction.

An important goal of my data analysis was to discover a BVI student's mental model under a dissonant condition. I believe this knowledge is necessary for a clear understanding of the special needs and challenges of BVI students in WEI interactions. As I explained in the previous chapter, the mental model representation I am using in this research has two components – Knowledge Structure and Cognitive Processes. The knowledge Structure informs how a BVI student conceptualizes the structure of the task environment – interface objects needed for the task and their relative positions on a Web page. The Cognitive Processes informs how a BVI student conceptualizes the necessary actions on these objects and consequent system responses. I analyzed the two kinds of a participant's transcript to understand her knowledge structure and cognitive processes for an event representing a dissonant condition. Segments coded as Method, Expectation, Action and Interpretation revealed the knowledge structures and cognitive processes.

4.2.3.B. Assessment II: WCAG Assessment of WEI Environment

The main purpose of performing Assessment II was to understand how existing Web accessibility and usability standards defined the problems experienced by BVI students in WEI environment. WCAG represents the current state of knowledge and best available practices in accessible and usable Web design. Therefore, understanding WCAG's perspective on the problems identified using BVI student assessment was appropriate for Assessment II.

WCAG is the de facto standards on Web accessibility and usability. Its objective is to inform Web developers and designers how to make Web sites and Web-based systems accessible and usable for people with disabilities, including the BVI (www.w3.org/tr/wcag/). It forms the basis of legal stipulations on equal access such as Section 508 of the U.S. Rehabilitation Act. Section 508 mandates that WEI environments must be accessible and usable to students with disabilities. WCAG recommendations form the basis of traditional evaluation approaches including automated testing, expert technical review and user testing. As a secondary objective of the WCAG assessment, I also wanted to examine the extent to which the WEI environment was compliant with WCAG's criteria for accessibility and usability.

I therefore designed Assessment II using two evaluation methods that serve a specific purpose each.

Method 1: WCAG text analysis to define BVI student's' WEI interaction problem

Method 2: WCAG-based automated testing to objectively evaluate the accessibility and usability of WEI environment;

I next describe the two evaluation methods of my WCAG assessment.

Method 1: WCAG text analysis to define a BVI student's problem in WEI

The objective of Method 2 is to understand how WCAG design principles characterize a problem that my BVI participants faced in completing the online exam. I achieved this through a textual analysis of WCAG literature against each of the six problems my BVI student assessment identified. WCAG literature comprises a set of four guidelines and eighteen success criteria. Below, I provide an interpretation of these guidelines and success criteria applied to the unique needs of BVI students.

Guideline 1-Perceivability: BVI users can perceive all content of a Web-based IS by listening to screen-reader's announcements. It includes three relevant success criteria:

1. Images have texts describing their purpose or embedded information that is readable by screen-readers;
2. Content is designed such that screen-reader users can simplify its layout without losing its purpose or information; and
3. All content is easily audible, including differentiation of main content from background noise.

Guideline 2-Operability: BVI users can operate all interface elements of a Web-based IS using key commands. It includes three relevant success criteria:

1. All functionality is available through keyboard;

2. Users have enough time to read and use content by listening to screen-readers; and

3. Mechanisms are available to navigate, locate desired information and find one's position by listening to screen-reader

Guideline 3-Understandability: BVI users can understand all content and controls of a Web-based IS by listening to screen-reader's announcement. It includes three relevant success criteria:

1. Text content must sound clear and meaningful when announced by screen-reader;

2. Web pages must sound and work in a predictable way using screen-reader; and

3. Users are able to avoid and correct mistakes by listening to screen-reader announcement.

Guideline4-Robust: All components of a Web-based IS are compatible with screen-readers. It includes one relevant success criteria:

All Web technology used interoperates effectively with current and future screen-reading technology.

Through my analysis, I evaluated individual Success Criterion of WCAG 2.0 in the context of a specific problem. For this purpose, I first identified the interface objects in the WEI environment associated with the problem. I achieved this by retracing the path of my BVI participants. I then identified how each interface object contributed to the problem through a careful analysis of participants' verbal reports for that scenario. I then performed a thorough textual analysis of WCAG Success Criteria that made any reference to such a contribution made by an interface object to a problem for a screen-reader user's. I characterized the problem in terms of failure of the specific Success Criterion that refers to the problem. The output was a mapping between the interface objects associated with a problem and the WCAG Success Criteria that the design of these objects violated.

Literature informs that WCAG 2.0 is an improvement over WCAG 1.0 in that it takes into account usability of a Web site (Leuthold, et al., 2008. The guidelines and success criteria make use of three usability principles. These principles are:

a. Jacob Nielsen's Web usability criteria (Nielsen, 1993);

b. Donald Norman's principles of good design (Norman, 1988); and

c. Shneiderman and Plaisant's golden rules of interface design (Shneiderman and Plaisant, 2004).

I included these usability principles as a part of the assessment activity to see how a BVI student's problem is defined. The ten usability criteria I adapt for my analysis were:

A. Web Usability Criteria (Nielsen, 1993)

1. Learnability. If first-time BVI students can become productive quickly in terms of finding information and using functionality on the WEI environment;
2. Efficiency. If BVI students can complete online exam quickly, without much cognitive effort, after learning about the WEI environment;
3. Errors. If BVI students are prone to committing errors, and if they recover quickly;
4. Satisfaction. If BVI students are satisfied with how the WEI environment works;
5. Memorability. If returning BVI students have to relearn how to use the WEI environment.

B. Principles of Good Design (Norman, 1988)

1. Visibility. If BVI students can tell what is going on with the WEI environment, and derive alternatives for action through observation;
2. Good mappings. If BVI students can determine the relationships between actions and results, between the controls and their effects, and between the state of the WEI environment and what is perceivable;
3. Feedback. If BVI students receive full and continuous feedback about the results of actions;

C. Golden Rules of Interface Design (Shneiderman and Plaisant, 2004).

1. Consistency. If the sequence of action is consistent in similar situations; if labeling, order and effects of interface objects are consistent;
2. Working memory load. If displays are kept simple, multiple page displays are consolidated, and window-motion frequency is reduced.

I followed the same process for analyzing each problem identified in the BVI student assessment against usability criteria as I did with the WCAG's success criteria.

Method 2: WCAG-based automated testing for objective evaluation of WEI accessibility and usability;

Automated testing is the most commonly used assessment method for WCAG Compliance [Lazar, et al., 2004]. It uses automated evaluation tools - software programs that crawl through Web pages to identify individual interface elements that violate WCAG recommendations. They generate an objective evaluation report that lists the number of element-wise violations on a Web page. Some tools also offer explanations or solutions for identified problems based on WCAG's recommendations.

I used iProwe for WCAG-based automated testing of the WEI environment. iProwe (http://www.infosys.com/offerings/products-and-platforms/iprowe/Pages/index.aspx) is a proprietary automated evaluation tool developed by the Future Web Research Lab of Infosys. It leverages built-in intelligence to automatically analyze accessibility problems in websites and provides detailed reports. It evaluates accessibility of a Web site using a number of parameters classified under Content (Audio, Graphics/Video), Comprehension, Presentation (Text, Colour, Tables, Language), Navigation, Structure (Site Structure, Links, Forms, Semantic Data, Help), User Controls (Time Limits, Updates, Focus), and Technology Alternatives (Frames, Javascript, CSS). It performs a keyword-based search to analyze parts or all pages of a website for compliance with specific design standards. It suggests remedial measures to improve accessibility of the Web site. This iProwe evaluation uses an intelligent rules engine based on standards such as WCAG 1.0, WCAG 2.0 as well as country specific accessibility guidelines such as Section 508 of US Rehabilitation Act. It generates reports in PDF, HTML and an overlay HTML mock-up format. The summary report provides a high level view of accessibility break point statistics, whereas the detailed report captures all the accessibility break-points, their line numbers and suggests measures to remedy them.

I performed an iProwe scan of the CMS pages comprising the online examfor the WCAG-based objective evaluation. iProwe crawled through each of the six pages of the online exam and checked whether individual interface elements complied with specific accessibility criteria of both versions of WCAG.

Output of Method 1 WCAG assessment included two sets of six page-wise evaluation report, each set corresponding to a specific version. Each report provided a snapshot of html elements and criteria-based error report for a single CMS page. Html elements include input areas, forms, body, anchors, dividers, images, tables, scripts and paragraph headers. While WCAG 1.0 reports refer to the evaluation criteria as priority levels, WCAG 2.0 refer to these as conformance levels. I carefully analyzed each iProwe evaluation report individually, and then compared the two reports for each exam page. I examined the total number of errors on various pages of the online exam to understand the extent of the problem as per WCAG standards.

WCAG-based automated evaluation significantly reduces the time and effort required for testing Web accessibility. However, it falls short of a comprehensive assessment of a BVI student's accessibility and usability challenges in WEI. For example, we cannot use these tools for an effective assessment of the information equivalence of Alt Text and its impact on task completion. An Alt Text entry is the textual description of an image which makes it accessible for BVI users. Information Equivalence implies that this description should accurately convey the information embedded in the image without loss of information. Tools can identify images that are missing alt text, but cannot determine if the alt text is equivalent. Thus, Web sites that are assessed compliant by automated evaluation tools may still present accessibility and usability problems for the BVI in accomplishing the objectives of the online task. If WCAG compliance - the target of all existing approaches - is not enough, BVI users will continue to face problems even when developers build "accessible and usable" Web sites by ensuring WCAG compliance. Therefore, WCAG-based assessment is a necessary but not sufficient for accurate evaluation of WEI accessibility and usability for BVI students. My multi-method evaluation considers WEI experiences of BVI students as the basis of understanding the accessibility and usability problem, and triangulates this with perspectives of WCAG and Web developers. I believe this provides a more complete evaluation of the WEI environment for NVI accessibility and usability.

A WCAG-based assessment focuses only on the interface design aspect of what is a multi-faceted problem. The focus of WCAG is to ensure that the text content of the web page is accessible to screen-readers [Moss, 2006; Kelly, et al. 2005]. The level of compliance of a Web site is influenced by the constraints and conceptualizations of designers and developers. Understanding the perspectives of Web developers and designers is important. My multi-method evaluation is expected to provide a holistic understanding of BVI students problems as it also includes assessment from Web developer perspective.

4.2.3.C. Assessment III: Web Developer Assessment of WEI environment

The purpose of Assessment III was to triangulate the results of the BVI student assessment using the perspectives of Web developers and designers. I wanted to understand how Web developers and designers analyze a problem situation experienced by BVI students. Specifically, I was interested in identifying the sources of their problems in the WEI environment. Therefore, I interviewed Web developers and designers and obtained their assessment of these problems. In the following, I describe the details of this assessment, including the participants, materials and procedure.

Participants: For Assessment 3, I recruited 5 Web developers (Mean Age = 29 years) with four males (80%) and one female (20%) as participants. Each participant had a minimum of three years experience in Web development. Three developers were employed by Infosys, while two developers were employed by Braille without Borders (www.braillewithoutborders.org) at the time of the study. Infosys offers Web accessibility consultancy service to clients from around the globe. Web developers evaluate Web sites for accessibility standard compliance using iProwe. Braille without Borders trains the BVI in social entrepreneurship. The fourth participant was the Web master for Braille without Borders at the time of the study. The fifth participant was an instructor at Braille without Borders at the time of the study with considerable prior experience in Web development.

Material: Material for this method included an interview protocol. I developed this protocol around the observed difficulties that my BVI participants faced in Assessment I, informed by the results of the Assessment II. This protocol included a script describing each scenario where BVI participants faced difficulty completing the online exam in the WEI environment. It included an open-ended question that sought a Web developer perspective on problems identified through the BVI student assessment. The question was:

Based on your understanding of difficulty experienced by BVI students, what do you believe is the problem source?

In addition, the protocol included questions seeking demographic and background information from Web developer participants

Procedure: The developer assessment consisted of five one-on-one interviews with Web developers. In each interview, I explained the purpose and implication of the research to the participants. I briefed them on the observation study with BVI participants, and described the six problems identified. I explained each scenario where BVI participants experienced these problems as they attempted the online exam. For consistency and accuracy purposes, I followed the script in the interview protocol to describe each scenario. I then asked them to retrace the path of a BVI participant who experienced that problem. For this purpose, I gave the Web developers the log-in credentials of the BVI participant's CMS account and asked them to do the following:

1. Log-on to the CMS account;
2. Visit each page of the online exam, Starting from the page with the link "Web Accessibility Quiz" and ending on the page to review the exam;
3. Examine the WEI environment corresponding to the 15 activities comprising the online exam; and
4. Explain what you think could have caused the problem for my BVI participants.

I urged them to be as descriptive as they could while presenting their analysis. I clarified that I am specifically interested in understanding how the WEI environment could have contributed to the BVI participant's difficulty in that scenario. I audio-recorded each interview in its entirety.

I analyzed the interview data collected from Web developers using recursive abstraction technique. In recursive abstraction, qualitative evidence is distilled to obtain knowledge through a process of summarization without using codes (Crabtree and Miller, 1999). I transcribed the audio-recordings of developer interviews in their entirety and divided each transcript into three components –

a. Component 1: Text corresponding to participant’s response to the question: Based on your understanding of difficulty experienced by BVI participants, what do you think is the problem source?

b. Component 2: Text corresponding to participant’s demographic and background information

c. Component 3: Miscellaneous.

I summarized and re-summarized Component 1, including information directly relevant to the questions for each participant. The summaries included statements that attribute a problem experienced by BVI participants to interface element (s) and page lay-out of the online exam.

CHAPTER V

RESULTS AND ANALYSIS

Chapter I explained that the purpose of this research is to develop an understanding of the nature of accessibility and usability problems blind and visually impaired (BVI) students face in Web-enhanced instruction (WEI). Chapter II identified a critical gap in existing literature about an accurate and in-depth understanding of this problem, and explained the inadequacies in existing research approaches to develop this understanding. Chapter III explained the novel user-centered, task-oriented and cognitive approach adopted in research to develop an in-depth, contextually-situated, observational and experiential knowledge of the problem. Chapter IV explained my multi-method evaluation technique and outlined the research design using which I implemented my novel approach to understand the problem. This chapter presents the results and analysis of the multi-method evaluation of the WEI environment. As discussed previously the multi-method evaluation involves synthesizing three kinds of assessments of the WEI environment consistent with the representation in Figure 5.1.

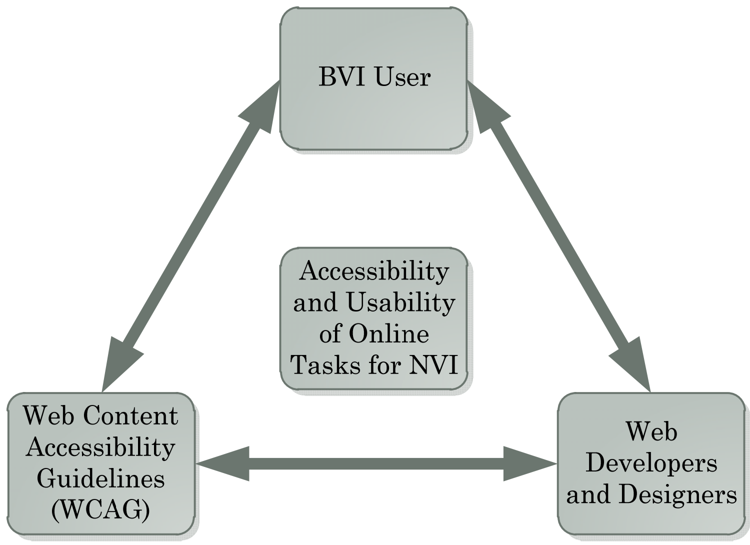


Figure 5.1. Multi-method evaluation of WEI accessibility and usability for BVI students.

Figure 5.1 shows that an accurate and in-depth understanding of the nature of accessibility and usability problems in WEI can be acquired by evaluating it from the perspectives of BVI student, WCAG and Web developer. This chapter presents results of the three assessments. I first describe how well the design of the WEI environment complies with existing accessibility and usability standards. I then describe the nature of the challenges BVI students face in interacting with this WEI environment when performing an academic task. Here, I explain where and how a problem occurs, how BVI students conceptualize their WEI interaction under this situation and how design principles define this problem. In addition, I explain how each problem represents a gulf between a BVI student and the WEI environment. I then explain the source of each problem in the design of the WEI environment. Finally, I present an integrated understanding of where, why and how problems occur during a BVI students WEI interaction for an academic task by combining perspectives of BVI users, WCAG and Web developers.

5.1 Analysis of WCAG Assessment of WEI Environment

I performed the WCAG assessment of the WEI environment using iProwe – an automated testing tool that analyzes a Web page for poorly designed interface elements. This generated an evaluation report with a list of all problems on a page. iProwe evaluation reports show that all pages of the online exam had interface elements which violate the specifications of both WCAG 1.0 and 2.0. The problem begins from the first page, which provides the link to the online exam, and persists throughout the subsequent five pages that comprise the online exam task (shown in Figure 5.2.1 through Figure 5.2.5).

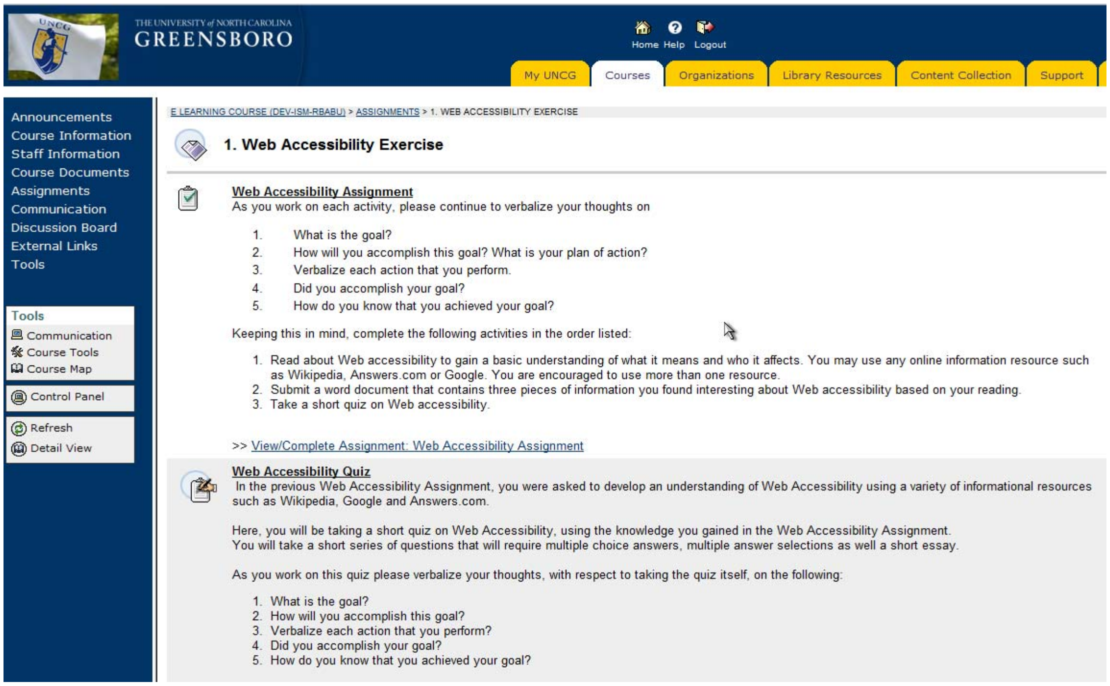


Figure 5.2.1: Students find the Web Accessibility Quiz under the Assignments section of Blackboard

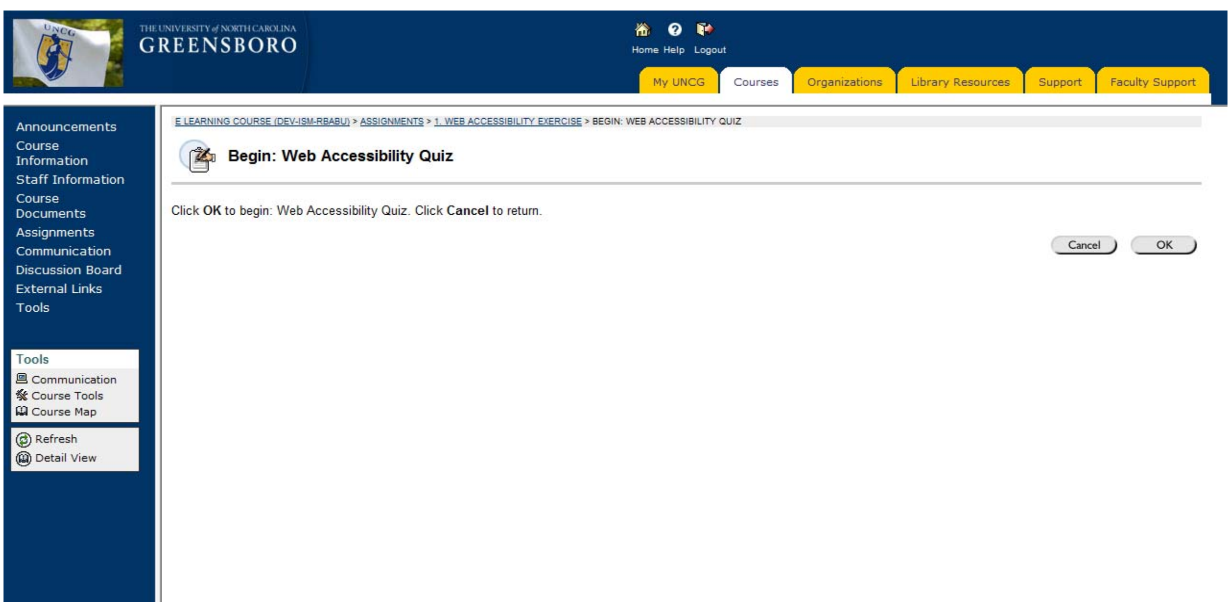


Figure 5.2.2: Students begin the exam by activating the “OK” button

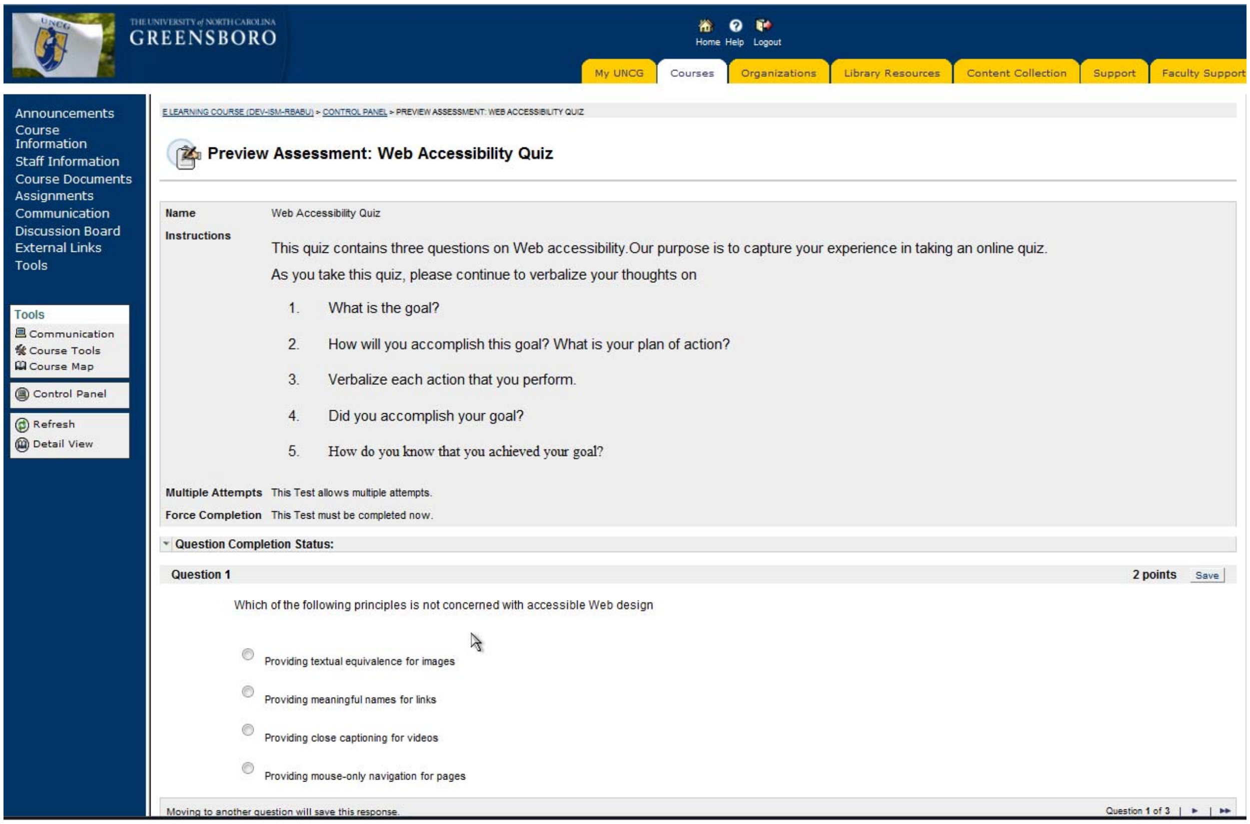


Figure 5.2.3: Students arrive on Question 1 page

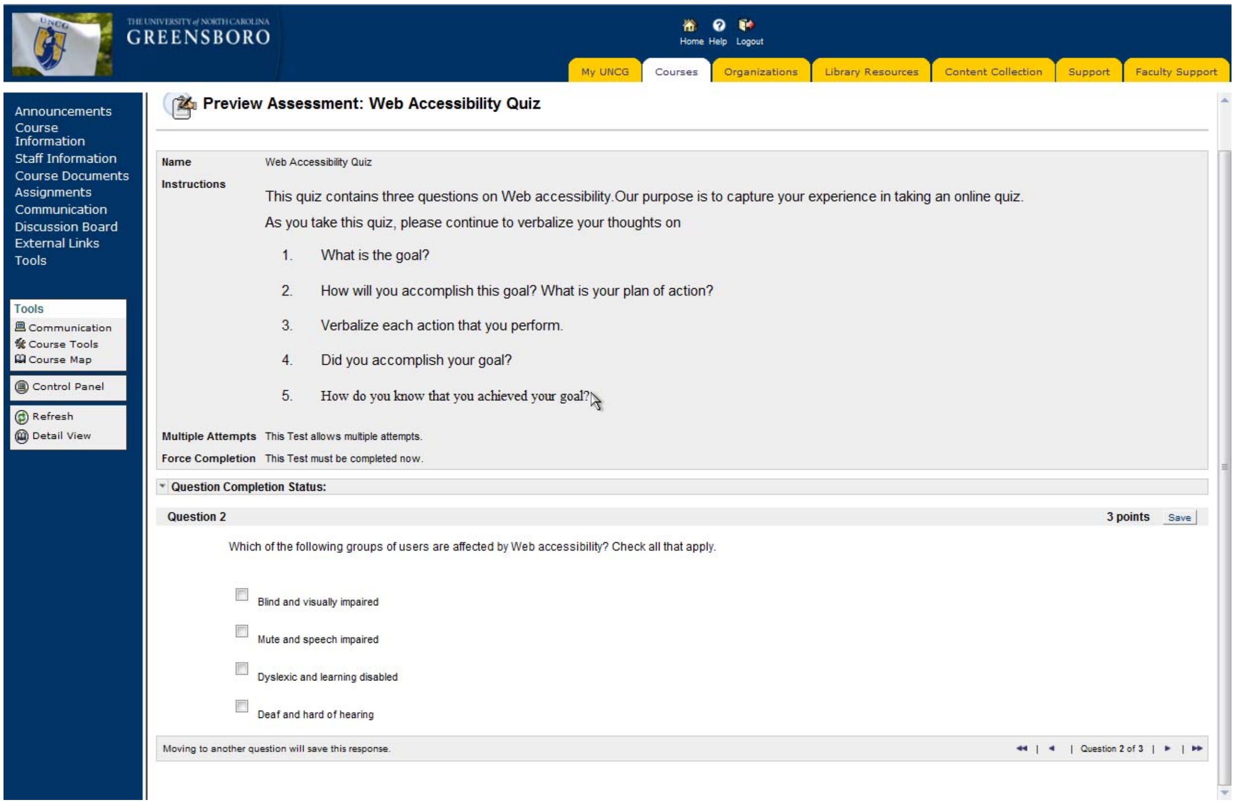


Figure 5.2.4: Students move to Question 2 after confirming response for Question 1.

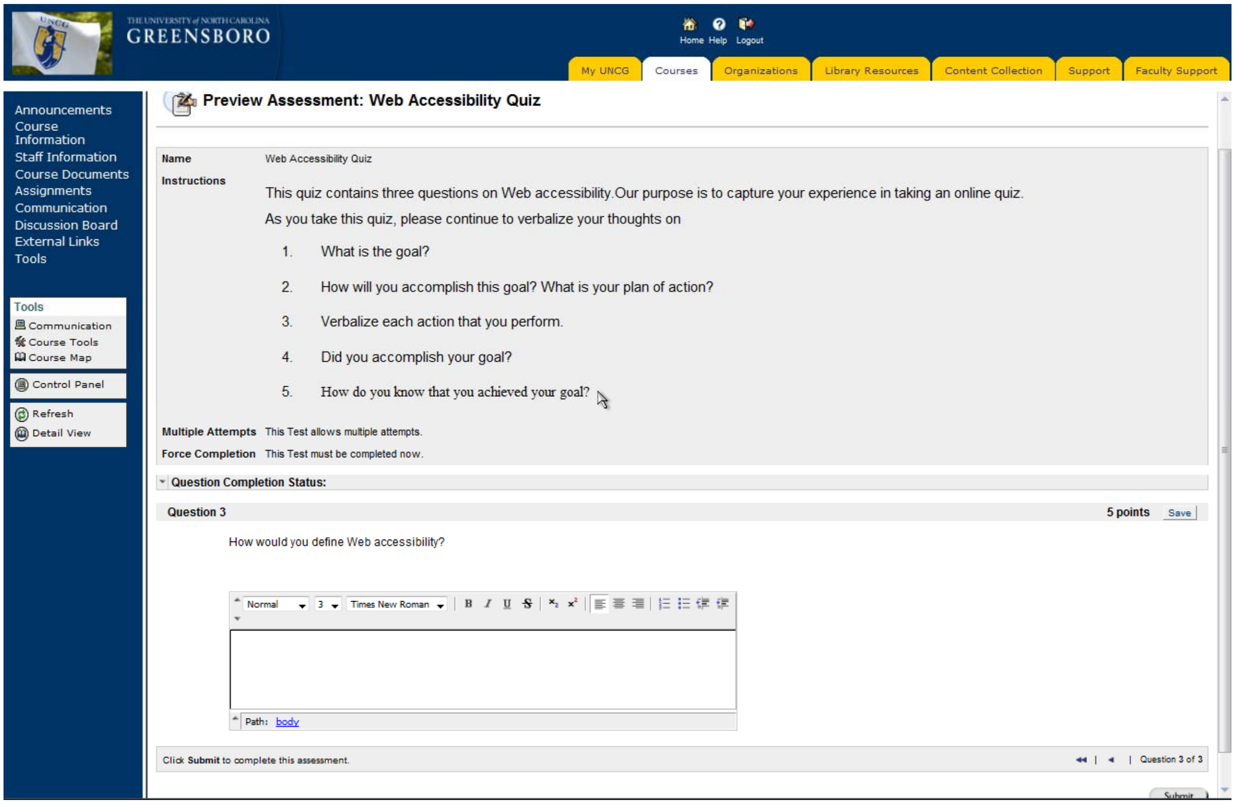
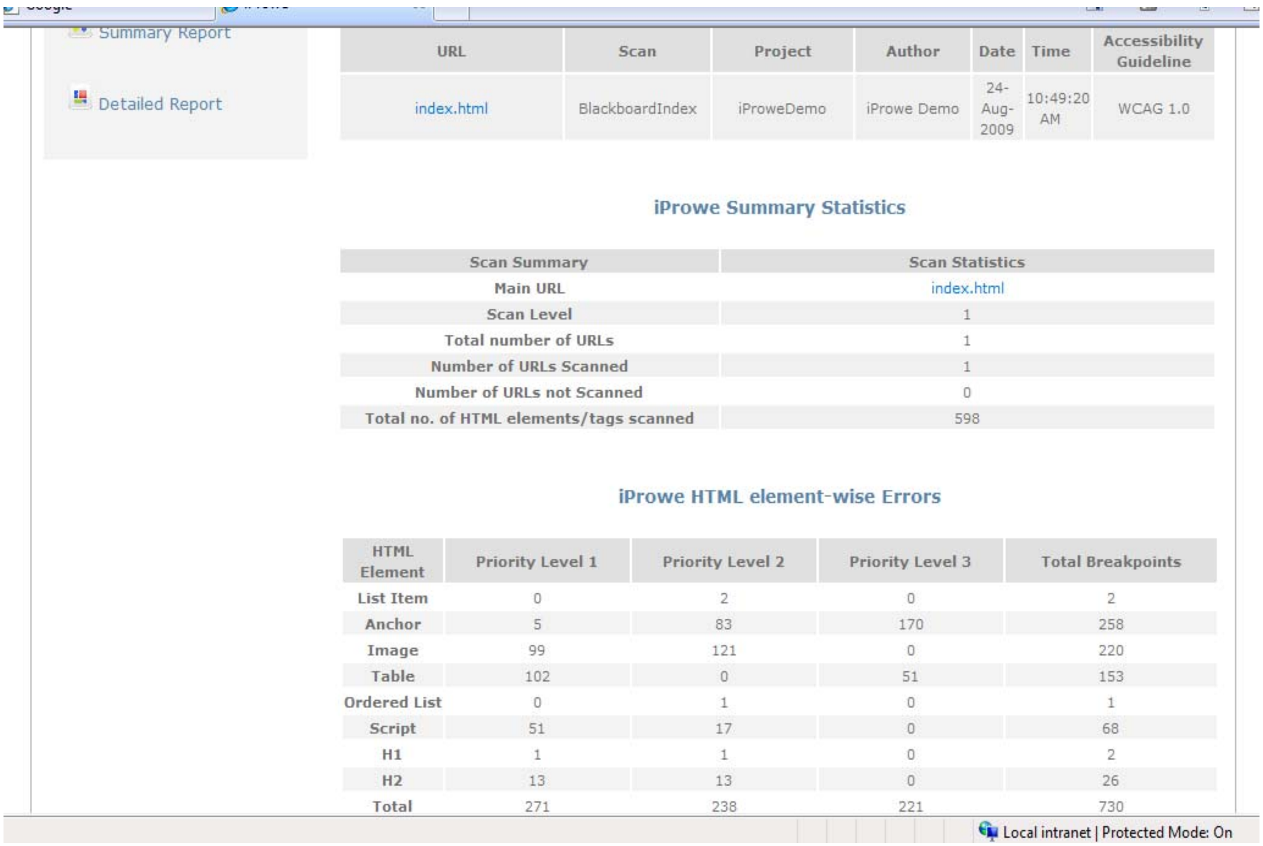


Figure 5.2.5: Students type in response for Question 3 and submit the entire exam.

Two findings are particularly noteworthy. First, the first page of the online exam contained over 650 interface elements that both versions of WCAG consider inaccessible. WCAG 1.0 based evaluation consistently provided higher frequency of errors per page compared to the WCAG 2.0 based evaluation. For instance, the first page of the exam had 730 errors based on WCAG 1.0 and 634 errors according to WCAG 2.0 specifications. Second, systemic accessibility problems were observed in interface elements including forms, tables, scripts, anchors, images, and paragraph headers. I provide screenshots of evaluation reports for the first page with respect to WCAG 1.0 and WCAG 2.0 in Figure 5.3 and Figure 5.4 respectively.



URL	Scan	Project	Author	Date	Time	Accessibility Guideline
index.html	BlackboardIndex	iProweDemo	iProwe Demo	24-Aug-2009	10:49:20 AM	WCAG 1.0

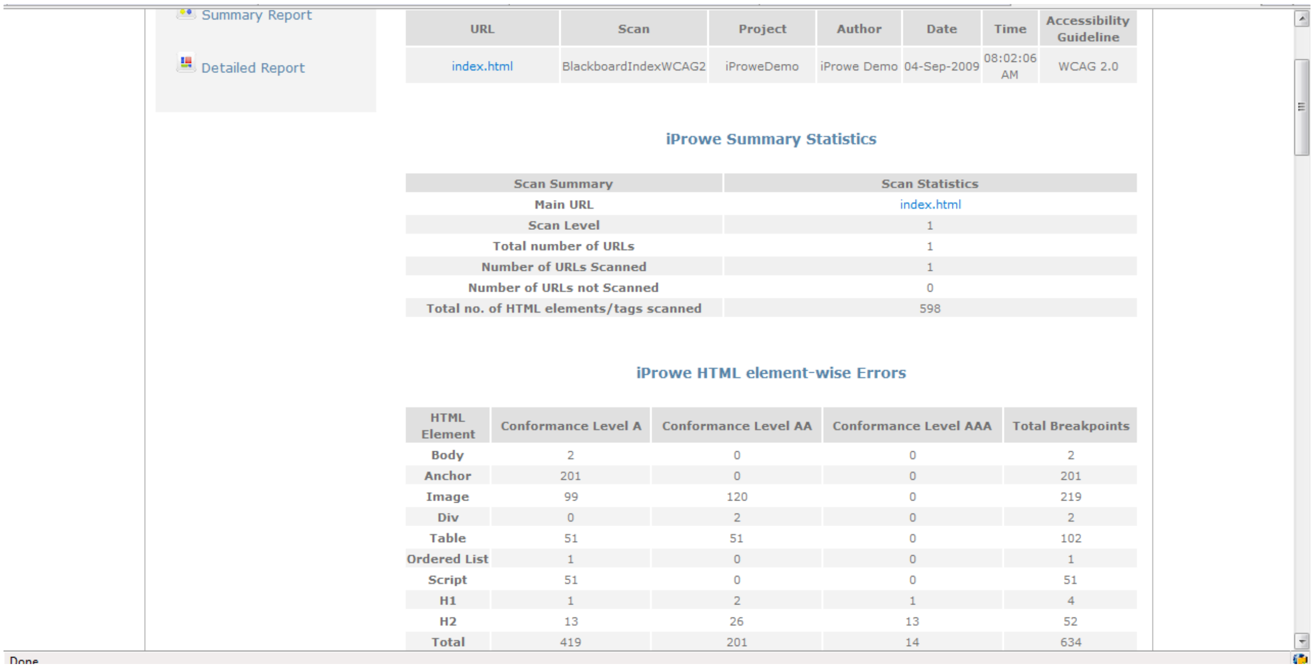
iProwe Summary Statistics

Scan Summary	Scan Statistics
Main URL	index.html
Scan Level	1
Total number of URLs	1
Number of URLs Scanned	1
Number of URLs not Scanned	0
Total no. of HTML elements/tags scanned	598

iProwe HTML element-wise Errors

HTML Element	Priority Level 1	Priority Level 2	Priority Level 3	Total Breakpoints
List Item	0	2	0	2
Anchor	5	83	170	258
Image	99	121	0	220
Table	102	0	51	153
Ordered List	0	1	0	1
Script	51	17	0	68
H1	1	1	0	2
H2	13	13	0	26
Total	271	238	221	730

Figure 5.3. Screenshot of iProwe evaluation report for homepage against WCAG 1.0 specification



Summary Report

Detailed Report

URL	Scan	Project	Author	Date	Time	Accessibility Guideline
index.html	BlackboardIndexWCAG2	iProweDemo	iProwe Demo	04-Sep-2009	08:02:06 AM	WCAG 2.0

iProwe Summary Statistics

Scan Summary	Scan Statistics
Main URL	index.html
Scan Level	1
Total number of URLs	1
Number of URLs Scanned	1
Number of URLs not Scanned	0
Total no. of HTML elements/tags scanned	598

iProwe HTML element-wise Errors

HTML Element	Conformance Level A	Conformance Level AA	Conformance Level AAA	Total Breakpoints
Body	2	0	0	2
Anchor	201	0	0	201
Image	99	120	0	219
Div	0	2	0	2
Table	51	51	0	102
Ordered List	1	0	0	1
Script	51	0	0	51
H1	1	2	1	4
H2	13	26	13	52
Total	419	201	14	634

Done

Figure 5.4. Screenshot of iProwe evaluation report for homepage against WCAG 2.0 specification.

Next, I present my analysis of WCAG assessment of the online exam task environment based on iProwe reports for each type of interface element, including images, tables and anchors. For illustration, I use WCAG 1.0 and WCAG 2.0 evaluation of the first CMS page.

5.1.1 Image

iProwe assessment showed that the online exam pages included a significant number of images that did not comply with basic accessibility standards. For instance, the first page included 220 images that WCAG 1.0 considers inaccessible for NVI. However, 219 of these images were deemed inaccessible by WCAG 2.0. Both versions of WCAG deem images inaccessible primarily when the <<Alt Attribute>> lack equivalent text descriptions. Other conditions in which WCAG considers images inaccessible include inadequate text descriptions in their <<Alt Attribute>>; their usage for mark-up; and their usage as spacers, decorative pictures, and bullets with Alt Texts. These are most common image-related errors that web developers often overlook while designing Web-based systems (Lazar, et al., 2004). Such errors can significantly hinder Web accessibility and usability for the BVI who rely on the Alt Text to perceive, understand, and perform operations on the graphical element. Alt Text is important to convey the meaning or purpose of an image to a BVI user as she cannot perceive it visually. When the screen-reader comes across an image without Alt Text, it may do one of two things:

1. It could simply skip the image as if it were not even on the page.
2. It could find some text that is associated with the image such as the file name and read that instead.

The end result is that the BVI user either misses the image content completely, or hears some text that is meaningless. If the information communicated by the image is necessary for completing a task, the BVI user will fail to achieve her goal. Here, I would like to highlight that WCAG's requirement of Alt Text for the image is a necessary but not sufficient condition for NVI accessibility. The BVI user will fail to effectively perceive the information communicated by the image if the Alt Text does not clearly describe its purpose in the context of the task she is trying to perform. Therefore, a user-centered, task-based assessment by BVI users is important. Online tasks frequently require the use of such images. Including meaningful description of an image in its ALT Attribute that communicates its purpose in that context is important for the success of the Web site for BVI users.

5.1.2 Table

iProwe assessment identified multiple tables that do not conform to WCAG accessibility standards. For instance, 150 WCAG 1.0 and 102 WCAG 2.0 table-related errors were identified on the first page of the online exam. WCAG deems a table inaccessible if it does not include descriptive headers for rows or columns or if there is no "linear text alternative". A linear text alternative is a textual description of the information presented by the table. A lack of linear text alternative in a table is a major accessibility and usability problem in NVI. Descriptive titles of rows and columns and alternative text descriptions allow the screen-reader to communicate the tabulated information to BVI users. Without meaningful description, the BVI user will be unable to perceive or understand the relationship between cell values. This is because BVI users do not "see" the rows and columns of a table. They perceive each table cell as a line of its own without any context. For example, a 3*4 table becomes 12 different lines for a screen-reader user. When an online task requires the use of a table that lacks descriptive headers or linear text alternative, a BVI user will fail to understand the information communicated; her goal will remain unattained. Table-related errors are both an accessibility and usability problem since it negatively impacts the understandability of the tabular information. While WCAG recommends providing text descriptions as the accessibility solution, a user-centered, cognitive and task-based assessment is necessary to evaluate the effectiveness of these descriptions in helping BVI users accomplish their goals. I observe that it is important for html tables are designed with descriptive row/ column headers and linear text alternatives that make sense to a BVI user when announced by a screen-reader. This will help convey the tabular information effectively to the user for the task she tries to perform.

5.1.3 Anchor

WCAG assessment shows that the online exam pages included a significant number of anchors that did not comply with accessibility standards. There were 258 WCAG 1.0 defined anchor-related errors and 201 WCAG 2.0 defined anchor-related errors on the first page of the online exam. According to WCAG, an anchor-related error is a condition where:

a. Scripts are disabled for dynamic content;

b. Adjacent links overlap;

c. No description is available in the “Title Attribute” of target page;

d. No logical tab order is provided; and

e. No logical keyboard shortcuts are available.

Anchor errors create significant accessibility and usability problems in NVI and make online tasks very challenging for the BVI. For example, a common anchor-related error is the absence of a description of the target page in the Title Attribute of a hyperlink. The consequence of this error is that when a BVI user activates the hyperlink, she does not receive adequate screen-reader feedback describing the destination page. Without adequate screen-reader feedback about the destination page, she will fail to detect a change in page; she will be unable to proceed ahead with the task she was trying to perform.

WCAG assessment using automated testing tools can provide broad-based understanding of accessibility and usability problems in non-visual interaction. It identifies interface elements that do not comply with success criteria of WCAG. However, this interface element-wise assessment does not explain where, how and why BVI students face difficulty completing online exam due to these inaccessible content. Developing this kind of understanding requires a high degree of user interaction as well as consideration of Web developers' perspectives. According to my multi-method evaluation technique, this is achieved through a BVI student's assessment of the WEI environment. This will answer the *what, where and how* of the problem. The multi-method technique then suggests a Web developer assessment to answer the why of the problem.

5.2 Analysis of BVI Student Assessment of WEI Environment

The BVI student assessment was the most important aspect of the multi-method evaluation as it provided in-depth observational and experiential knowledge of accessibility and usability problems in WEI. Analysis of this assessment showed that non-visual interaction with the WEI environment was significantly challenging. BVI students face systemic and functional impediments in completing common WEI tasks. BVI participants faced six major accessibility and usability problems that obstructed their progress in the online exam to varying degrees. Analysis of the BVI student assessment, in terms of the six problems participants faced is explained below. It is noteworthy that some of these problems were debilitating enough for participants to either leave the exam incomplete, or require sighted intervention to proceed with completing the task.

5.2.1 Confusion while Navigating between Exam Pages

Analysis shows that BVI students are confused while navigating between different pages of the online exam. It demonstrates their difficulty verifying if they had arrived on the destination page after activating a link in the source page of the online exam. I observed that the reason for their confusion was the inconsistency in the nature of system feedback they receive in response to their link activation. This confusion, coupled with the resultant frustration, was quite evident in the verbal reports of BVI participants. I provide evidence of this confusion as experienced by two participants – BVI2 and BVI4. The evidence includes participant verbalizations (labeled BVI), speech output of screen-reader (labeled SR) and my questions (labeled Q).

Participant BVI2 expressed this confusion and frustration while navigating from the first to the second page of the online exam in the following manner:

> SR: Link Web accessibility quiz..
> BVI2: Ok, web accessibility quiz. I am going to hit enter on this.
> SR: Enter. Web accessibility quiz visited link. Frame..
> BVI2: Once again, I entered into the same problem. It didn't tell me I have entered into a new page. It didn't say page has how many links. It just said frame. I don't know what that means. But I clicked on a link. And I assume it worked.

The evidence I present here shows BVI2 expected a specific kind of feedback to ascertain that the link activated correctly and brought up a new page. The evidence I present informs that traditionally, BVI students know that a link is activated when they hear the screen-reader announce two kinds of information:

(1) Percentage figures, such as 1%, 10% . . . 100%. The figures correspond to the percentage of downloaded content of the destination page; and

(2) A summary describing the frequency of interface objects present in the downloaded page. For example, it announces “This Page has 80 headings and 41 links” when I open the website www.voa.gov.in

The BVI user interprets the percentage figure announcement as the progress of page download, 100% meaning the download is complete. She interprets the summary announcement as the indication to begin browsing the new page. Considering a BVI student cannot perceive visual cues from the Web site, she detects a page change based exclusively on the two kinds of announcements. If the screen-reader fails to announce a part or all of this information, the BVI user is in the dark; she cannot tell what goes on in the WEI environment. The consequence is that she cannot go through with the task she was trying to complete. When my BVI participants activated a link to go to a new page of the online exam using the Enter key, they did not hear any screen-reader announcement. They could not tell if their action of activating the link was successful; if the destination page had downloaded or not. Below, I present verbal reports of participant BVI2 as she tried to move to the third page of the online exam as evidence of the confusion:

> BVI2: I am going to go back to the bottom of the page with control end, and scroll up to complete the quiz.
> SR: Click ok to begin the quiz.
> BVI2: Just click ok to begin the quiz. I am going to hit ok.
> SR: Ok link graphic. Ok.
> BVI2: Once again, I have no indication whatsoever from the speech program that I am starting the page, updating the page. So frustrating. I have made note of that several times, so I am not going to continue doing this in each page. But it is somewhat frustrating. When you do click on a link, it is not saying you have arrived on a new page. It just doesn't say anything at all.

In some instances, when a participant activates a link on an exam page, the screen-reader announced two kinds of information:

(1) the percentage figures; and

(2) "Content Frame Updated"

A comparison of this kind of announcement to the traditional announcement I describe earlier shows that this was partially inconsistent. As the verbal reports of participant BVI4 shows, the "Content Frame Updated" announcement caused a great deal of ambiguity. This was not consistent with her expectation. She was unable to make sense of this announcement in the context of her goal of moving to a new page. She was not able to verify if her attempt to activate the link was successful and that she moved to a new page or not. She felt uncertain about the state of the system. This state of mind in which the student has to deal with conflicting cognitions is called "Dissonance". As explained in earlier chapters, dissonance in WEI interaction is undesirable for BVI students. It results in confusion and frustration as students cannot decide on the next course of action without adequate feedback from the WEI environment. I provide evidence of this confusion and inconsistency citing verbal report of BVI4 as she activates the link to go to the second page of the online exam.

> SR: Blank link web accessibility quiz.
> BVI4: Web accessibility quiz! I was looking for that. Enter on that.
> SR: Content frame updated. Content frame end blank .
> BVI4: What the heck! It's the contact, it's saying something about contact. I don't know what it's like. Maybe I should go up some?
> SR: Link graphic cancel.
> BVI2: Oops!
> SR: Click okay to begin colon web accessibility quiz.
> BVI4: O!
> SR: Blank heading level

As I explained in the earlier chapters, a basic tenet of my research is that accessibility and usability problems in WEI interaction are the result of a gulf between a BVI student and the WEI environment. Specifically, I discussed *gulf of execution* and *gulf of evaluation* defined by Norman (1988). These represent inconsistencies between the BVI student's mental model for performing a WEI activity and the mental model behind the design of the WEI environment. I also explained that this inconsistency manifests itself as a discrepancy between the expected and observed outcomes of a student's action in interacting with the WEI environment for a specific purpose. Identifying such discrepancies form the basis of my analysis.

Participant verbalizations were analyzed to identify situations where a participant's expected outcome for an action was different from what she observed based on the screen-reader's announcement. Discrepancies between the expected and observed feedback from the WEI environment in response to activation of a link to navigate to a desired page of the online exam were observed. Participants were confused while navigating between pages of WEI environment when there was a discrepancy between the expected and observed feedback for link activation. They perceive the observed feedback as incomplete, ambiguous, and frustrating that creates a lot of confusion. Due to this uncertainty, they spend extra time trying to verify their position and location in the exam. This negatively impacts their ability to complete the exam in a timely manner, and may lead to poor performance. Thus, analysis of BVI student assessment successfully identified a situation where BVI students face a problem - confusion while navigating between exam pages – as a result of a discrepancy between their expected and observed outcomes for activating a link. According to the Action Model (Norman, 1988), this problem represents a gulf of evaluation since BVI participants could not interpret the feedback of the WEI environment (announced by screen-reader) in response to their action of activating a link.

Another tenet of my research is to understand the thought processes of BVI students in performing WEI activities. I was particularly interested in discovering their mental model for interacting with the WEI environment when they faced a problem. The idea is to understand the problem as it arises from difference in mental models of BVI students and that tacit in the WEI environment. Therefore, my analysis also focused on discovering the mental model underlying the confusion while navigating between exam pages. As explained in my theoretical foundation, the mental model representation I am using has two components – Knowledge Structure and Cognitive Processes. The knowledge Structure informs how a BVI student conceptualizes the structure of the task environment – interface objects needed for the task and their relative positions on a Web page. The Cognitive Processes informs how a BVI student conceptualizes the necessary actions on these objects and consequent system responses. Based on the verbal reports I present above, I observed the mental model of interest was concerned with navigating to a new page of WEI environment. Based on my interpretation of BVI participants' verbal reports, I present the following representation of a BVI student's mental model for navigating to a new page in Table 5.1. It shows how BVI students conceptualize the structure and function of a link by outlining their knowledge structure and cognitive processes respectively.

Table 5.1: BVI student's Mental Model for navigating to a new page of WEI environment

Knowledge Structure	Cognitive Processes
A hyperlink on the source page leading to a destination page	1. Locate the hyperlink using Arrow key to hear "Link" followed by the link text; 2. Activate the hyperlink using Enter;3. Verify arrival on destination page after hearing: a. Page download percent; and b. Number of headings, links, tables,

	etc.

In Table 5.1, Cognitive Process # 3 is of most interest for my analysis. It informs that BVI students expect two kinds of screen-reader announcement following link activation:

(1) Percentage of destination page downloaded culminating in 100%; and

(2) Number of interface objects – links, headers, tables - available in the destination page.

However, I observed that this cognitive process was not consistent with the system feedback observed. The screen-reader announcement that corresponds to the CMS response for link activation was contrary to expectation. Occasionally, it may announce the percentage of page downloaded, but never the number of interface objects in the destination page. Sometimes, the screen-reader announces “Content Frame Updated”. This is an unexpected feedback for link activation for a BVI student. I observe that this inconsistency created the confusion in the minds of BVI participants, and they were unable to verify the arrival on a destination page of the online exam environment.

After identifying the problem and understanding the underlying mental model, the analysis is focused on characterizing this problem as accessibility and/ or usability problem. As explained in the methodology, WCAG text on accessibility and texts of three usability principles are analyzed to characterize a problem. I present results of this analysis for BVI students’ confusion while navigating between online exam pages below.

WCAG text analysis informs that the confusion problem represents a violation of “Page Title” design principle by the WEI environment (CMS). WCAG’s Success Criterion 2.4.2 states that a Web page must have a title that describes its topic or purpose to the user. The aim is to design each Web page with a descriptive title that helps users find content and orient themselves within this content. Titles identify the current location without requiring users to read or interpret page content. WCAG explains that Web pages that have no titles make it difficult for users to locate goal-relevant information. It specifically talks about the difficulties of BVI users in identifying such pages. They rely on screen-reader announcements to perceive that a new page is available or if the page has the information they are looking for. Based on analysis of participant verbalizations and accompanying screen-reader announcements, I observed that *none* of the exam pages had a descriptive title accessible with a screen-reader. Therefore, the confusion of BVI students while navigating between exam pages is characterized as an accessibility problem in WEI design.

Success Criterion 2.4.2 of WCAG is founded on the assumption that the screen-reader is able to access and announce the page title immediately after the page downloads. However, I could not find support for this criterion based on my WCAG textual analysis. It did not explain that when Web pages have descriptive titles, screen-readers can effectively access and readily announce this title to help BVI students in verifying the arrival on a new page. In other words, WCAG does not clarify whether the provision of a page title communicating its topic and purpose is a necessary or a sufficient condition for page identification through screen-reader.

Analysis of the usability principles informs that the confusion of BVI students while navigating between exam pages reflects violation of the “Feedback” and “Satisfaction” principles. As I explained in the earlier chapter, the Feedback principle (Norman, 1988) requires that the system must provide full and continuous feedback to users about the results of their actions. I observed that the WEI environment did not adhere to the Feedback principle. The verbal reports of my participants inform that they could not understand the CMS feedback for link activation. The screen reader’s announcement communicating this feedback was inconsistent with their expectation. The Satisfaction principle (Nielsen, 1993) requires that website users are satisfied with how it works. I observed that my participants were not satisfied with the way the WEI environment responded to their action of activating a link. They found the CMS feedback incomplete and ambiguous. They got frustrated as this lack of adequate feedback disrupted their progress in the online exam. I therefore characterize the confusion of BVI students while navigating between exam pages as an usability problem in WEI design.

5.2.2 Susceptibility of Skipping Exam Questions

Analysis of BVI students’ assessment of WEI environment showed that these students are susceptible to inadvertently skipping exam questions on a CMS. I present evidence that demonstrates how participants in my study skipped Question 2, completely unaware about the error being committed. I first provide evidence of this error committed by participant BVI1, and then provide the evidence of this error narrowly avoided by participant BVI4.

Participant BVII skipping Question 2

I observed this participant's error primarily from the speech output of the screen-reader. Below, I present evidence of this error in three forms:

a. Screen-reader's typing echo (labeled SR*1, SR*2, etc.) that reveals what keystrokes the participant is executing;

b. Screen-reader's announcement (labeled SR1, SR2, etc.) that communicates the snippet of content on the question page in focus of the cursor, as well as the CMS response to participant's action; and

c. Participant verbalizations (labeled BVI1).

SR1: Microsoft Internet Explorer Dialogue: Confirm question submission. Okay button. To activate, press spacebar.
SR*1: Space.
SR2: two percent...one hundred percent. Frame 4. Course content frame. Updated. Go to first question button. Go to previous question. Question 2 of 3. Go to last question. Blank. Graphic links to assessment questions and answers. Same page link. Read question. Same page link. Course content frame.
BVI1:Just going up and down.
SR3: Go to next question button.
SR*2: Enter.
SR4: Microsoft Internet explorer dialogue. Question may be incomplete. Do you want to Continue? Okay button. To activate, press space bar.
SR*3: Space.
SR5: Microsoft Internet explorer dialogue. Confirm question submission. Okay button. To activate press spacebar.
SR*4: Space.

Evidence for this problem mainly consists of screen-reader's announcement and a typing echo. I begin providing evidence from the point where BVI1 confirmed the submission of his answer to question 1 (SR1, SR*1 and SR2). SR3 shows that BVI1 arrived on the Question 2 page, positioned near the Next button. SR*2 informs that BVI1 activated this button, completely unaware of skipping question 2. Interestingly, SR4 and SR*3 inform that BVI1 proceeded further in spite of a warning “Question may be incomplete”. SR5 and SR*4 show how BVI1 confirmed the submission, moving to next question.

Susceptibility of BVI4 skipping Question 2

The situation is that Question 2 page has loaded, and the cursor focus is on the navigation bar. However, BVI4 is completely unaware of her arrival on page that contains Question 2. I observed her error primarily based on my conversation with her. I provide the evidence of this error starting with her first verbal report in this situation. Three forms of evidence include:

a. Screen-reader’s announcement (labeled SR1, SR2, etc.) that communicates the snippet of content on the question page in focus of the cursor

b. My questions (labeled Q);

c. Participant verbalizations and responses to my questions (labeled BVI4);

BVI4: I'm going to the next question. So Enter on Go to Next Question.
Q: Which question are you on now?
BVI4: One. So, I'm going to go to question 2.
Q: How do you know that you are at question 1?
BVI4: Because it says ‘go to question two’. Go to the next question...
Q: Where does it say that?
SR1: Question two of three.
BVI4: There we go! Right there.
SR2: Go to next question button.
BVI4: Alright.

Q: So what are you going to do?
BVI4: Go to question two.
Q: How are you going to do it?
BVI4: By “Go to next question.”
Q: Which question are we on?
BVI4: Question one. Maybe go on that one.
Q: What did it just say?
BVI4: Question two of three.
Q: What does that mean?
BVI4: I'm on question two.
Q: So why did you go to next question?
BVI4: Oh! Well, I thought I was still on question one.

The verbal reports I present here shows how BVI4 was about to activate the Next button in the Question 2 page when I intervened. The conversation that followed helped BVI4 avoid the error of skipping the question. However, the last segment of this verbal report clearly demonstrates that BVI4 was not aware of arriving on a new question page.

Based on the evidence available in the screen-reader feedback during this episode, I observe that the susceptibility of skipping exam questions arises due to a misconception about one’s location In an online exam without access to any context information. Participants were susceptible to skipping the question when the default cursor focus moved to the navigation bar of this question page without adequate feedback about change of exam page. I observed that when the new question page loaded, the cursor focus moved to the navigation bar with the “Next” button (refer to the SR2 evidence for BVI1). Incidentally, participants arrived here by activating the “Next” button in the navigation bar of the previous question page. I observe that they did not perceive a change in context – positioned on the navigation bar. It appears they thought their first attempt to activate the button failed, and made another attempt to do so-activate the

“Next” button. I observed that in this condition with a misperception of their location, participants heard two messages without any contextual information at two different times:

a. “Question 2 of 3” while browsing the navigation bar; and

b. “This question may be incomplete” after activating the Next button.

I traced the path of my participants on the WEI environment to the point beyond activating the “Next” button without answering Question 2. I observed that the first message corresponds to a short text on the navigation bar that is supposed to inform a student about her location. I found the second message corresponds to the text in a dialogue box that asks the student to confirm the action. Evidence showed that my participants ignored these messages with a misconception that they were positioned on the page where they just answered a question. I observe that a misperception about one’s location represents a dissonance due to inadequate contextual information on a new question page. Such dissonance forces the user to either ignore a warning considering it irrelevant, or commit an error believing it is a necessary action. The consequence is a BVI student skips an exam question without any knowledge of commiting this error.

I analyzed the evidence relevant to this episode for the discrepancy between the expected and observed outcomes of user action to trace the root of the susceptibility to skipping exam questions. I observed that the discrepancy lay in the CMS feedback for a new question page. Carefully examining the evidence, I observed that after BVI participants activated the Next button on the Question 1 page, they expected two kinds of outcomes:

a. Screen-reader feedback for link activation (two kinds of screen-reader announcement);
b. Change in context indicating change in location (based on position of cursor focus).

However, participants did not observe these two outcomes. The screen-reader did not announce the two kinds of information to suggest there was a new page. The position of the cursor focus on the navigation bar did not indicate the change in context – that they were on a new question page. This created the misconception that they were still on the Question 1 page, following which participants committed the error of activating the Next button of Question 2 page. This way, my analysis successfully identified a second situation where BVI students face a problem – unintentionally skipping exam question – due to a discrepancy between expected and observed outcomes of activating the "Next" button. According to the Action Model (Norman, 1988), this problem indicates a gulf of evaluation as BVI students cannot perceive or interpret CMS feedback indicating their arrival on a new question page.

The next focus of my analysis was to discover the mental model underlying the susceptibility to skipping exam questions. Based on the evidence relevant to this episode, I observed that the mental model of interest is concerned with the availability of a new question page. I present the following representation of a BVI student's mental model for availability of a new question page in Table 5.2. It shows how BVI students conceptualize the structure and function of a new question page by outlining their knowledge structure and cognitive processes respectively.

Table 5.2: BVI student's Mental Model for Availability of a new Question page

Knowledge Structure	Cognitive Processes
A new Web page with following items arranged vertically 1. Question text; 2. Input area; 3. Next button in navigation bar.	1. Verify arrival on the new page through two kinds of screen-reader announcement; 2. Locate question text using down arrow; 3. Locate input area using down arrow; 4. Locate Next button using down arrow and screen-reader announcement "Go to next question button".

In Table 5.2, Cognitive Processes #1 and #2 are of interest for my analysis. They inform that BVI students expect two kinds of CMS behavior when a new question page is available:

a. Two kinds of screen-reader announcement – percentage figures of downloaded content and frequency of interface objects available; and

a. Cursor focus positioned towards the beginning of the new page before the question text.

However, my analysis informed that these cognitive processes are not consistent with the observed CMS behavior when Question 2 page appeared. The screen-reader announcement indicating availability of a new page was totally absent. Without this announcement, participants could not verify their arrival on the new page after activating the Next button of Question 1 page. This lack of CMS feedback forced them to explore the surrounding area in search for evidence to suggest the context had changed (or change in page). Exploring the adjoining area with arrow keys, participants heard the labels for navigational elements such as "Go to Next Question". They understood that the cursor was positioned on the navigation bar. This observation was inconsistent with Cognitive Process #2 according to which the cursor focus moves to the top of the page, much before the navigation bar when a new question page becomes available. The two observations were in direct conflict with participants prior cognition of a new question page. This dissonance created the misconception in the minds of BVI participants that they were still on Question 1 page, and prompts them to activate the Next button so that they could move to Question 2 page. This misconception without no contextual information will make BVI students susceptible to skipping exam Questions inadvertently.

After identifying this problem and understanding the underlying mental model, the focuss of my analysis changed to characterizing the problem. The WCAG text analysis informs that the susceptibility to skipping exam questions represents a violation of "Page Title" and "Consistent Identification" principles in WEI design. As I explained earlier, the

“Page Title” principle is specified in Success Criterion 2.4.2 that requires a descriptive title for a Web page that communicates its topic or purpose to the user. WCAG specifically explains that such descriptive titles help the user identify her current location without having to explore the page and read or interpret page content. During analysis of the evidence, a descriptive title on any question page that was accessible through a screen-reader was not found.

The “Consistent Identification” principle applies to the “Next” button that my analysis informed was a graphic with an embedded link labeled “Go to Next Question”. The “Consistent Identification” principle, described in Success Criterion 3.2.4, states “Components that have the same functionality within a set of Web pages are identified consistently”. The intent is to ensure consistent identification of functional components using consistent labels that appear repeatedly within a set of Web pages. This consistency applies to descriptive texts for graphics, links and buttons. If these objects have the same functionality across pages, as the Next button, then their text alternatives should be consistent but not identical. For instance, the text alternative for the graphic “Next” on Question 1 page could read "Go to question 2." Naturally, it would not be appropriate to repeat this exact text alternative on the next Web page. However, my analysis shows that the Next buttons on every exam page had the identical label – Go to Next Question. This is undesirable for screen-reader users who have access to no contextual information when hearing this label to realize that the context has changed. Based on this WCAG text analysis, I characterized the susceptibility of skipping exam questions as an accessibility problem.

The text of the three usability principles to understand the usability character of the susceptibility problem was analyzed. My analysis informs that this problem represents a violation of “visibility” and “error avoidance” principles. The Visibility principle (Norman, 1988) requires that system design helps users to understand what is going on with the system, and derive alternatives for action by observation. My analysis showed that BVI participants were unable to tell what was going on with the WEI environment (CMS) once they activated the Next button on Question 1 page. This made the Question 2 page “invisible” to participants who were skipping this question unanswered. Error avoidance principle (Nielsen, 1993) recommends that Web design should reduce user’s susceptibility to committing error and facilitate quick recovery. Committing the error of skipping an exam questions is something students cannot afford. BVI students are prone to this error on moving to a new question page with a misconception about their location due to no context information. Based on my analysis, I characterized the susceptibility of skipping exam questions as a usability problem in WEI design.

5.2.3 Difficulty Determining How to Submit Multiple-Option Questions

Analysis of BVI student assessment of WEI environment shows that determining how to submit answers to multiple option questions is difficult for BVI students. Multiple option questions include both multiple choice and multiple answer questions where the response method involves highlighting selection controls (e.g. radio buttons or check boxes) corresponding to the right options. Selection controls function like switches – users can toggle between the “on” state (highlighted) and “off” state (un-highlighted) through mouse clicks or key presses (Enter key or Spacebar). My BVI participants faced problem when these selection controls behaved like submit buttons and brought about a page change in response to user action. I observed that participants who faced the difficulty were able to provide their responses by highlighting these selection controls with a single hit of the Enter key, and submit the response by activating these controls with a second hit of the Enter key. The second Enter triggered a page change in the forward direction on Question 1 page, and in the reverse direction on Question 2 page. This created confusion in the mind of participants; they could not understand why this method of answer submission did not bring up the next question page consistently. This behavior of selection controls as submit buttons meant participants did not need to search for the a legitimate submit button (Next button of the navigation bar). Thus, they committed the error of adopting an incorrect submission procedure.

Evidence of BVI student's difficulty to determine the submission procedure for multiple option questions using the experience of participant BVI4 is presented below. The episode begins with BVI4 on the Question 1 page. She hears the question text announced by the screen-reader. She next explores the area below the question text with the arrow keys. She hears "radio button" followed by a short text four times. I provide evidence starting with her first verbal report in this situation. This evidence comprises her verbal reports (labeled BVI4), the screen-reader's announcement (labeled SR) and my questions (labeled Q).

> BVI4: So how do you select...? I'm going to say you Enter on the one that you want. I mean I don't know but I'm going to try it well.
> SR: Enter, content frame updated.
> BVI4: I got it, but now, I can't get to the next question. Maybe try…Enter?
> SR: Enter. Forms mode off. Enter. Out of table.
> BVI4: Whoa.
> SR: Confirm question submission.
> BVI4: Yes!

Based on the evidence available, I observed that BVI4 first pressed Enter on the radio button that corresponds to an option that represents her response to Question 1. She ponders for a moment about how to submit this response. Here, I wish to emphasize that unlike sighted students, a BVI student cannot scan the page quickly to see the Next button, and associate that to her goal of submitting her response. At a time, she has access to only a snippet of page content based on position of cursor focus. Accordingly, BVI4 had to think about her next course of action. She finally concludes that she could submit her response by pressing Enter a second time on the same radio button. I believe in the past, BVI4 had an experience of submitting a form with a button that helped her arrive at this conclusion. She executes her plan and hits Enter on the selected radio button. She observes that the CMS brought up Question 2 page in response to her action. With this observation, she develops a notion of submitting responses to multiple option questions. According to this notion, she could highlight an option with a single hit of the Enter, and submit this response with a second hit of the Enter key. With this notion, she arrived on Question 2 page. She provided her response to Question 2 by selecting appropriate options with a single hit of the Enter key on corresponding check box. I observe that BVI4 did not discriminate between the purpose and behavior of radio buttons and check boxes as she treated the check boxes in the same way as she did to the radio button in the previous question page. She pressed *Enter* a second time on a check box with the goal of submitting her response. Her expectation was the CMS will bring up Question 2 page. However, she observed that the CMS took her back to Question 1 page. This inconsistency in expected and observed outcomes of her action to submit her response created dissonance in her mind about the submission procedure for multiple option questions. I present evidence of this dissonance experienced by BVI4 in the Question 2 page:

> BVI4: The answer to two… I think it's that one. So I'm going to do Enter.
> SR: Enter. Checkbox checked...
> BVI4: Ah! So I checked that one. Alright. Then Enter again.
> SR: Enter. Question one of three.
> BVI4: Oh.
> Q: What question are you on?
> BVI4: Question one. I need to go to the next—go to question three. Wait.
> No. I Entered on something I shouldn't have. Go up
> SR: Question one of three
> BVI4: Well, I went to question one, and I'm trying to get to three.

On examining the evidence, I observe that BVI4 hit Enter twice on the check box corresponding to an option she thought was the answer for Question 2. I also observe that she selected only one option as she would do in a multiple choice question. She expected to arrive on Question 3 page following her action. Instead, she realized the CMS brought up the previous - Question 1 page. She became confused, believing she must have committed an error. Traditionally, the WEI environment allows students to submit their responses to multiple-option questions by activating the “Next” button on the navigation bar. This is the designated submit button that records student responses, and brings up the subsequent page of the online exam consistently. This helps students to develop an effective cognition for submitting a response to a multiple option question. But I observe that in the case of BVI4, the selection controls assumed the function of submit button, except they did not bring up the subsequent exam page consistently. This inconsistent behavior of the WEI environment gives rise to a conflict between the student's prior cognition and present observation, which results in cognitive dissonance (Festenger, 1957). This dissonance will prompt the student to modify her cognition of answering multiple-option questions. However, repeated dissonance across multiple attempts will prevent her from understanding the submission procedure for multiple option questions. She must relearn how the system works in every instance of use. This creates problems in the form of extra steps or increased cognitive load (Norman, 1988).

According to the Action Model (Norman, 1988), the difficulty determining how to submit multiple-option question indicates both a gulf of execution and a gulf of evaluation between BVI students and the WEI environment. I observe a gulf of execution due to the fact that BVI participants could not determine the correct action sequence for submitting response for multiple option questions. They believed pressing Enter twice on a selection control (checkbox) would submit their response and bring up the next question page. Instead this brought up the previous question page. I observe a gulf of evaluation in the fact that the WEI environment failed to communicate to BVI participants that a Next button available on that page was the designated interface object to submit responses and move to next exam page. My analysis also traced the root of the problem to a discrepancy between the expected and observed CMS behavior for activating selection control in multiple option question. The user action in question is pressing Enter twice on a selection control or switch. The outcome in question is how the CMS behaves in response to this action.

The next focus of analysis was to understand BVI participants' mental model for interacting with the WEI environment when the problem arose. Specifically I was interested in understanding their Knowledge Structure and Cognitive Processes of the WEI environment in that event. Based on the verbal reports I present above, I observed the mental model of interest was concerned with submission of multiple option question. Based on my interpretation of BVI participants' verbal reports, I present the following representation of a BVI student's mental model for submitting multiple option question in Table 5.3. It shows how BVI students conceptualize the structure and function of a multiple option question page by outlining their knowledge structure and cognitive processes in a dissonance condition.

Table 5.3: BVI student's Mental Model for submitting multiple option question

Knowledge Structure	Cognitive Processes
Web page with following items arranged longitudinally: 1. Question text; 2. Line items comprising a	1. Read question by listening to question text; 2. Locate selection controls using Down Arrow to hear "Radio Button" or "Check Box"; 3. Read each option by listening to answer text;

selection control and an answer option	4. Provide response using Enter on selection control(s) corresponding to correct answer(s); 5. Submit response using Enter on a selected selection control; 6. Move to next question page using enter on “Okay” in “Confirm Question Submission” dialogue box.

In Table 3.3, the Knowledge Structure as well as Cognitive Process # 5 are of interest for my analysis. I observe that the Knowledge Structure is erroneous as it does not include the “Next” button. The absence of this component means the student has no cognition of a designated submit button to submit the response and move to next question page. I observe a problem in Cognitive Process # 5. It uses the radio button or check box as if they were navigational elements. This means BVI students will try to submit their responses for multiple option questions by pressing Enter twice on the selection control – radio button or check box, expecting the new question page to appear. However, evidence shows that the CMS behavior is inconsistent across different situations. Participant BVI4 moved back to Question 1 page from Question 2 page following this action. This is an unexpected CMS response for submitting multiple option questions. The BVI student is unable to predict the behavior of the WEI environment, and has difficulty understanding the appropriate procedure to submit responses to multiple option questions.

The focus of my analysis next moved to understanding if a BVI student's difficulty determining how to submit multiple option question was an accessibility and/or usability problem. I analyzed the WCAG text to see if and how this difficulty is referred to. This informed that the difficulty of a BVI student determining how to submit response for multiple-option question represents a violation of “On Input” principle. WCAG describes the “On Input” principle in Success Criterion 3.2.2. According to this principle, a change in state of a radio button or a check box should not launch a new Window without prior warning. WCAG explains that “change of state” means checking or unchecking a radio button or a check box. My analysis of BVI student assessment showed that such a change of state brought about a change of exam page. Success Criterion 3.2.2 states “Changing the setting of any user interface component does not automatically cause a change of context unless the user has been advised of the behavior before using the component.” WCAG's intent in this Success Criterion is to ensure that Web sites are designed such that selecting a form control or entering data has predictable effects. My analysis showed that predictability of CMS behavior was a problem when BVI students selected radio buttons or check boxes. WCAG explains that when Web sites do not comply with this success criterion, BVI users have difficulty predicting interactive content. The consequent unexpected changes of contexts create disorientation for the BVI; they fail to use the content for intended purpose. Although my analysis did not show that participants failed to use content due to the “On Input” problem, it clearly revealed their disorientation after pressing Enter twice on the check box took them to the previous question page. Based on my analysis of WCAG text, I characterize a BVI student's difficulty determining how to submit multiple option questions is an accessibility problem.

WCAG text analysis identified a G80 Technique that recommends that a Web-based system must initiate a change of context only through the use of a Submit Button. The objective is to change a context only when the user explicitly requests for it. WCAG explains that the intended use of a Submit Button is to generate an HTTP request that submits a user’s inputs (or responses)on a form (e.g. multiple option question page). WCAG considers Submit Button an appropriate control to trigger a change of context that does not create confusion for users. My analysis demonstrates that the selection controls triggered a change of context by submitting student response and changing the question page, creating confusion for BVI participants who could not tell that a Next button was available. The radio buttons and check boxes behaved like a submit button, except they changed the exam page in different directions. Under such a situation, BVI participants observed dissonance and could not determine the correct procedure to submit response for multiple option questions. I observe that while WCAG recommends the use of a submit button to initiate a change in context, a more appropriate recommendation would be to disallow the change of context due to change in setting of other interface objects such as radio buttons or check boxes.

Analysis of usability principles informed that BVI student’s difficulty understanding how to submit multiple answer question represents a violation of the “Good Mapping”, “Learnability” and “Consistency” principles. The good mapping principle (Norman, 1988) requires the WEI environment to help the student in mapping a single action to a single outcome. My analysis shows that this was not the case; participants observe a many -to-many correspondence between student action to submit a response and the consequent CMS behavior. In other words, the action of hitting Enter twice on a selection control can change the exam page in either direction. In addition, two different actions – Enter twice on selection control and Enter once on Next button – may both cause a change of context to the next question page. Accordingly, I believe WEI environment violates the good mapping principle by not providing a one-on-one mapping between student actions and CMS response. The lack of a one-on-one mapping implies that students relearn how to navigate out of multiple-option question in every attempt. This violates the memorability principle (Nielsen, 1993). This principle requires that students should not have to relearn system functionality and navigational items. This is also a violation of consistency principle (Shneiderman and Plaisant, 2004) that requires that the sequence of student actions remain consistent for similar task situations. Based on this analysis, I characterize a BVI student's difficulty determining the process for submitting multiple option questions as a usability problem in WEI.

5.2.4 Inability to Negotiate Security Information Pop-Up

Analysis of BVI student assessment of the WEI environment shows that BVI students cannot negotiate security information pop-ups or security dialogs. I observed that they failed to perceive, understand or operate on the security information presented by a dialogue box. The CMS pops up this dialogue box immediately after Question 3 page loads. It restricts the cursor focus to a small section of it, and prevents the screen-reader from announcing any information outside of this section. BVI students do not perceive any information about the WEI environment, except that the dialogue box contains a "Yes" and a "No" button. They can neither understand the purpose of the dialogue, nor which option to choose between Yes and No. The consequence is they get trapped in this dialogue box, unable to do anything with the inaccessible and unusable pop-up. I observed that this problem is the most debilitating for BVI students out of all the problems identified by my participants through the assessment. If no sighted help is available, this problem can completely halt the progress of BVI students in online exams.

The inability to negotiate security information pop-up by a BVI student was evident from the verbal reports of my participants. Although every participant experienced this problem, I use the experience of participants BVI3 and BVI5 for evidence. Both of these participants had slightly different experience – the experience of BVI3 being the worse that can happen to BVI students under these conditions. This evidence comprises their verbal reports (labeled BVI3 or BVI5), screen-reader announcement (labeled SR), screen-reader typing echo (SR*) and my query (labeled Q). I begin with the experience of BVI5 dealing with security information pop-up.

> SR: Moving to another question will save this response.. go to previous question button..
> BVI5: Moving to another question will save this response,
> SR*: enter.
> SR: Confirm question submission. Are you sure you want to … Press space bar.
> BVI5: We are sure we want to go. So, I will press spacebar to continue.
> SR*: space.
> SR: Go to next question button. 4%. 84%. .
> BVI5: Waiting for. .

SR: vertical bar. Go to last question button. Blank. vertical bar. Go to next question button. vertical bar . Go to next question button. vertical bar. Go to. vertical bar. Go to next question button.

SR*: Enter.

SR: Vertical bar.

BVI5: Jaws is a bit slow right now.

SR: 100%. table, column0, row0. no button. more info button. To activate. Yes button. no button. to activate. Yes button. To activate. No button. to activate, press space bar. Yes button. To activate, press space bar.

BVI5: There's something to answer, yes or no. So, I will finally see if I can "Alt B" it.

SR*: alt B. alt B.

BVI5: No. Can't read it to me. I have a question. There is a yes No question on my screen. What do I do?

I: Click on yes

BVI5: I didn't know what was in that dialogue box.

SR*: Enter.

SR: Table, column18, row1.

BVI5: There apparently appeared a dialogue box that I could not read. But I had a yes button and a no button. So, I asked the instructor for directions.

The last segment of evidence summarizes the experience of BVI5 dealing with the security information pop-up. He was able to dismiss the dialogue box only after a sighted instructor guided him. She told him to choose Yes on the dialogue box. This meant BVI5 avoided a more debilitating problem that the other participant –BVI3 – faced for choosing No. I next present evidence of what BVI3 went through dealing wit the security information pop-up. The episode begins with evidence about the appearance of the security information dialogue box a few moments after BVI3 confirmed submission of answer for Question 2.

SR: Security information dialogue. To navigate use Tab…20%

BVI3: Warning security.

SR: Thirty three percent

BVI3: Huh! This is weird.

SR: Retail Certificate Dialogue.

BVI3: This is a non-visual, this is a non-screen access thing. And I have no idea what it did. It is still loading the page. And, it wants me to do something. Do we have any visual assistance?

SR: Thirty two percent.

BVI3: I basically can't. . . My screen...Jaws is not reading anything except for the progress bar announcements. And there's something else on this screen.

Q: Do you need help?

BVI3: You'd do better to do it with the mouse.

SR: Retailed certificate dialogue. To navigate, use tab.
BVI3: And that part is not accessible.
SR*: tab. Escape.
SR: Warning Security Dialogue.
SR*: Escape.
SR: Blackboard.
SR* Alt Tab. Alt Tab.
SR: Blackboard Academic Suite. Microsoft.
BVI3: Let's see what we did.
SR: No button, to activate. yes button, to activate. . Space bar.
BVI3: Oh! It's asking me a question. Hang on. Let me see what it wants.
SR*: Alt tab.
blackboard academic suite. Microsoft Internet Explorer. security information dialogue. This page contains both secure and nonsecure... Do you want… .
BVI3: Yes we want to . . .
SR: -
BVI3: Now, it basically just stopped.
Q: Where are you now?
BVI3: I have no idea.
SR: blackboard academic suite. Microsoft.
BVI3: It says blackboard academic suite. But I'm seeing absolutely nothing.
SR*: Tab. shift tab.
SR: word...
BVI3: I need to get to question three. And right now, it's just, it's just not doing anything. So I'm gonna hit Alt Left Arrow. For some strange reason, I have a feeling . . Better yet, I'm going to hit the F5 key. It refreshes the screen. . . .
SR: -
BVI3: And that didn't seem to work. So I'm going to hit Alt+Left Arrow. Takes us back.
SR: Real player.
SR*: Alt Tab.
SR: blackboard academic suite. Microsoft Internet Explorer.
SR*: Insert F7
SR: no links found.
BVI3: And that didn't seem to work either. So unfortunately, I have to close this out. But no worries, I can open it back. I will need sighted help to see what's going on. I'm stuck at some point. I don't know where I am. Nothings found.

I observed from this evidence that when the security information pop-up appeared, BVI3 could not perceive it for some length of time. The screen-reader did not make any announcement except intermittently reading the percentage figures. Then I observed that a Retail Certificate appeared on the screen that rendered the screen-reader completely speechless and ineffective. I examined the CMS behavior under this condition by retracing the path of BVI3. I wanted to understand the context in which the Retail Certificate appears. I concluded that it appears when a user selects the "No" button in the Security Information dialogue box. And more importantly, it aborts the screen-reader session. This explained the severity of the problem that BVI3 experienced. According to me, this condition of BVI3 is comparable to a sighted student trying to take an online exam using a computer without a display monitor.

To summarize, the evidence I present shows that after participants confirm the submission of their response to Question 2, they do not receive prompt feedback about the state of the WEI environment. The CMS pops up a dialogue box that does not allow the screen-reader to announce the message it carries. This is in contrast to the Confirm Question Submission dialogue box where the screen-reader had no problem announcing the message automatically. When participants explored the inaccessible dialogue box using the Tab key, they heard "Yes" and "No", but nothing else. If they selected 'Yes' they were able to dismiss the dialogue box and move ahead. If they selected 'No', they got completely stuck. A Retail Certificate dialogue popped up and rendered the screen-reader completely speechless and ineffective. Participants could not perceive, understand and operate the security information dialogue box. They spent additional time and effort trying to get out of this trap. I observed that for most BVI students, getting sighted intervention could be the only way out.

The next focus of my analysis was to trace the root of the inability of a BVI student to negotiate the security information pop-up. I observed that this problem occurs due to discrepancies between the expected and observed outcomes of two actions in completing an online exam. The first action is concerned with confirming the submission of response for exam question. The operation for confirming question submission is pressing Enter on “Okay” button on Confirm Question Submission dialogue box. I observed discrepancies in the expected and observed outcomes for this action. The expected outcome is that this action will bring up the next question page. The observed outcome is that this action brings up the Security Information dialogue box if the next question is in essay-type format. The second action is dismissing the security information dialogue box. The operation to dismiss this dialogue box can be:

a. Pressing Enter on Yes or No buttons; and

b. Pressing Escape.

The expected outcome of this action is arrival on a new question page. The observed outcome for this action is dependent on the operation chosen. Pressing Enter on Yes is consistent with expectation. The observed outcome of pressing *Enter* on ‘No’ is the Retail Certificate dialogue. The observed outcome of pressing Escape is nothing. According to the Action Model (Norman, 1988) the inability to negotiate security information pop-up in online exam indicates both a gulf of execution and a gulf of evaluation. It points to a gulf of execution as BVI students cannot determine how to dismiss the security information dialogue box. Evidence shows my participants tried to dismiss it by pressing Escape without success. It points to a gulf of evaluation as BVI students could not perceive the message communicated through the dialogue box or predict the outcomes of activating the Yes and the No buttons. This highlights the severity of this problem for BVI students.

The next focus of my analysis was to map the mental model of a BVI student under the situation where she is unable to negotiate the security dialogue box. I needed a better explanation of why and how participants experienced this difficulty. Based on the evidence I present above, I observed that the mental model of significance here is how to interact with a dialogue box. Based on my interpretation of the verbal reports , I present a representation of a BVI student's mental model for interacting with a dialogue box in Table 5.4. It shows how BVI students conceptualize the structure and function of a dialogue box through an outline of their knowledge structure and cognitive processes respectively.

Table 5.4: BVI student's Mental Model for interacting with Dialogue box

Knowledge Structure	Cognitive Processes
A box containing: 1. A short text; 2. A Yes button and a No	1. Read the information through screen-reader announcement of the text; 2. Identify appropriate response from Yes and No;

button	3. Dismiss the box by pressing Enter on Yes or No buttons, or pressing Escape.

In Table 5.4, all items listed are of significance for my analysis. The knowledge structure assumes no difference between Confirm Question Submission, Security Information and Retail Certificate dialogue boxes. This is inconsistent with my observation. It assumes a short text in the Security Information dialogue box that is not perceivable. It also assumes all three components – short text, Yes button and No button – in the Retail Certificate dialogue box that is "invisible". Cognitive Process # 1 assumes that the screen-reader gets automatic access to the security information text just as it gets in the Confirm Question Submission dialogue box. My analysis shows that this requires a specialized screen-reader command – "Insert B" – that only expert BVI users employ. Cognitive process # 2 again assumes that the screen-reader reads out the security information by default. Cognitive Process # 3 assumes that choosing either Yes or No in the dialogue box or hitting Escape will dismiss the dialogue box. I observed that the use of Escape has no impact on the dialogue box. I also observed that choosing No brings up the "Retail Certificate Dialogue" that makes the screen-reader ineffectual. The BVI student becomes helpless; sighted help remains the only option out.

My analysis of WCAG text informs that the inability of BVI students to negotiate security information pop-up represents violation of the "No Keyboard Trap" and "Compatibility" principles in WEI design. The No Keyboard Trap principle is discussed under Success Criterion 2.1.2 of the WCAG text. It recommends that under no circumstance should a component of a Web page trap the focus of the keyboard. The Success Criterion states “If keyboard focus can be moved to a component of the page using a keyboard interface, then focus can be moved away from that component using only a keyboard interface, and, if it requires more than unmodified arrow or tab keys or other standard exit methods, the user is advised of the method for moving focus away.” Compliance with this principle, according to WCAG, ensures that content does not "trap" keyboard focus within subsections on a Web page. The evidence I present clearly shos that the dialogue box trapped the keyboard focus, and BVI participants could not negotiate the security information pop-up. My WCAG text analysis informs that these dialogue boxes are often guilty of trapping keyboard focus. WCAG recommends that the system must inform the user about keystrokes necessary to exit the dialogue box by providing instructions before its launch, as well as within this dialogue box. I observed that the WEI environment did not provide any form of instruction on the use of the security information dialogue box that was accessible through screen-reader. BVI participants had no way of knowing what keystroke will dismiss the security information pop-up.

The “Compatibility” principle is discussed under Guideline 4.1 of WCAG. It states “Maximize compatibility with current and future screen-readers. For this purpose, WCAG recommends two Web design principles:

a. Avoid using poorly formed markup that breaks the screen-reader. My BVI student assessment showed how The Retail Certificate dialogue broke the screen-reader;

b. Avoid using unconventional markup or code that circumvent the screen-reader . The assessment also showed how the Security Information dialogue box circumvented the screen-reader;

c. Expose information in the content following standard techniques so that a screen-reader can recognize and interact with. The BVI student assessment demonstrated how the screen-reader could not recognize or interact with the information contained in the Security Information and Retail Certificate Dialogue boxes.

WCAG explains that with rapid advancements in Web technology, developers of screen-readers have difficulty keeping up with it. Hence, design of Web content must follow conventions and be compatible with Application Programming Interfaces. This ensures that screen-readers work more effectively with new technologies as they evolve. My analysis showed that the dialogue box used for security information pop-up was not compatible with the screen-reader. Participants were unable to dismiss it by activating the No button. More importantly, the Retail Certificate dialogue box broke the screen-reader. Consequently, participants could not perceive, understand or operate on the information. Therefore, I characterize the inability to negotiate security information pop up as a major accessibility problem.

5.2.5 Ambiguity in Essay-Type Question Page

Analysis of BVI student assessment of the WEI environment shows that these students experience a great deal of ambiguity in an essay-type question page. This ambiguity is a multi-facetted problem with three aspects:

a. Confusion about necessary response method: BVI students cannot tell if answering the question involves selecting options or typing a response;

b. Perplexity due to text formatting tools: The purpose of text formatting tools is difficult to understand. BVI students get disorientated;

c. Obscurity of text area: Locating the text area for typing response is difficult to impossible.

I observed evidence of these three aspects of the problem in verbal reports of almost all of my participants. I provide evidence for each aspect of the problem separately using experiences of participants BVI1, BVI2 and BVI4. The episode I refer to commences with participants reading the question text and in the process of navigating further down Question 3 page. What I observe in each case is a great deal of uncertainty, confusion and disorientation of participants. The evidence I provide below includes verbal reports of participants (labeled BVI1, BVI2 or BVI4), screen-reader announcement (labeled SR), and my questions to participants (labeled Q).

Evidence for confusion about necessary response method.

Below I present evidence of how participants could not tell if they must select an option or type a answer to respond to the question. The evidence comprises excerpts from verbal reports of participant BVI4 during the episode.

SR: Blank link save. Question. How would you define web accessibility?
BVI4: How would you define web accessibility?
SR: Graphic question three answers.
BVI4: So, I'm gonna hear the answers.
SR: Same page link graphic. skip visual text editors. link graphic. Edit. graphic text. Blank. blank.
BVI4: Oh no I can't find the answers. I'm gonna go up until it says something like answers...Maybe you have to type it? I'm gonna look and see if it says answers.
SR: Text blank link graphic blank same page link graphic question three answer blank how would you define blank click save find question three. Question completion status link blank blank table end.
BVI4: May be, you do have to type it because I'm not seeing anything that says answers. So, I should go back to where it says how would you define web accessibility?
SR: Five points link save blank how would you define web accessibility. Blank. graphic question three answers
BVI4: Oh! I found the answers. I'm gonna Enter on that.
SR: Enter. out of table. menu frame. Frame. visited link. announcements.
BVI4: Aww man! I can't find the answers. May be, I should look at the whole thing. So I'm gonna go down.
SR: Link external link link tools blank pause table link graphic communication collect graphic course ….
BVI4: Gosh! Okay.
SR: Link graphic link table end link blank blank menu frame course content frame.
BVI4: I think I'm getting to it.
SR: Same page link e-learning visited link assignments link one web accessibility exercise… Graphic and...heading level one heading link .
BVI4: I'm going down.
SR: Blank table with two frames.
BVI4: Looking for the answers.
SR: Instructions this list contains... Blank five list end blank multiple, list of four test table.. Test table one blank blank… Blank table with graphic

question.. Five points, how would you define. Blank graphic question three same page blank link graphic expanded blank text style.
BVI4: I think I did find the answers. Maybe not.
SR: Text style combo box one of eight blank font size.
BVI4: I think expanded is one of the answers.
SR: Blank text text blank.
BVI4: It just sounded different. May be, I went to something wrong. Well, I thought I messed up on it. I'm going up to where it says expanded.
SR: Graphic expanded.
BVI4: It's one of the answers I think. I'm gonna Enter on it.
SR: Answer table column one row three expanded visited link graphic.
BVI4: Gosh!

Evidence for perplexity due to text formatting tools

I provide evidence showing how participants had difficulty understanding the purpose of text formatting tools interspersed between the question text and the text area. These poorly labeled tools had a disorientating effect on students; they feel lost among a group of incomprehensible interface objects. The evidence I include excerpts of verbal reports by BVI1 for this episode.

BVI1: Now I answer question three. So, now I'm going to try to...
SR: Question three. Five points, how will you define web accessibility. Blank. Graphic question three answers. Expand. . . Text style. Same page link graphic. Italic. same.. fonts. formats....
BVI1: Down arrow, down arrow.
SR: Same page link graphic align left...click submit to submit this assessment.
BVI1: I don't understand what this is. I don't really understand what's going on with this part of the question, with the internet. I don't understand why it's saying a whole bunch of superscript, numbering, bullets, indents, its kind of tough. It's not really telling me. I mean, its far more easier to do like radio buttons when it came to like five out of four when it was like multiple choice that way. Otherwise, if its this way its harder, its much more tough.
Q: How did you know that it is not a multiple choice question?

> BVI1: Because it didn't say...because it said multiple attempts on the first question. But I don't really know how to answer these. I don't understand how to really answer them. SR: Question 3 text question 3, 5 points.
> BVI1: Oh it's text questions. You have to write your answers into it. Got it.

Evidence for obscurity of text area.

I finally present evidence that demonstrate the challenges my participants faced in locating the text area for typing their answers for essay-type question. The evidence includes excerpts of verbal reports by BVI2 for this episode.

> SR: Five points. how will you define web accessibility?
> BVI2: How would I define web accessibility? Keeping in my mind, I am going to go down the edit field and type the answer.
> SR: Blank. Text style. Same page link graphic italic, same.. fonts, formats.... . . Same page link graphic. Align left...Click submit to submit this assessment
> BVI2: I am having difficulty. I need to enter into the edit field and answer the question. But its not reading the edit field. Its reading the forms mode, but not reading the edit field. I'm on the webpage and I can't seem to find the edit field.
> SR: Collapse. Frame. Blank. Frame end.
> BVI2: Last time between the frame and frame end there was the edit box where i could type the answer in; now it is not. It just says blank. Don't know what to do.

The evidence I provide here demonstrate the ambiguity of a BVI student in essay-type question page. It shows there are three aspects to this ambiguity.

1. First, the required response method is not obvious. BVI participants were unsure how to provide their response – by choosing an option or by typing an answer. They hear an interface object named “Graphic Link Question 3 Answers” due to

which they developed a false expectation that possible answers, such as those in multiple option questions, lay ahead. The link “Expand” appeared to be particularly distractive. While one participant mistook it to be a possible answer, another thought it will open up an input field.

2. Second, the purpose of text formatting controls below the question text is unclear. BVI participants could not understand what these objects had to do with answering the question. They came across a link named “Skip Visual Text Edit Buttons” to jump over these controls. Participants could not make the connection between the link and its purpose- that it could take them to the text area.

3. Third, aspect is that locating the text area for typing the answer is either difficult or impossible. BVI participants had significant difficulty identifying an edit field surrounded by several other objects. Here, I wish to highlight the means through which BVI students perceive text areas. They detect the availability of a text field based on screen-reader announcement “Edit”. In the essay-type question page, the text area was surrounded by numerous other interface elements with poor labels.

Evidence of this strategy is available in verbal reports of BVI1.

> Q: Can you tell how you concluded that this question required to type an answer considering you were unsure few minutes back?
> BVI1: What I did was I figured, because I read the beginning of the question before and it said text style which I thought write your answer. And when it said “Edit”, “expanded”, something, “links”, and then I pressed the up arrow and it said “Edit”, I just wrote my response to that question.

Sighted students can recognize that a question requires typing an answer when they see the rectangular text area through a quick visual scan of the page. BVI students recognize an input field when the screen-reader announces “Edit”. To locate an input field surrounded by several poorly labeled interface objects by deciphering the screen-reader's announcements is like searching for a needle in a haystack. Consequently, the text area remained obscured to participants. Under such situations, BVI students will spend extra time and effort dealing with this ambiguity; answering exam questions in the allotted time will become difficult.

My analysis next focused on tracing the root of the ambiguity of BVI participants in essay-type question page. I observe this problem arises due to a discrepancy between the expected and observed outcomes of search for the input area in an exam question page. BVI students search for input areas for exam questions by listening to screen-reader announcement while ‘arrowing’ (navigating) down from the question text. The expected outcome is that screen-reader will announce the availability of possible answers (for multiple option questions) or edit fields (for essay-type questions) in lines immediately below the question text. The observed outcome is that the screen-reader announces the availability of other interface objects (e.g. “Graphic Question 3 Answers”, Link Expand” and labels for formatting tools) for several lines below the question text. I wish to emphasize here that for BVI students, the question text, a possible answer or the edit field will appear in different lines of a page. This is because they hear only a small chunk of information on a Web page at a time, depending on what component receives keyboard focus at that moment. Therefore, they do not “see” the text area in Question 3 page even after navigating several lines below the question text. Instead, they keep hearing the labels of individual formatting tools in each of these lines they navigate. According to the Action Model (Norman, 1988), this ambiguity of a BVI student in essay-type question pages indicates a gulf of evaluation as the CMS fails to effectively communicate to these students about the response method necessary, the purpose of text formatting tools, and the availability of the text area beyond these tools.

I next analyzed the evidence to delineate the mental model of a BVI participant for the situation when she faces the ambiguity in essay-type question page. My objective was to better explain why and how BVI students experience this problem. Based on the verbal reports I analyzed, I observed the mental model of interest is concerned with responding to essay-type question. I present the following representation of a BVI student's mental model for responding to essay-type question in Table 5.5. It shows how BVI students conceptualize the structure and function of an essay-type question page by outlining their knowledge structure and cognitive processes respectively.

Table 5.5: BVI student's Mental Model for responding to essay-type question

Knowledge Structure	Cognitive Processes
1. A question text presented on a Web page that requires a response; 2. An edit box immediately below the question text to type	1. Navigate to the question using arrow keys; 2. Read question text by listening to screen-reader's announcement of question text; 3. Navigate to edit box using down arrow;

an answer	4. Verify cursor position inside edit box using screen-reader announcement “Edit”; 5. Type an answer.

In Table 5.5, the Knowledge Structure is of interest for my analysis. This Knowledge Structure includes the question text followed by an edit box, and nothing else in between. This is inconsistent with the observed structure of the task environment. This environment includes many other interface elements, such as the graphic link “Question 3 Answers”, link “Expand”, set of text formatting controls, etc. that are scattered between the question text and the edit box. According to this mental model, a BVI student expects the input area right after the question text, and does not expect other interface objects that may be useful for this purpose. She has difficulty locating the text area, and cannot understand the purpose of the text formatting controls or other objects. Consequently, she fails to determine a response method, and experiences disorientation among the formatting controls.

My analysis informs that a BVI student’s ambiguity in essay-type question represents both an accessibility and usability problem in WEI design. Based on my WCAG text analysis, I observe violation of multiple accessibility principles by WEI design.

The WEI design violates the Sensory Characteristic principle discussed in Success Criterion 1.3.3 of WCAG. According to this principle, “Instructions provided for understanding and operating content do not rely solely on sensory characteristics of components such as visual location or orientation. The intent is to ensure that people who cannot use information about spatial location or orientation can access instructions to use Web content. For this purpose, WCAG recommends providing additional information so that the user does not lose any information due to inaccessible formats. This can be achieved for example, by including an easy-to-read summary at the beginning of each section of content. My analysis showed that the WEI environment relies predominantly on visual location and orientation of interface objects to inform students how to provide inputs and use formatting tools for essay-type answers. It does not provide any textual instruction after the question text to inform students that the text area was available beyond a set of text formatting tools.

The WEI design violates the Link Purpose principle for assigning a misleading label (e.g. Expand) to a link immediately below the question text. Success Criterion 2.4.4 states "The purpose of each link can be determined from the link text alone or from the link text together with its programmatically determined link context. The intent here is to help users understand the purpose of each link so they can decide whether they want to follow the link. My analysis showed that the purpose of the link "Expand" was not comprehendible to BVI participants.

The WEI design also violates the Name, Role, Value principle since it does not assign an implicit label for the text area. Success Criterion 4.1.2 explains "For all user interface components (including but not limited to: form elements, links and components generated by scripts), the name and role can be programmatically determined; states, properties, and values that can be set by the user can be programmatically set; and notification of changes to these items is available to screen-readers". The intent is to ensure that the screen-reader can access and announce information about the state of interface controls on a Web page. My analysis did not show that the text area in the essay-type question page had a label describing its name and purpose accessible through a screen-reader.

My analysis of usability literature informs that the ambiguity in essay-type question page represents violation of multiple usability principles. The WEI design violates Visibility principle. According to Principles of Good Design (Norman, 1988), users should be able to tell what is going on with a Web site, as well as derive alternatives for action by observation. My analysis showed that BVI participants could not perceive the text area in the essay-type question page. It also demonstrated their difficulty deriving appropriate response method for the question by just observing. The WEI design also violates the Learnability and Efficiency principles. According to the Web Usability Criteria (Nielsen, 1993), Learnability principle ensures that first-time users can become productive quickly in terms of finding information and using functionality on the Web site. Nielsen (1993) explains that Efficiency principle ensures that Users can accomplish online tasks quickly, without much cognitive effort, after learning the Web site. My analysis showed that BVI participants spent a lot of time and effort locating the input field that adversely affected their productivity in the online exam. The WEI design also violates Norman's (1988) Good mapping principle as participants faced difficulty determining the relationship between formatting tools and their effect. This principle recommends that Web design must help users to determine the relationships between actions and results, between the controls and their effects, and between the system state and what is visible.

5.2.6 Vulnerability of Premature Exit from Online Exam

Analysis of BVI student assessment of WEI environment shows that BVI students are vulnerable to premature exit from an online exam. This threat arises while typing an answer for an essay-type question. The use of typical word processing operations in the text area assigned for typing an answer can terminate the exam permanently without giving any warning to the student. I specifically observed that the use of Backspace inside the text area for deleting typographical error can abruptly expel the student out of the exam, without allowing her to resume it. I provide evidence of this problem as experienced by participant BVI6.

Evidence includes participant verbalizations (labeled BVI6), screen-reader's announcement (labeled SR), screen-reader's typing echo (labeled SR*) and my questions to participant (labeled Q). I differentiate screen reader’s announcement from its typing echo to identify keyboard operations of BVI6that correspond to un-verbalized actions.

> BVI6: But...how do I define accessibility? Let's see, I'm gonna type this.
> SR*: Space.
> SR: Frame four. course Content..
> BVI6: What?! What...
> SR*: Space.
> SR: Frame four.
> BVI6: What?
> SR*: space.
> BVI6: This computer is being crazy
> SR: Web accessibility.
> BVI6: Jaws for some reason went forms mode off for some reason. And now I'm... Oh wait! I'm not stuck.
> SR: Frame form course content updated one web accessibility
> BVI6: I don't know why it's doing that.

SR: Frame 4, course content updated
BVI6: It was supposed to type in
Q: And you were pressing backspace to delete the text that you had typed?
BVI6: I hit backspace to delete mistakes I had made. It took me out of that.
Q: And do you know where you are right now?
BVI6: I do not know where I am right now.
SR: forms mode blank content frame frame end
BVI6: I know where I was ok, never mind
SR: View graphic item visited link web accessibility. visited link graphic okay. course content frame. frame end.
BVI6: Oh! Now I gotta take the quiz again
SR: Blank visited as you work on each activity
BVI6: Oh my gosh
SR: Link refresh link graphic
BVI6: I don't' know what happened
Q: So, were you trying to answer question three and you typed a few characters…?
BVI6: Somehow it took me back to where I started from. . as the beginning to the assignment list. It says review assessment
SR: Heading level link graphic assessment heading level one link heading level one link level one review assessment web accessibility quiz
BVI6: It somehow jumped
SR: Review
BVI6: Okay so it wont let me take that again
SR: Visited link graphic okay
BVI6: It took me out, and did not allow me back to the quiz

The evidence I provide covers the entire episode relevant to the problem. This episode begins with BVI6 placing the cursor focus inside the text area assigned for the essay-type question. He recollects the question, formulates an answer in his mind and starts typing his response. He had typed some part of the response when he realizes that he had misspelled the word he had just typed in. He decides to go back deleting this word with the goal of retyping it with the correct spelling. He presses the Backspace key multiple times to delete this text. I observe this based on the screen-reader's typing echo (SR*: Space). Although the screen-reader typing echo for pressing both Spacebar and

Backspace is “Space”, I confirmed it was the typing echo for Backspace from BVI6. Using Backspace to delete a character on the left of the cursor is a common text editing operation that most online forms and word processers support. I believe BVI6 expected every hit of Backspace to delete a character to the left of the cursor inside the text area. However, every time BVI6 hit the Backspace, he heard an unexpected announcement – “Frame Four, Course Content Frame Updated”. I observed that he is puzzled by this strange behavior of the WEI environment. He fails to understand what was going on-why did the screen-reader make announcements that seemed irrelevant to his action. A moment later, BVI6 realizes that the screen-reader had switched from edit mode (screen-reader announcement “Forms Mode on”) to browse mode (screen-reader announcement “Forms Mode Off”). Here, I wish to point out that the edit mode of the screen-reader allows the user to type characters through key presses in an input field. These same key presses allow the user to execute specialize screen-reader commands on the Web in the browse mode. For example, pressing the N key allows her to jump over a collection of links on a Web page. However, the switch from one mode to the other typically occurs through an explicit user request. For example, the user can change from edit mode to browse mode by pressing the Escape key. However, BVI6 did not explicitly request to switch to browse mode, yet he heard “Forms Mode Off”. He understood he could not type in his response, and that he was out of the text area. His verbal reports showed his perplexity with the unexpected behavior of the WEI environment. He expressed the disorientation he experienced as “I do not know where I am right now.”. Following this, he explores the area surrounding the cursor focus with the arrow keys to discover his location. The screen-reader reads a message “Review Assessment”. BVI6 now understands he was expelled out of the online exam for using Backspace. He tries to retake the exam. However, the WEI environment does not allow him to retake it. I noticed that the WEI environment did not provide any Warning message or appropriate feedback to the student about the state of the CMS or the impending danger of using Backspace in the text area. This places a BVI student at a huge disadvantage in WEI environment, particularly in the absence of CMS feedback that a screen-reader can communicate.

The next focus of my analysis was to trace the root of BVI participants’ vulnerability to premature exit from the online exam. I observe this problem arises due to a discrepancy between the expected and observed outcomes of deleting typographical errors of descriptive answers typed in text area of essay-type exam questions. The operation to delete typographical error includes pressing the Backspace key. The expected outcome is that this will remove the characters to the left of the cursor. The observed outcome is the arrival on the “Review Results” page beyond the online exam. According to the Action Model (Norman, 1988) the vulnerability of premature exit from online exam indicates a gulf of evaluation. The student did not receive accurate and timely feedback about the consequence of using Backspace. She could not tell what was going on in the WEI environment following her action- that she was actually terminating the exam prematurely and not deleting characters.

My analysis next tried to understand the mental model of a BVI student under the condition of premature exit from the online exam. The goal is to better understand why and how the problem occurred. Based on the verbal reports I present above, I observed the mental model of interest was concerned with the use of text area for essay-type question. Based on my interpretation of the verbal reports, I present the following representation of a BVI student's mental model for using a text area for essay-type question in Table 5.6. It shows how BVI students conceptualize the structure and function of a text area by outlining their knowledge structure and cognitive processes respectively.

Table 5.6. BVI student's Mental Model for using text area for Essay-type Question

Knowledge Structure	Cognitive Processses
Edit box for providing descriptive response to a question	1. Verify cursor focus inside edit box through screen-reader announcement "Edit"; 2. Insert characters to compile response by pressing appropriate keys; 3. Delete characters to fix typographical errors using Delete or Backspace keys; 4. Exit edit box to complete response by pressing Tab key.

In Table 5.6, Cognitive Process # 3 is of significance for my analysis. It informs that BVI students correlate the use of Backspace to deleting typed characters inside the text area.

However, I observed that this cognitive process was not consistent with the observed outcome of using Backspace in the text area. Each press of Backspace changed the online exam environment by a page, ultimately exiting out of the exam. This represents an unexpected behavior of the Backspace operation and the WEI environment for a BVI student. I observe that this inconsistent behavior confused BVI participants; they felt disoriented. But most importantly, they were extremely frustrated as they were kicked out of the exam permanently.

Analysis next focused on characterizing the vulnerability of premature exit from online exam as accessibility and/or usability problem. Analysis of WCAG text informs that this problem represents a violation of "Change on Request" principle in WEI design. Success Criterion 3.2.5 of WCAG discusses the Change on Request principle. According to this principle, a change of context in a Web site happens only when the user explicitly requests for such a change through appropriate commands. An example of a Change on Request is the appearance of the destination page when a user presses Enter on the designated link in the source page of a Web site. When a Web site changes the context without the user's explicit request, it violates the "Change of Request" principle.

I observed that the premature exit from online exam is the result of multiple instances of backward page navigation that is triggered by the use of Backspace in the text area. The change of context in this situation is the backward navigation of the exam page. Since this backward navigation is neither initiated nor intended by BVI participants, this represents a violation of "Change of Request" principle.

Success Criterion 3.2.5 recommends that users must have full control of changes of context in a Web site. It explains This eliminates potential confusion for users due to unexpected changes of context. WCAG specifically explains that violation of the Change on Request principle hurts BVI users as they cannot detect changes of context visually. That is why, it recommends warning the user in advance that a change of context is about to happen. As I mentioned earlier, my analysis did not find any warning to caution participants that the backward page navigation was about to happen following the use of Backspace. Therefore, I conclude that the vulnerability of premature exit from online exam represents an accessibility problem in the WEI design.

Results of my analysis of BVI student assessment comprise six accessibility and/or usability problems in the WEI environment that significantly hamper a BVI student's ability to complete an online exam. I explained where and how BVI participants faced these problems, what was their thought processes under these situations and how design principles define their problems. I explained how each problem represented a gulf between a BVI student and the WEI environment. However, my analysis stopped short of clearly identifying the sources of these problems – the problem from the perspective of Web design. I next present the results of my analysis of Web developer interviews that helped me clearly identify the problem source and triangulate findings of the BVI student assessment of WEI.

5.3 Analysis of Web Developer Assessment of WEI Environment

The objective of the Web developer assessment of WEI environment was to triangulate the results obtained from the BVI student assessment and the WCAG assessment. I asked Web developers to explain the source of a BVI student's problem in the WEI environment that my verbal protocol analysis identified. Web developers answered my questions in two ways. Sometime they identified the components of the WEI interface responsible for the problem, and sometimes by explaining what design *could have* helped avoid the problem.

My analysis of Web developer assessment identified and explained the source of a problem. Some of the findings found resonance in the WCAG text analysis. Some other findings referred to problems not defined by WCAG. In addition, it also identified feasible design modifications that seemed very promising as potential solution for this problem. I provide results of my analysis for each of the six problems identified through the BVI student assessment.

5.3.1 Web Developer Assessment of Confusion while Navigating Between Exam Pages

My analysis of Web developer assessment informed that the source of a BVI student's confusion while navigating between exam pages is the frame-based page structure of the WEI environment. It explained that due to this frame-based page structure, the CMS feedback for link activation is different than the feedback expected from a typical Web site. It explained that these frames had no unique titles to enable a screen-reader announce the change of context. The inconsistent feedback, coupled with lack of descriptive frame titles contribute to a BVI student's confusion; they have difficulty verifying arrival on a new exam page. I consistently heard this explanation from the Web developers during the interviews. I provide evidence of this explanation in the form of summarized responses of my Web developer participants

Responding to my question about the source of the problem, WD2 explained:

> Traditionally, a Web page update occurs through HTML. The Web site consists of content wrapped around something called an HTML body. Browsing to a new page means new content is loaded into the HTML body. In such a scenario, the screen reader announces 1%, 10%, 50% etc. However, in this particular case, the CMS loads new content through another means called frames. Frames basically divide the whole body into multiple parts, such as body 1, body 2, body 3, body 4, in that way. And what they do is, they only update body 3 which is relevant to you, and do not update body 1, body 2 and body 4. So, only part of the body is updated. Essentially, over here it means that page has changed and yet the page has not changed. The screen reader may not be capable enough to announce the frame data changes.

Analysis of this evidence informs that the task environment of the online exam comprises multiple pages that are structured differently from pages of a typical Web site. Each page consists of a set of frames, including a header frame and a content frame. The content frame in turn comprises a menu frame and a course content frame. These frames help organize the dynamic content of an online exam, including exam questions, separately from its static content such as menu items. Therefore, a change of exam page occurs by loading new content in the course content frame while contents in the other frames remain unchanged. In this respect, frame-based Web-based IS are unlike typical Web sites where a new page involves loading new content into HTML bodies. This difference may not be apparent to a typical sighted user. However, this alters how system responses are communicated aurally through a screen-reader. The screen-reader does not perceive a change in page when a link is activated. It may only detect a change in content of one frame. It does not have access to information necessary to announce the arrival of a new page when a student activates a link. Occasionally, the screen-reader may get access to information about new content in a course content frame. Based on this, it will announce "Content Frame Updated". This may not make any sense for the BVI; students cannot verify their arrival on a new page. This creates confusion for BVI students while navigating to a new exam page.

In explaining the source of the confusion of BVI users in WEI environment, Web developer participants discussed feasible design modifications that can potentially remove or eliminate this confusion. For instance, participant WD1 suggested:

> It is definitely possible to indicate that there are changes happening using ARIA – Accessible Rich Internet Applications. They have a whole bunch of tags, including tags specifically designed to inform the user about a change. It is possible to extend this to pages with frames, and provide some additional information about the new content.

Being more specific about such design modifications, participant WD3 explained:

> For example, the body is divided into 4 frames-three frames are not updated; only 1 frame is updated with its content. Now, the screen reader will say 1 frame has changed, and convey to the user “This area of the body has changed. “ Developers could even include frame names like “Main Content”, “Side Bar”, “Top Bar”, etc. Accordingly, the Screen Reader will read the frame name and tell the user exactly which one has changed.

The evidence I provide here clarifies the source of a BVI student’s confusion while navigating between different pages of the WEI environment. I observe that the source of this problem is the use of a frame-based page structure of the WEI environment in which the dynamic frames are not labeled with descriptive titles. When a BVI student activates a link on the source page of this frame-based WEI environment, the only thing that changes is the course content frame. This occasionally prompted the screen-reader to announce “Frame Four, Course Content Updated”. However, the lack of descriptive titles for these frames meant the screen-reader could not communicate the identity of a newly loaded frame. Consequently, the occasional screen-reader announcement following link activation further confused BVI participants.

Analysis of Web developer assessment also informs that the confusion problem can potentially addressed through simple design modifications. The two design modifications include:

(1) Providing unique and descriptive labels in the <<Title Attribute>> of each course content frame of the WEI environment; and

(2) Using ARIA (Accessible Rich Internet Application) tags to prompt the screen-reader announce the descriptive label of the new frame loaded.

According to the Web Accessibility Initiative, ARIA provides a framework to improve accessibility of dynamic Web content and advanced user interface controls that use Ajax, HTML and JavaScript. ARIA tags add attributes to identify features for user interaction, how they relate to each other, and their current state. It describes new navigation techniques to mark regions and common Web structures as menus, primary content, secondary content, banner information, and other types of Web structures. For example, with ARIA, developers can identify regions of pages, allowing screen-reader users to easily move among regions, rather than having to press Tab many times.

If the WEI environment undergoes the two kinds of design modifications, online exams could become more accessible and usable for BVI students. The ARIA tag will provide the screen-reader the information necessary to announce the loading of the destination page once the course content updates following link activation on the source page. Here, I wish to clarify that identifying potential solutions was not one of the goals of my research. Web developers made these suggestions voluntarily during the interview as a part of their explanation of the source of a problem. I also wish to acknowledge that these suggestions made by Web developers must undergo validation. Only then can they be treated as design principles for reducing BVI students' confusion in navigating the WEI environment.

5.3.2 Web Developer Assessment of Susceptibility to Skip Exam Questions

My analysis of Web developer assessment shows that the source of a BVI student's susceptibility to skipping exam questions in WEI environment lies in three design problems:

a. Frame-based page structure;
b. Default cursor focus on navigation bar;
c. Poor labeling of Next button.

Assessment of Web developers' interviews explained that the frame-based page structure gives rise to inconsistent feedback for page change. In addition, it explained that the default cursor focus on navigation bar gives rise to the misperception that the page did not change. These two factors together exacerbate the perceptibility of the new question page. A BVI student under this condition believes she is still on the previous question page, and will try to navigate to the subsequent question page. Finally, my analysis explained that the use of identical labeling convention for the Next button does not identify the target page. Consequently, the screen-reader fails to provide contextual information about the availability of a new question page; BVI students navigate away from this page inadvertently skipping a question unanswered. Evidence of this reasoning was apparent in the responses of my Web developer participants during the interviews. I provide evidence of this explanation using a summary of the assessment of different participants. Sometimes participants express their assessment of the problem by explaining its source in WEI design and sometimes by providing suggestions for potential solutions.

> WD1: The problem results primarily because it is a frame-based environment.

> WD2: The frame can be labeled correctly using a “Legend”. This is an html feature with which you provide legal names to the structure of the frame. What it does is it covers multiple HTML controls on a page, giving each group a heading that identifies the specific controls available including a “Submit button. Using these legends, the screen reader can tell the user that the legend has changed. That would be very helpful. When the new page loads after clicking on the next button, the focus should move to the beginning of the changed content, which is the header of the next question frame. The best possible solution would be to have the header and move the cursor focus to this header.

> WD1: What happens is that it does not take you to the top of the frame when you click “Next”. Instead, it takes you to the same place relative to the previous page. In other words, the default cursor focus moves to the navigation bar of the new question page.

> WD5: That problem could definitely be mitigated by re-focusing your starting input location. This is possible using something called “Named Anchors”. When you click on Previous Question or Next Question button, or Last Question or First Question button, instead of just going to the next page you go to a Named Location – ideally the top of the page. I mean, if you think of the page as a vertical thing, the navigation buttons are at the bottom. If you name going to the top then when you click on Next Question, you go to the top of the next question rather than to the bottom. So, using named anchors, you could to some degree mitigate the problem. The named anchor will force the cursor focus to go to the top of the page, or for that matter, to the top of the question. Here, there are two parts to the question pages. There seems to be a repeated instruction on the top of each question. So maybe it should go to the top of that. It is easier to skip

> past something than to realize that there is something before what you have. If I was doing this, I would do it to the top of the frame.
>
> WD3: The system does not properly communicate to the user about her exact position, or about the exact purpose of the button. The label “Go to next question” does not say you are in question one; it does not give the complete information. If the person is sighted, she can see that she has moved to Question number two. But for a visually challenged user, it is not apparent. It should be written on which page the user is currently positioned. When meaningful labels are not provided, the user is prone to errors.
>
> WD2: The solution is to communicate the information about the question number through meaningful labeling of the Next button. You can do that by providing a suitable title in the title attribute of the corresponding anchor. Here, you can provide the information that the user is in question number one, and clicking this button will lead you to question number two. In the next navigation bar, this title will inform the user that she is on question number two, clicking it will lead her to question number three.

Analysis of this evidence reveals that the three design factors that contribute to a BVI student’s susceptibility to skipping exam questions include the frame-based page structure, the default cursor focus and the poorly labeled Next button. Here, I wish to explain that based on an examination of the CMS pages relevant to this task, I observed that all question pages of the online exam includes a navigation bar below the question. This navigation bar includes a left arrow and a right arrow graphic that correspond to the back button and the Next button respectively. BVI students perceive these buttons when the screen-reader announces their label texts. For example, the Next button for the BVI student “appears” as the announcement “Go to next question”. They do not hear any contextual information to indicate the question number they will be moving to. This is why unique labeling of the Next button is important.

I also observe that the susceptibility of BVI students to skip exam questions could potentially be addressed through simple design modifications in the WEI environment. The design modifications suggested by my Web developer participants include:

(1) Providing a unique and meaningful header to each question frame using a Legend;

(2) Set the default cursor focus on this question frame header using Named Anchor; and

(3) Providing unique and meaningful labels to Next button of the navigation bar that identifies the question number in the target page.

On the basis of my analysis, I believe these design modifications hold promise and are worth further investigation. Once validated, these design modifications could make online exams more accessible and usable for BVI students. This is because the cursor focus on the descriptive title of the new question frame will prompt the screen-reader to announce the availability of a new question page. The uniquely labeled Next button will help the screen-reader convey the specific question number available in the destination page to BVI students. I believe such a WEI environment will make BVI students less vulnerable to skipping exam questions.

5.3.3 Web Developer Assessment of Difficulty Determining How to Submit Multiple-Option Questions

My analysis of Web developer assessment informs that the source of a BVI student's difficulty determining how to submit multiple-option questions is the inconsistent keyboard navigation procedure defined for selection controls (e.g. radio buttons and checkboxes provided). A keyboard navigation procedure is a set of codes embedded into a selection control. It determines the consequence of user action on this control for moving within and across Web pages. According to my Web developer participants, the selection controls provided for multiple option questions did not have a keyboard navigation procedure consistently across exam pages. This means when a student activates these controls to submit her response, the direction in which the page change occurs will differ in different attempts. As a result, the student cannot predict the behavior of the WEI environment in response to her actions. She fails to understand what navigation strategy can submit a question and move to the next. My participants also hinted that the source of the problem was the malfunctioning of selection controls as submit buttons. This finds resonance with the results of my WCAG text analysis. I provide summaries of their responses as evidence of this reasoning. I wish to highlight that participants framed their assessments both as explanation of problem source as well as suggestion for potential solution.

Speaking about the inconsistent behavior of the WEI environment, participants WD4 and WD3 expressed their views as follows:

> WD4: The problem is the developer does not use the same “use and feel” in all the pages. For example, in the first question page, the user is able to submit the answer and move to the next question page by hitting enter on the radio button. But in the second question page, this action brings the user back to the first question page.

> WD3: The developer should use the same technique on all pages. If hitting Enter on a radio button in the first question submits the form, then hitting Enter on the checkbox in the second question should submit that form instead of taking the user to the previous page. If there are ten pages, all pages must have the same look and feel. That will be a user-friendly website. You should follow the same technique to submit the questions in all the three pages.

Clarifying that the problem here had to do with a coding error, WD2 explained:

> This is the result of a simple coding problem. It is not a design problem. Here, the coder has not enabled the browser to handle user navigation. Today’s advanced browsers, such as IE, Firefox, Chrome are adept in assisting the user in keyboard navigation. They include a “key structure” for html controls such as radio buttons, check boxes, input boxes and submit buttons. This allows a user to navigate through these html controls using the left, right, up and down arrows, and finally submitting with the “Submit” button. This is the browser way of navigation. If the coder has not enabled the browser-driven navigation, he must provide the key structure that includes a sequence of user actions that ultimately takes the user to the submit button. Here, the problem is first the coder has disabled the browser way of navigation, and second did not provide the navigation procedure. This almost halts the keyboard usage; you can submit the form only through the mouse, or probably through tab. If the page is very simple and you are not bothered about the sequence of the html controls, let the browser handle the navigation. Otherwise, you should provide the keyboard navigation procedure for each of the html controls – radio buttons, check boxes, input box, etc. In addition, you can provide a keyboard shortcut for every HTML control on the web page. This means the user does not browse through the page to the “Next” or “Submit” buttons. She can press the S key to move to the “Submit” button and the K key to move to the input check box where she reads the label of that control.

Explaining the consequence of this problem, WD2 further explains:

> In a form, “Enter” is regarded as the submit button and “Backspace” as the back button. In a Multiple option Question, the user thinks if I am in a check box or a radio button, I can press enter to select my answer, and then press enter another time to submit this. This is a wrong perception. This is not how forms actually work in Multiple option Questions.

WD1 attributed this misperception to the design of the page and explained:

> A convention is built up in the user’s mind by the previous question that she could move forward by hitting enter twice on the radio button. The issue is that you are building a false expectation on how a system will function. It is much better from a Web accessibility perspective to have a page change or a state change to only occur when a user has explicitly requested this change in state. It would be better to move the change from a non-explicit command, which is pressing enter twice, to pressing on a button which is assigned for moving to the next question. The changes could be made in the previous question with the radio buttons that pressing enter twice does not do anything; it retains the selection. That might help in not establishing the convention that pressing enter twice to move to next question.

Based on the evidence above, I observe that the source of a BVI student’s difficulty determining how to submit answers to multiple option questions is a combination of two design-related problems:

a. Selection controls assuming the role of submit button; and

b. Selection controls coded without consistent keyboard navigation procedure.

A feasible design modification that can potentially address the problem is to recode the selection controls to include a consistent keyboard navigation procedure, possibly letting the browser handle the navigation sequence. In addition, the codes must disable a change of page as a consequence of any user action on these controls. However, I acknowledge that we cannot say anything about the effectiveness of the design modification unless we validate them appropriately.

5.3.4 Web Developer Assessment of Inability to Negotiate Security Information Pop-Up

My analysis of Web developer assessment informs that the source of a BVI student's inability to negotiate security information pop-up is an inaccessible alert dialogue box. Web developer participants consistently blamed the alert dialogue box used for the security information for the accessibility problem of BVI students in WEI environment. I present evidence of this explanation using summarized assessments of participants WD1, WD2 and WD5. While WD2 expressed his assessment in terms of the source of the problem explicitly, WD1 and WD5 expressed theirs through recommendations to mitigate the problem.

> WD2: What happens here is that the system pops up a dialogue box that is not built in an accessible way. This pop-up is triggered by a Java applet. It is definitely possible to make this dialogue accessible. But obviously, not enough time was spent in analyzing this interaction between the Web page and the Java applet in triggering the pop-up.

> WD5: It is advisable that developers do not use the alert dialogue box. Instead, they should use the simple command mode as in a confirm dialogue box.

Citing an example, WD1 explained the use of confirm dialogue box for similar purpose:

> WD1: Standard sites like Google and Microsoft allow the user to move between secured and unsecured sites in a minute. Basically, what happens is that the user gets only one confirmation dialogue that asks: "Moving from secure page to unsecure page. Do you want to go?" This is pretty simple.

Based on the evidence presented, the security information pop-up was actually an application side alert dialogue box that the CMS throws up on the last page of the online exam. The alert dialogue box blocks access to the essay-type question page immediately after this page loads. It is incompatible with screen-reading technology. As a result, the security information it contains is inaccessible to BVI students. They cannot perceive, understand and operate on this dialogue box; they simply become helpless and cannot move forward. Thus the use of alert dialogue box can make an online exam inaccessible and unusable for the BVI.

My analysis also informs that a feasible solution that can potentially reduce the accessibility problem with the security information pop-up is to present the security information in a simple command mode using a confirm dialogue box, instead of the alert dialogue box. My analysis already showed that the screen-reader has easy access to the information contained in these confirm dialogue box. Consequently, the dialogue box will become perceivable, understandable and operable to BVI students. They can negotiate this content independently.

5.3.5 Web Developer Assessment of Ambiguity in Essay-Type Question Page

My analysis of Web developer assessment informs that the source of a BVI student's ambiguity in essay-type questions page is the poor labeling convention for three interface objects:

a. A graphic with a label "Question Three Answers" just below the question text;

b. A text formatting tool bar just over the text area; and

c. A text area for typing answer

During the interview, Web developer participants explained that a graphic just below the question text that the screen-reader announced as "Graphic Question Three Answers" had a misleading label. This label can build a false expectation in the minds of BVI students that possible answers lay ahead. They further identified a text formatting toolbar between this poorly labeled graphic and the text area with several formatting controls. When these controls received keyboard focus, the screen-reader announced their labels. They pointed out that these labels can confuse BVI students, creating disorientation in the essay-type question page. In addition, they explained that the text area right after the formatting toolbar did not have a descriptive caption. Such a text box can remain obscure for screen-reader users who perceive interface objects through text descriptions. I provide evidence of this explanation using summarized assessments made by participants WD1, WD2 and WD4.

Speaking about the misleading nature of the graphic label “Question 3 Answers”, WD1 explained:

> WD1: Basically what has to happen is that we need some sort of information before we enter the text area field. This information is not available here. And that particular graphic that says “Question 3 answers” is misleading.

WD3 spoke about the problem in terms of improvements to WEI design as:

> WD3: Instead of saying Question 3 Answer, it could say “Space to enter answer for question 3”. So, that could be just a question of modifying that label to be more descriptive.

Recognizing a lack of clear guidance for screen-reader users about the response method for this question, participant WD5 observed:

> WD5: One solution may be to add in a description of what’s going to come in immediately as you are pulling up a text area. It’s definitely possible to ensure that for the text area, you insert a short description that is only visible to the screen reader.

Speaking about the disorientating effect of the poorly labeled text formatting toolbar, WD1 observed:

> WD1: What happens here is that you are being provided a space to enter a long form answer. And that space includes a toolbar that has buttons which allow you to format the text you are entering – bold, italic, left, right, center. As you rightly said it is confusing for a screen-reader user.

Further elaborating on this topic, WD2 explained its negative implications for the BVI:

> WD2: These are all text formatting options that the user is not supposed to read. This is the first mistake. If there were only 5 to 6 options, then the user could have been able to make out where the screen-reader announced "Edit". Because there are thirty to forty announcements that correspond to specific options, the user gets confused.

> WD2: I think that HTML syntax must not be put into readable content. The 2nd thing is that the design should be in a way that the contents are grouped correctly; users must know which section they are going into so that they are able to make the decision whether to go or not to go.

Speaking about absence of descriptive caption for the text area, participants WD1, WD2 and WD4 explained:

> WD1: The text area currently doesn't have a caption associated with it. For any text box or input control they say that you should put the caption or label.

> WD2: Here the problem is the developer has not surrounded the input attribute with a label.

> WD4: If there is a question, it should be provided with some label saying this is Question one. If there is an input text box, we must define it by saying that this particular text box is being used for answering question number one. That will be very informative for the user.

Based on the evidence I provide, I observe that the source of a BVI student's ambiguity in essay-type question is a lack of appropriate labels for three objects needed for the essay-type question: a graphic, a set of formatting tools and an input field. My analysis also indicated that we can potentially address the ambiguity problem through simple design modifications in the WEI environment. These include:

(1) Replace the text “Question Three Answers” with “Space to Type Question Three Answer” as the label for the misleading graphic;

(2) Provide a label for the text formatting toolbar informing the user about an impending space to type answer beyond the text formatting toolbar; and

(3) Include a meaningful caption for the input area (e.g. “Type your answer for question 3 here”).

Again, I wish to clarify that these are mere suggestions and not design principles. However, they seem to have the potential to remove the ambiguity problem and are worth further investigation.

5.3.6 Web Developer Assessment of Vulnerability of Premature Exit from Online Exam

My analysis of Web developer assessment informs that the source of a BVI student’s vulnerability of premature exit from online exam lies in two design problems:

a. Malfunction of Backspace as browser’s Back button in the text area

b. No error avoidance mechanism for accidental exit from exam

During the interviews, Web developer participants identified these two sources of the premature exit problem. They explained that the traditional function of the Backspace inside the text area of an online form is to delete text. Outside the text area, the use of

Backspace can trigger a backward page navigation, assuming the function of the Back button of the Web browser. The behavior of Backspace as the browser's Back button when the cursor is inside the text area is against the norm, and makes users prone to errors. The error in the case of BVI students is accidently quitting the exam. Participants further explained that even if the Backspace behaved incorrectly, the WEI environment should have provided some mechanism to warn the student about the error she is committing. My analysis showed that no such warning mechanism was available to BVI students. The consequence is what my BVI participant experienced. They pressed Backspace multiple times inside the text area believing they were deleting several characters of the answer to the essay-type question. But in reality, every press of the Backspace key was taking them a page back. By the time they realized an unexpected behavior of the WEI environment, they were completely out of the exam, and not allowed back. My Web developer participants consistently blamed the Backspace malfunction for this problem. I present this evidence using summarized responses of some participants

Speaking about the problem, WD1 explained:

> WD1: The problem is that within the text field, Backspace performs the wrong function. Backspace is associated with two functions. One function is to delete text when the cursor is inside the text field. The other function is to go back to the previous page when the cursor is outside the text field - it duplicates the functionality of the Back button in the browser. For whatever reason, here the use of Backspace inside the text field moves the user to the previous page. And there is no feedback from the system.

On this topic, WD2 explained:

> WD2: The Backspace issue is a designer problem. In the standard browser practice, one Backspace is equivalent to one Back button. If you're inside the text box, Backspace is used as an editing tool that removes one character before the cursor. This is the standard use of the Backspace. However, in this situation, with the use of Backspace, the user moved to the previous page - the start page. It should not behave like that. Especially since the user can delegate the system to go forward and backward with the "Next" and "Back" buttons, there is no need for the Backspace to duplicate the function of the browser's Back button. Ideally, this should not happen when you are inside the text box because Backspace is the alternative for the Delete button.

WD4 explained the problem as follows:

> WD4: https sites disable the back button of the browser. So the backspace will always be useful deleting the content of a textbox. Only the developer defined back button will take you back to the previous page.

Speaking about the absence of any error avoidance mechanism for situations where students accidentally quit the exam, participants WD2 and WD1 explained:

> WD2: What it should have ideally done is it should warn the user giving them a message that cautions they would be out of the exam. This is a standard practice that many of the guys follow. So, you always confirm that after you click this button, you will lose everything.
>
> WD1: If you press backspace, you get a dialogue box which says "Are you sure you want to delete this page? You may have unsaved changes." In gmail, they give you proper way which says are you confirmed or not. Exactly, the same dialogue box is repurposed to ensure that accidently backward navigation does not happen.

Based on this evidence, I conclude that the source of a BVI student's vulnerability of premature exit from the online exam is a problem in WEI design due to which (1) the Backspace malfunctions inside the text area making users error prone; and (2) no warning is available to prevent users from committing the error.

Analysis showed that the feasible design modification that can potentially reduce the vulnerability of premature exit from the exam is to disable the Back button of the Web browser such that the Backspace does not assume its function inside the text area. And if that is not possible, then program the system so that it triggers a confirm dialogue box before the use of Backspace changes the page backward. Here, my belief is when BVI students will read the message in the confirm dialogue box, they will be able to prevent the loss of the in-progress exam. These suggested design modifications appear to have the potential to address the problem and are worth further investigation.

5.4 Chapter Summary

The user-centered, cognitive, task-based, multi-method analysis provided a broad yet deep understanding of accessibility and usability challenges BVI students face in WEI environment. Specifically, it explained that the task environment (online exam) consisted of thousands of interface objects (e.g. images, tables, anchors and scripts) whose design did not comply with WCAG's standards on accessibility and usability. Interestingly, the frequency of poorly designed interface elements were higher as evaluated by WCAG 1.0 compared to WCAG 2.0. WCAG 2.0 is a result of several years of discussion in the Web Accessibility Initiative about making the standards up to date with new and advanced

Web technology. One would expect that WCAG 2.0 identifies more problems than WCAG 1.0 in a poorly designed page. However, the consistently lower frequency of error detection of WCAG 2.0 is puzzling, and demands further investigation. My analysis also showed that completing the online exam in WEI environment is significantly challenging for BVI students. This is due to several accessibility and usability problems as described below:

5.4.1 Confusion While Navigating Between Exam Pages

Analysis shows that BVI students experience confusion while navigating between different pages of the WEI environment. This is due to the difficulty verifying arrival on destination page after activating a link. At the core of this confusion is the inconsistency between expected and observed CMS response to link activation. BVI students expect two kinds of screen-reader announcement for link activation: (a) percentage of destination page downloaded and (b) number of interface objects in the destination page. However, they observe a CMS response that does not follow this feedback pattern for link activation. They have difficulty verifying if the link had activated or not. This confusion while navigating between exam pages represents a violation of two usability principles - Feedback and Satisfaction. This represents a violation of Page Title principle. The source of the confusion is a frame-based page structure because of which the CMS generates unexpected feedback in response to link activation. According to Web developers, this confusion can be potentially remedied by: (1) Providing a unique and meaningful label for each course content frame; and (2) Using ARIA tags to prompt the screen-reader announce the name of the frame loaded. I believe by making these two minor modifications in the CMS design, frame-based online exams will become more accessible and usable for BVI students. This is because the ARIA tag will provide the screen-reader the information necessary to announce the loading of the destination page once the course content updates following a link activation on the source page.

5.4.2 Susceptibility of Skipping Exam Questions

Analysis shows that BVI students are susceptible to skipping exam questions inadvertently in the WEI environment. The default cursor focus on navigation bar misleads the student to believe the question page has not changed, prompting her to activate the Next button. This problem indicates a discrepancy in the expected and observed outcomes of the arrival on a new question page. The susceptibility of BVI students skipping exam question represents violation of two usability principles - Visibility and Error Avoidance. This represents a violation of two accessibility principles - Page Title and Consistent Identification . Two sources of the susceptibility problem are (a) default cursor focus on navigation bar; and (b) inappropriate labeling of “Next” button. The potential solution to address BVI students’ susceptibility of skipping exam questions involves: (1) Providing a unique and meaningful header to each question frame using a Legend; (2) set the default cursor focus on this question frame header using Named Anchor; and (3) labeling the Next button identifying the question number. I believe these will make online exams more accessible and usable for BVI students . Cursor focus on the descriptive question frame header will allow the screen-reader to announce the arrival on a new page. The uniquely labeled Next button will allow the screen-reader to announce the specific question number in the destination page. With all this information, BVI students will be significantly less vulnerable to skipping online exam questions.

5.4.3 Difficulty Determining How to Submit Multiple-Option Questions

Analysis shows BVI students have difficulty determining how to submit answers for multiple option questions. This happens because they move in different directions when submitting answers by using selection controls – radio buttons in multiple choice questions and check boxes in multiple answer questions. Generally, students can submit responses to multiple-option questions by activating the "Next" button on the navigation bar. As is evident in this case, students can also achieve this goal by hitting Enter twice on a radio button or a checkbox corresponding to an option. However, this second method of submitting the response does not always result in moving to the next question page. The CMS may sometimes bring up the previous question page instead of the next question page. This causes the confusion in the mind of the student. A discrepancy in the student's mental model for submitting the answer comes into play. This mental model does not consider the availability of "Next" button. Instead, it treats the radio button or check box as a navigational element. This is why, she faces difficulty determining how to submit an answer for multiple option question. This difficulty of BVI students represents a violation of three usability principles -the Good Mapping, Memorability and Consistency principles. This represents a violation of accessibility principle as per

WCAG's On Input Success Criterion. The source of BVI students difficulty understanding how to answer multiple-option questions is the inconsistent keyboard navigation procedure coded into the selection controls in multiple option questions. A lack of such procedure in radio button and checkbox resulted in inconsistent behavior of the CMS exam environment. A potential solution to address this problem involves: (a) include correct keyboard navigation procedure in selection controls disabling the navigational property; and (b) disable page change as a trigger for changing the setting of selection controls.

5.4.4 Inability to Negotiate Security Information Pop-Up

Analysis shows BVI students were unable to negotiate security information pop-up in online exam. This is because they cannot perceive, understand or operate the information presented by an alert dialogue box. Most likely, sighted help will be required. The inability to negotiate security information pop-up is associated with an inaccurate mental model for using the alert dialogue box. This does not include the availability of any information other than a "Yes" and a "No" button in the dialogue box. It assumes that security information will be read out automatically by the screen-reader, and selecting No will dismiss the dialogue – both wrong assumptions. Consequently, BVI students with such erroneous mental models cannot proceed further without sighted help. The inability of BVI students to negotiate security information pop-up represents a significant usability problem. This represents a violation of accessibility principles such as No Keyboard Trap and Compatibility Success Criteria of WCAG. The source of this problem is an inaccessible alert dialogue box used to pop up security information. This alert dialogue box is incompatible with screen-reading technology and makes the security information inaccessible for the BVI. A potential solution to address the inaccessible security information is to present this information in a simple command mode through a confirm dialogue box. This will provide screen-reader access to the security information and the input buttons; the dialogue box will become perceivable, understandable and operable through NVI. Consequently, BVI students will negotiate with this content independently and complete the exam in time.

5.4.5 Ambiguity in Essay-Type Question

Analysis shows BVI students face ambiguity in essay-type question. They experience disorientation due to a group of text formatting controls. They find it extremely difficult to locate the input area assigned for typing the answer. They require additional time and effort figuring out that they must type in a response, instead of choosing an option (s)., The ambiguity problem has three aspects: (a) required response method is not apparent; (b) purpose of text formatting controls is not clear; and (c) locating input area is difficult. This amounts to a gulf of execution, pointing to an inaccurate mental model for essay-type question. According to this mental model, the input area follows immediately after the question text. It does not account for other interface objects such as the link “Expand”, set of text formatting controls, etc. This is why, the BVI student has difficulty locating the input area, and cannot understand the purpose of the interface objects or the response method . The ambiguity problem of BVI students represents a violation of several usability principles – Visibility, Efficiency, Learnability, Good Mapping and Working memory load. This represents a violation of several accessibility principles such as Sensory Characteristics, Link Purpose, Instruction, Location and Name-Role-Value Success Criteria of WCAG. Sources of this ambiguity problem include a lack of appropriate labels for three objects needed for essay-type questions: a graphic, a set of formatting tools and an input field. Potential solution to address the ambiguity problem include: (1) Replacing text "Question Three Answers" with "Space to Type Question Three Answer" as the label of the misleading graphic; (2) Providing a label for the text formatting toolbar informing the user about an impending space to type answer after the formatting controls; and (3) Including a meaningful caption for the input area (e.g. "Type your answer for question 3 here"). These modifications will provide clear guidance to students on how and where to respond to the question removing the scope for any ambiguity.

5.4.6 Vulnerability of Premature Exit from Online Exam

Analysis shows that BVI students are vulnerable to premature exit from online exam on using Backspace to delete text in the input area of essay-type question. Use of backspace to delete typographical errors is a common operation in word processing. Input fields are meant to support word processing operations; students will typically use the backspace key to delete text. If the outcome of pressing backspace is to lose the exam, BVI students are at a huge disadvantage. This points to a discrepancy between observed and expected outcomes of use of backspace inside input area. This indicates a discrepancy in the mental model for using input area for essay-type question. This mental model treats the input area as a word processor. It also considers the use of Backspace as a legitimate text-editing operation. However, both of these assumptions are debatable as the Backspace assumes the roles of text-editor as well as browser's Back button interchangeably. This is why, a BVI student keeps navigating backward by several pages, ultimately exiting the exam when she tries to delete typographical errors with Backspace. The vulnerability of premature exit from online exam represents a violation of Satisfaction criterion of usability. This represents a violation of accessibility principle as per WCAG's Change on Request Success Criterion. The source of this problem is the malfunction of Backspace inside the input field of essay-type question. A potential solution to address this problem involves (a) disabling Back button of the browser; or (b) pop up a confirm dialogue box before bringing up the previous page triggered by use of Backspace. When BVI students will read the message in the confirm dialogue box, they may salvage the in-progress exam.

5.5 Conclusion

The six challenges amount to accessibility and usability problems in the task environment that negatively impact BVI students' ability to complete the exam effectively and in time. Poor accessibility and usability severely hampers the purpose of CMS as a WEI tool to evaluate student learning. The extent to which the task environment is accessible and usable, affects test scores for BVI students. Considering the widespread use of CMS as a platform for course delivery in the academia, BVI students cannot enjoy equal learning opportunities in today’s education system. The simple design modifications I identify need further validation before becoming design principles on accessible and usable online exams for NVI. When such design principles are used for building WEI environments, BVI students can effectively complete online exams.

CHAPTER VI

DISCUSSION AND CONCLUSION

Chapter I explained that the purpose of this research is to develop an understanding of the nature of accessibility and usability problems blind and visually impaired (BVI) students face in Web-enhanced instruction (WEI). Chapter II identified a critical gap in existing literature about an accurate and in-depth understanding of this problem, and explained the inadequacies in existing research approaches to develop this understanding. Chapter III explained the novel user-centered, task-oriented and cognitive approach adopted in research to develop an in-depth, contextually-situated, observational and experiential knowledge of the problem. Chapter IV explained my multi-method evaluation technique and outlined the research design using which I implemented my novel approach to understand the problem. Chapter VI explained the results and analysis of the multi-method evaluation of the WEI environment. In this chapter, I conclude this dissertation by presenting a discussion of my findings, implications, limitations and future research plans.

Approximately one in twenty people around the world lack the functional vision to see information presented on computer screens or operate mice. They use computers and the Web by listening to speech output from screen-reader software. They face significant accessibility and usability challenges on the Web that is sight-centered by design. Prior research tries to address this problem through technical solutions – improved interface design and better screen-reading technology. Yet, the blind and visually impaired (BVI) continue to face systemic and functional impediments in using Web resources necessary for day-to-day activities. My literature analysis informs that we lack (a) an accurate and in-depth understanding about the problem; and (b) research tools to develop this kind of understanding. This doctoral dissertation demonstrates a research approach to develop an in-depth, contextually-situated, observational and experiential knowledge of accessibility and usability challenges BVI users face in Web interactions. It adopted a user-centered, task-oriented, cognitive view, and employed a multimethod evaluation approach to investigate: What is the nature of accessibility and usability problems BVI students face in Web-enhanced instruction (WEI) environments? The context of investigation was an online exam over a CMS – a typical WEI task. Results explained where, how and why BVI students face difficulty interacting with a poorly designed CMS to complete WEI activities. In the following, I discuss the contribution and implications of my doctoral research.

The first contribution of this doctoral research is an accurate and in-depth understanding of a BVI student's the accessibility and usability problems in WEI environment. This understanding is captured in the seven findings described below.

1. BVI students get confused and feel disoriented in WEI environment when navigating across pages with frame-based structure with no frame labels. My multimethod evaluation of the WEI environment explained that BVI students get confused when they do not receive expected feedback from the CMS for a link activation. In a typical Web site, this feedback comprises two screen-reader announcements about destination page –

download percentages and frequencies of interface objects. A CMS cannot generate such feedback due to its frame-based page structure. This structure means that a link activation triggers a change of frame, and not a change of page as in a typical Web site. Without adequate audio feedback, BVI students cannot verify that the link has activated. Thus, the use of frame-based structure to organize Web content contributes to lack of WEI accessibility and usability for the BVI. And if these frames do not have unique labels, they make the availability of a new page imperceptible through NVI ; BVI students feel disorientated. This finding will explain Web developers the negative consequences of frame-based page structures in Web sites. The confusion and disorientation consumes additional time, effort and mental resources for accomplishing WEI activities. Therefore, BVI students may run out of time in an online exam dealing with confusion and disorientation while navigating between CMS pages. In traditional classroom instruction, BVI students receive 50% additional time to complete a test using the service of a scribe. My research findings indicate that educators need to allot BVI students additional test time in WEI taking into account the time lost ascertaining the state of the CMS. This finding also reveals a perceived limitation in WCAG that represents the de facto standards on Web accessibility and usability. The multimethod evaluation did not find clear reference to the potential accessibility and usability problems in frame-based page structure for screen-reader users in any WCAG Success Criteria.

2. BVI students are susceptible to submitting incomplete work in WEI environment when a new question page does not provide location and contextual information. Such information remain obscured when CMS page (a) uses frame-based structure; (b) brings

cursor focus to navigation bar after download; and (c) does not use unique label for Next button. My multimethod evaluation of the WEI environment explained that BVI students will skip exam questions when they cannot tell that a new question page has loaded. In a normal scenario, BVI students detect a new question page by observing: (a) screen-reader announcement of download percent and frequency of interface objects; (b) cursor focus positioned at the beginning of a new page. As I explained earlier, the CMS cannot generate the feedback they expect due to its frame-based page structure. More importantly, it moves the cursor focus to the navigation bar after the new question page loads. This means BVI students cannot observe a change in context to detect a change in content (or change in question page). They think their previous action of activating the Next button was not successful and attempt to repeat that action. Since the Next button does not have a unique label, it fails to draw the BVI student's attention to the error she is about to commit. This finding informs Web developers about the importance of setting the default cursor focus at the top of a new page of their Web sites. This finding indicates that when a BVI student does not attempt a question in an online exam, it could very well be due to her failure to "see" the question page load. Educators need to keep this in mind when evaluating the exams of BVI students. This finding points to a perceived limitation in WCAG. It shows that WCAG does not recognize the importance of setting the default cursor focus at the top of a new page.

3. BVI students have difficulty understanding how to submit their work in WEI environment when the selection controls for multiple option questions lack a consistent keyboard navigation procedure. My multimethod evaluation of the WEI environment

explains that BVI students face this difficulty when they observe inconsistent page navigation pattern for pressing Enter twice on selection controls available in multiple option questions. Normally, a selection control behaves as a switch – turns off or on with a hit of the Enter key. However, the selection control in the CMS behaved as a submit button except it did not consistently bring up the subsequent page. This happens when the selection controls are not coded to disable keyboard navigation for restricting its behavior to that of a switch. Its malfunction as a submit button means BVI students do not look for the Next button designated to submit the form. As a result, they remain unaware about the correct submission procedure for multiple option questions, and spend extra time and effort determining how to move forward in the exam. This finding informs Web developers the negative consequences of not coding selection controls with proper keyboard navigation procedures. It also highlights the potential confusion that Next buttons with identical labels can cause for BVI users. This finding identifies another scenario where WEI interaction demands extra time from BVI students. Educators need to consider this factor too while allotting BVI students the extra text time in WEI environments. This finding identifies a perceived weakness in WCAG. In the G80 technique, WCAG recommends that a Web site must initiate a change of context only through the use of a Submit Button. This technique will discourage Web developers from including keyboard navigation procedures into interface objects other than submit buttons. However, I believe WCAG must explicitly recommend Web developers to disable any change of context due to change in setting of a selection control or any other interface object.

4. BVI students get stuck in WEI environment when it uses an alert dialogue box to present security information. My multimethod evaluation of the WEI environment informs that BVI students become helpless when they cannot perceive, understand or operate on an alert dialogue box thrown up by the CMS before loading the essay-type question page. In a normal scenario, BVI students can perceive, understand and operate on a dialogue box that allows the screen-reader access to all its features and functionality. An example is the Confirm Question Submission dialogue box. However, the alert dialogue box restricts the screen-reader only to a small section with the Yes and the No buttons. BVI students fail to perceive the message communicated by the dialogue box. They fail to determine whether to select Yes or No without knowing what the question is. They fail to dismiss the dialogue box by selecting No or hitting the Escape key as they would do in a normal scenario. This problem becomes most debilitating for BVI students in WEI interactions. This finding will help Web developers understand the negative implications of using an application-side alert dialogue box for non-visual interaction. It also highlights the difference in accessibility and usability of confirm and alert dialogue box. This finding identifies a potential situation for educators where BVI students may need sighted intervention.

5. BVI students experience a great deal of ambiguity in WEI environment when an essay-type question page does not use meaningful labels for (a) graphic pointing to the input area; (b) input area itself; and (c) text formatting tools. My multimethod evaluation of the WEI environment showed that a BVI student’s ambiguity begins with the confusion about the response method. She gets confused that this was a multiple option question

when she comes across a graphic labelled “Question 3 Answers” immediately after the question text. As she navigates further down, the ambiguity increases further as she gets perplexed with the text formatting tools. The perplexity arises when she fails to understand the purpose of these tools from their labels. The ambiguity reaches its height with the obscurity of the text area for typing the answer. BVI students have significant difficulty locating a text area without a caption that lies among other poorly labelled objects. The consequence of this ambiguity is that the BVI student will get confused, disorientated and frustrated. Under this condition, she is likely to give up on her search for the input area, and forgo answering essay-type question. This finding highlights the negative consequences of poor labeling of interface objects on non-visual Web experience. It informs Web developers that when an interface object needed to complete a task does not have a label that describes its purpose for that task, BVI users will have difficulty completing this task. This finding informs educators about two potential challenges BVI students will face in an essay-type exam question. The first is their difficulty determining the response method. The second is the obscurity of the input area. Due to these potential challenges, they are likely to spend additional time, effort and mental resources dealing with the ambiguity. In the worst scenario, they may leave the question unanswered, failing to locate the input area promptly.

6. BVI students are vulnerable to losing their work in WEI environment when Backspace behaves like the browser’s Back button inside the text area. My multimethod evaluation of the WEI environment showed that BVI students face the threat of premature exit from an exam when they use Backspace to delete typographical errors while compiling the

answer for an essay-type question inside the designated text area. Under normal circumstances, a text area supports typical word processing operations such as inserting, modifying and deleting text. For example, it supports deleting text using the Delete or the Backspace keys. However, the CMS treats the use of Backspace inside the text area interchangeably as two user requests: (a) request to delete preceding character and (b) request to navigate back a page. The problem arises when it treats the use of Backspace as a request for backward page navigation inside this text area without warning the user of the outcome. As a result, BVI students keep navigating backward to come out of the exam, thinking they are deleting so many characters of a typographical error of their answer. The problem becomes significant when the CMS does not allow a second attempt, leaving BVI students stranded with an incomplete exam. This finding highlights the negative consequence of a Backspace malfunction inside the text area for non-visual Web experience. It informs Web developers about the disadvantage of BVI users in completing html forms when the Backspace behaves like the browser’s Back button inside an input field, as well as when no warning of this consequence is provided. This finding also informs that BVI students may lose the opportunity to complete an exam over the CMS while typing a response in the text area. Educators need to take this disadvantage of a BVI student in WEI environment when evaluating their performances in online exams.

All the six findings amount to accessibility and usability problems in the WEI environment that negatively impact BVI students ability to accomplish academic tasks effectively and in time. Poor accessibility and usability defeats the purpose of CMS as a mechanism to evaluate WEI learning outcomes. The extent to which the task environment is accessible and usable becomes a determinant of test scores for BVI students. Considering the widespread use of WEI as a practice to deliver academic programs in colleges and universities, BVI students cannot enjoy equal learning opportunities in today's education system.

7. WEI environment does not comply with existing design standards on accessibility and usability. My multimethod evaluation of the WEI environment informed that the CMS consisted of thousands of interface objects (e.g. images, tables, anchors and scripts) whose design did not comply with WCAG's recommendations. Interestingly, the frequency of poorly designed interface elements were higher as evaluated by WCAG 1.0 compared to WCAG 2.0. WCAG 2.0 is a result of several years of discussion in the Web Accessibility Initiative about making the standards up to date with new and advanced Web technology. One would expect that WCAG 2.0 identifies more problems than WCAG 1.0 in a poorly designed page. However, the consistently lower frequency of error detection of WCAG 2.0 is puzzling, and demands further investigation. WCAG recommendations form the basis of legal stipulations on Web accessibility such as those included in Section 508 of the Rehabilitation Act. A Web site that violates WCAG requirements for accessibility does not comply with stipulations of Section 508. Therefore, this finding indicates that the WEI environment is non-compliant with laws on equal Web access for people with disabilities. My multimethod evaluation of the WEI environment identified some limitations in WCAG recommendations. My future research will use the multimethod evaluation approach to further investigate the efficacy of

WCAG in addressing the accessibility and usability challenges in non-visual Web interaction.

Findings of this research have implications for the design of Web resources used for purposes beyond Web-enhanced instruction. Such resources include interactive forms and questionnaires. By including the three types of exam question formats: multiple-choice, multiple-answer, and short-answer, I have covered the three most common methods for soliciting user responses through Web-based questionnaires and online interactive applications. These applications are used for common purposes, such as online shopping, blogging, and filing tax returns.

The second contribution of this doctoral research is a set of mental model representations that explicate the thought processes of BVI students under conditions of dissonance. These representations outline the knowledge structures and cognitive processes that are responsible for challenges in non-visual Web interaction. They reveal what BVI users observe and experience during Web interaction. This finding has two broad implications.

First, it helps in the accurate assessment of the gulf between BVI users and the Web. This gulf makes non-visual Web interaction inherently challenging. Literature on BVI user Web experience is founded on a handful of research studies (e.g. Theofanos and Redish, 2003; Lazar et al., 2007). Such studies rely on participants' accounts of accessibility and usability problems. While this is necessary to understand the problem from the user's perspective, some problems may go unreported. Most users report a positive online experience even when they fail to accomplish a goal (Nielsen, 2001). This is particularly true for BVI users since they are accustomed to lack of Web accessibility (Gerber, 2002). Under such situations, users normally blame their lack of proficiency (Norman, 1988). Another limitation of prior research is its lack of attention to understanding the thought processes of BVI users in Web interactions. Accordingly, existing literature does not clarify where, how and why these users face obstacles in Web interactions. Such understanding is key to accurately assess the gulf between BVI users and the Web. My research demonstrates how to conduct an in-depth examination of perceptions, actions and cognitions of BVI users in Web interactions employing a combination of verbal protocol analysis and my integrated problem-solving framework. Through such examination, my research was able to map a problem to the gulf (gulfs of execution or evaluation) for BVI users. An accurate assessment of this gulf helps identify areas of improvement in the design of Web sites and Web applications such that they meet the unique accessibility and usability needs of BVI users. My future research will identify and test the efficacy of promising design modifications in WEI environment to accommodate the special accessibility and usability needs of BVI students.

Second, it informs that Web accessibility and usability problems have a cognitive component that originates from a user's misconceptions about Web interaction. For example, my multimethod evaluation showed that BVI students have difficulty understanding how to submit multiple option questions when they have misconception about the function of a selection control. Due to this misconception, they assume pressing Enter twice on a selection control submits their response. This misconception prevents them from finding the Next button. As a result, they follow a wrong submission procedure. This finding indicates that with proper training about the function of selection controls, BVI students will acquire an accurate mental model for submitting the multiple option question. I believe this wil prevent them from committing the error of using the selection controls to submit their responses. My future research will develop training on effective non-visual Web interaction by studying mental models of expert BVI users for specific online tasks.

The third contribution of this doctoral research is a user-centered, task-based, cognitive and multi-method approach to evaluate Web accessibility and usability. This approach considers an online task as the unit of analysis for a practical Web accessibility and usability evaluation. It synthesizes results of three assessments to generate a holistic and user-centered understanding of a problem. The three assessments include:

(1) BVI student assessment using verbal protocol analysis and focus group interview;

(2) Web Developer assessment using structured, open-ended interviews; and

(3) WCAG assessment using iProwe accessibility checker and textual analysis.

I demonstrated the feasibility and efficacy of this multi-method evaluation approach through a field study to assess the accessibility and usability of a representative Web interaction task - online exam over a CMS. I explained how this evaluation approach identifies design errors in a Web-based system, the consequent challenges for BVI users in completing an online task, the root cause of these challenges, and feasible design modifications to potentially address these challenges. This represents a more complete, practical and solution-oriented approach to Web accessibility and usability evaluation. The completeness is achieved through synthesis of the viewpoints of BVI users, Web developers and WCAG–three key entities in Web accessibility and usability in NVI. The practical utility comes from its task-based nature that places accessibility and usability of a Website in the context of the purpose it is designed to serve. The solution-oriented aspect is that it provides actionable guidance on addressing a problem, and not just identifying it.

An important benefit of the multi-method evaluation is that it is useful to make conjectures about design modifications that can potentially meet the special accessibility and usability needs of non-visual Web interaction. Such conjectures must undergo a validation process before they become good Web design principles to facilitate specific online tasks. Such design principles can lead to IT artifacts to effectively address Web accessibility and usability problems. IT artifacts include (a) design guidelines to render Web sites appropriate for NVI, and (b) cognitive models to guide the BVI in effective non-visual Web interaction. As my doctoral research demonstrates, the solution can be simple modifications in the interface design that can be achieved at a reasonable cost to the developer. For instance, modifying the design of an essay-type question page to include a short message underneath the question text or inserting a caption for the input area can be simple adjustments for the developer. However, these adjustments go a long way in improving the visibility of the input area and thereby reducing disorientation for BVI students in complex Web environments. In a future study, I will subject potential solutions such as those identified in this dissertation to a validation process through an experimental design with BVI users.

The multi-method evaluation technique provides a more complete assessment of a Web site as compared to traditional methods that focus on identifying poorly designed interface elements without explaining the implications for the success of the Web site. This technique can help organizations to enhance the success of their Web sites for the hundreds of millions of BVI and other groups that employ NVI. Web accessibility and usability have moral, legal, and economic value. The moral value is concerned with corporate social responsibility (CSR). Several industry leaders are committed to CSR. The design of accessible and usable Web technology is a CSR strategy that has significant implications for the integration of people with disabilities (PWD) in the information society. Industry will earn the goodwill of the approximately one billion PWD around the world. The economic value is that this goodwill translates into customer loyalty and increased revenue [Heerdt & Strauss, 2004]. The BVI population comprises a significant customer base. The approximately 10 million BVI Americans alone have a disposable annual income of $175 billion [American Foundation for the Blind, 2006]. There are intangible economic benefits as well. For example, it leads to reduced need for social investments. Accessible and usable WEI tools help Colleges and Universities provide BVI equal learning opportunities who comprise approximately nine percent of the student population. It can be a cost-effective alternative to special disability accommodations academic institutions provide to BVI such as note-taking and reading services. An analysis of Infosys Web development projects shows that designing for accessibility and usability consumes only five percent additional time and effort. In addition, laws such as the Americans with Disabilities Act, Section 508 of the Rehabilitation Act, and Individuals with Disabilities & Education Act require that learning technologies such as CMS are accessible and usable to the BVI. In this backdrop, our finding that a commonly used CMS lacks accessibility and usability assumes significance for academic institutions and education technologists. Our multi-method evaluation can help the industry and academia feasibly meet their social, moral, and legal obligations by ensuring the accessibility and usability of CMS and other Web applications.

It is critical that Web sites and Web applications are designed for accessibility and usability for the BVI. However, this must be achieved without undermining Web experiences and reducing Web functionality for other user groups. This requires a Pareto-efficient approach to Web accessibility and usability that benefits the BVI without hurting other user groups. For example, consider BVI users' inability to perceive graphical information. Eliminating all graphics from a Web page is an impractical solution as this could compromise usability for typical sighted users. Instead, we can adopt a middle path that targets accessibility of visual features for the BVI. This involves effectively communicating information embedded in graphics through alternative non-visual formats as well. Effective communication means this alternative format enables the BVI to perceive, understand and use the information to achieve their goals. This multimodality benefits the elderly, the dyslexic and users with other disabilities. In fact, research demonstrates that technology designed for BVI accessibility and usability is very usable for typical sighted users (Jana, 2009). Innovative organizations make strategic investments to improve the usability of their products by partnering with the VI as power users. Apple’s VoiceOver technology and NaturallySpeaking are prime examples of such well positioned strategic investments to develop accessibility and usability solutions for all. The idea is to make the Web more accessible and usable for the BVI, and in the process enhancing Web experience for the entire user population. My user-centered, task-based, cognitive and multi-method evaluation focuses on pareto-efficient solutions that are helpful for the BVI, useful for other user groups, and feasible to implement for Web developers. The findings of this doctoral research contribute knowledge about Web accessibility and usability problems for the BVI. However, I recognize that there are limitations in my research. My findings are based on verbal evidence collected from six BVI participants about their experiences in interacting with a popular CMS to complete a representative online exam. The small sample size, use of one Web application and a single task context limit the generalizability of the findings. I used qualitative methods to develop a deeper understanding of the nature of accessibility and usability problems that BVI students face in trying to accomplish academic tasks in WEI environments. This provides the basis for our continued work using different Web interaction tasks on different Web sites.

6.1. Limitations and Future Research

In future, I plan to further investigate the problems identified here to develop a more robust and in-depth understanding of the nature of accessibility and usability problems

BVI users face in Web interactions. Specifically, I want to create a more comprehensive understanding of these problems by replicating this doctoral research with a larger set of participants with varying degrees of vision impairment. In addition, I want to conduct future research using other common WEI tasks, such as completing online assignments and contributing to class discussions, to understand the nature of accessibility and usability problems with a wider range of WEI tasks. I plan to investigate the kinds of problems that occur when BVI users interact with Web applications in other genres, such as online stores and social networks. Findings from these future studies will allow greater generalizability of the understanding of the nature of Web interaction problems that BVI users face.

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