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ABSTRACT

We believe that Web lacks accessibility and usability, creating problems for blind user's in online activities. Literature recognizes this problem exists, but does not explain its nature. This understanding is needed to determine accessibility and usability requirements of the Web for blind users. We examine the question: What is the nature of accessibility and usability problems blind users face in completing online tasks? Adopting a task-oriented approach, we investigate this question in the context of online assessment. Employing verbal protocol analysis, we capture evidence of problems 6 blind participants observe and experience completing online assessment. Analysis reveals two aspects of Web design that present accessibility and usability problems for blind users in performing online tasks. Our study contributes with a deep understanding about blind user's problems due to lack of Web accessibility and usability. Future research may use this understanding to create blind user profile for online assessment applications.

Keywords

Web accessibility, usability, online task, blind user, verbal protocol analysis.

INTRODUCTION

There are more than 37 million blind people around the world (World Health Organization, 2002). Interacting with Web sites and Web application for these individuals is a challenge (Brophy and Craven, 2007; Lazar, et al. 2007). This is mainly because current Web technology lacks accessibility and usability (Theofanos & Redish, 2003; Leuthold, et al. 2008; Kelly, 2008). Accessibility allows users access to system functionality (Goodhue, 1986). Usability is the degree to which a system conforms to a user's cognitive perception about accomplishing a task (Goodwin, 1988). Although lack of Web accessibility and usability is undesirable for all users, it presents more problems for blind users in completing online tasks (Correani, et al. 2004). This assumes significance as many of our day-to-day activities like learning and shopping necessitate Web interaction.

Literature reveals that blind users' accessibility and usability problem on the Web has multiple aspects, but does not clearly explain the nature of this problem. These users interact with the Web through screen-readers that read on-screen text in a sequential manner (Leuthold, et al. 2008). This interaction style is associated with constraints like cognitive overload (Theofanos & Redish, 2003), inefficiency (Lazar, et al. 2007), and inability to recognize images (Harper, et al. 2006). Often, ignorance of developers and designers about non-visual Web interaction impedes design of accessible and usable Web sites (Lazar, et al. 2004). Although design Guidelines exist to help developers and designers in this regard, conformity does not guarantee effective accessibility for the blind (Clark, 2006). Research that examines blind user's' online experience is very scant and does not clearly explain where and why such users have difficulty in online tasks (Leuthold, et al. 2008). This understanding is necessary to determine Web accessibility and usability requirements for the blind. We develop this understanding by investigating the question: What is the nature of accessibility and usability problems blind users face in performing an online task?

A task-oriented approach is needed for a complete understanding of the problem (Goodwin, 1987). We choose online assessment as the context of our investigation. We employ verbal protocol analysis (Ericsson & Simon, 1984) to examine blind users' web interaction. We asked 6 blind participants to complete online assessment over the Blackboard system while verbalizing their thoughts and actions. Audio transcripts of verbalizations provide a rich set of qualitative evidence. Analysis reveals two aspects of Web design that presents accessibility and usability problems for the blind in online assessments. We discuss the nature and characteristics of these problems and suggest possible remedies.

In the next section, we summarize extant knowledge on the problems blind users face on the Web and identify the knowledge gap. We then discuss principles on good accessible and usable Web design. We provide a detailed description of our research design to evaluate Web accessibility and usability and discuss the findings of our qualitative analysis. We conclude the paper with a summary of our findings and with possible solutions to the problems discovered.

Our study makes an important contribution to Web accessibility research. It informs what blind users observe and experience while performing an online task. This represents the first step in creating a user profile of this group of Web users about whom our knowledge is scant. This understanding is important to determine accessibility and usability requirements of the Web for the blind. Our findings have implications for accessibility and usability in the design of systems used for online assessment and interactive forms.

BLIND USERS' WEB EXPERIENCE

Blind individuals comprise a significant user group with distinct Web interaction requirements. For blind users, Web interaction is a sequential listening activity. This interaction is mediated by a screen-reader that interprets on-screen text and presents this aurally (Di Blas, et al. 2004) by reading pages serially from top left to bottom right (Leuthold, et al. 2008). All inputs are made exclusively through keyboard (Harper, et al. 2006). This interaction style has its distinct accessibility and usability needs (Bornemann-Jeske, 1996).

Web technology lacks accessibility and usability for the blind (Theofanos & Redish, 2003; Correani et al., 2004; Leuthold, et al. 2008; Kelly, 2008). Research shows that 80% of Web sites do not meet basic accessibility requirements (Loiacono and McCoy, 2004). Web sites that comply with such requirements still present access barriers for the blind (Correani et al., 2004). Objective evaluation reveals Web accessibility and usability has declined recently (Leuthold, et al. 2008). A lack of Web accessibility and usability creates more problems for blind users in completing online tasks (Correani, et al. 2004).

Most researchers believe that blind users' accessibility and usability problems stem from the graphical user interface (GUI) (Franklin and Roberts, 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 graphical information to the user (Leuthold, 2008). These studies ignore a blind user's experience of the problem. This knowledge is needed for understanding the nature of the problem. Research that examines blind users' online experience informs that non-visual Web interaction suffers from following constraints:

1. Serial nature of interaction means at any moment, users perceive a snippet of the content, losing all contextual information (Lazar, et al. 2007).
2. Inability to quickly scan page means users have problem locating goal-relevant information (Di Blas, et al, 2004).
3. Complex page layout makes screen-reader's feedback ambiguous (Lazar, et al. 2007). This, along with screen-reader mispronunciations, make comprehension difficult for the blind (Theofanos & Redish, 2003).
4. Innumerable screen-reader commands are difficult to remember or use during Web interaction (Theofanos & Redish, 2003).
5. As a listening activity, Web interaction is a cognitively burdensome task (Millar, 1994; Thinus-Blanc & Gaunet, 1997).
6. These represent only glimpses of the problem. These do not tell us where and why such users face problem during Web interaction. This kind of knowledge is needed to understand the nature of the problem (Foley, Wallace, & Chan, 1984).

WEB ACCESSIBILITY AND USABILITY EVALUATION CRITERIA

In this section, our goal is to develop a set of evaluation criteria that helps us characterize a problem. The Web Content Accessibility Guidelines provide four principles of Web accessibility. We begin by discussing how we intend to use WCAG's principles to characterize a blind user's accessibility problems in Web interactions. HCI scholars have proposed several usability principles. We identify usability criteria to characterize a blind user's problems in Web interactions.

Web accessibility criteria

WCAG is the de facto standard on Web accessibility established by the World Wide Web Consortium (W3C) (Kelly, et al. 2005). Its current version (WCAG 2.0) became operational in December 2008 (http://www.w3.org/TR/WCAG20). This includes a hierarchy of 4 guidelines and 18 checkpoints. The guidelines – perceivability, understandability, operability and

robustness represent four principles of accessible Web design (Kelly, et al. 2007). In the context of non-visual Web interaction, these principles recommend:

1. Perceivable: A blind user can perceive a Web interface element;

2. Operable. A blind user can operate an interface Element;

3. Understandable: A blind user can understand all content and controls; and

4. Robust: Screen reader can interoperate with every interface element.

Web **Usability** criteria

In this study, we adopt 10 usability principles proposed by three renowned usability experts: Jacob Nielsen's (1993) Web usability criteria, Donald Norman's (1988) principles of good design and Ben Shneiderman golden rules of interface design (Shneiderman & Plaisant, 2004). These principles include:

1. Learnability. First-time Web site users quickly find information and use functionality.
2. Efficiency. Users accomplish tasks quickly and easily after learning the site.
3. Errors. Users are prone to commiting few errors and quick recovery from these.
4. Satisfaction. Users are satisfied with how the website works.
5. Memorability. Returning users don't have to relearn how to use the site.
6. Visibility. Users detect system state and alternatives for action by observing it.
7. Good mappings. Users determine the relationships between actions and results, between the controls and their effects, and between system state and what is visible.
8. Feedback. If users receive full and continuous feedback about the results of actions.
9. Consistency. Action sequence is consistent in similar situations; labeling, order and effects of user interface elements are consistent.
10. Working memory load. Displays are simple, multiple page displays are consolidated, and window-motion frequency is reduced.

We use the conceptualization about 4 WCAG accessibility guidelines and 10 usability principles to understand the character of a blind user's problem in Web interactions .

METHODOLOGY AND RESEARCH DESIGN

Participants for this study include six blind individuals, with an average age of 23 years, registered with an institution of special education for the blind. These institutions allowed us to use their computer labs for the study. Each participant had at least 5 years experience using the Web with Jaws screen-reader. None of these participants had ever used a learning management system, or other online assessment tools.

We employed verbal protocol analysis (VPA), in which participants think aloud while performing a task (Ericsson & Simon, 1984). Audio-recordings of participants' verbalizations comprise contextually-rich qualitative evidence of their experience with a system. A space of possible encodings representing task-relevant information is defined a priori (Todd & Benbasat, 1987). Audio-recordings are transcribed, and broken down into single units of thoughts – segments. Each segment is encoded by identifying the category that expresses the same information (Ericson & Simon, 1984).

We developed a coding scheme derived from the Seven-Stages of Action Model (Norman, 1988). It comprised seven categories - goal identification; intention formation; plan of action; execution ; perception of system state; interpretation; and goal accomplishment (Norman, 1988). We introduced two sub-categories in interpretation – consonance and dissonance (Festenger, 1957) and two sub-categories in goal accomplishment – failure and success. Segments labeled as dissonance and failures represent problems faced by participants during the task. Our coding scheme is data-driven; it evolved from analysis of evidence from our pilot study with two blind participants.

We designed a representative assessment task using the Test Manager functionality of the Blackboard LMS. We placed a link to the assessment on the "Assignments" page. This link takes a user to a second page with direction to begin the assessment by clicking Okay. The subsequent three pages present a question each in three different formats. These include multiple-choice, multiple-answer, and short-answer questions – three most commonly used formats. Participants began by reading a set of instruction about logging on to Blackboard, and completing the assessment while concurrently verbalizing. Audio-recordings of these verbalizations, along with screen-reader's speech output helped us capture participants' thoughts and actions. We transcribed the audio-recordings into a rich set of qualitative evidence. We decomposed participant's verbalizations into single units of thoughts or segments. We then categorized each segment according to our coding scheme.

We examined coded verbalizations, along with screen-reader's speech output, to understand where and why our participants faced accessibility and usability problems during the task. Our primary focus was on examining segments suggestive of dissonance or failure. Segments in other categories provided contextual information, and helped us gain a holistic understanding of a problem.

FINDINGS AND DISCUSSION

Our analysis reveals two aspects of Web design that create accessibility and usability problems for blind users in online assessments. Table 2 presents a summary of our findings. In subsequent subsections, we discuss each problem in detail.

Table 2. Summary of findings [(u) =Web Usability principle; (a) Web accessibility principle]

Problem from User's Perspective	Concerned Aspect of System Design	Design Principle Violated	Possible Remedies
I. Inability to construct a consistent mental model about answering multiple-option question	Inconsistency between user action for submitting an answer and its resultant effect	Consistency (u) Memorability (u) Good Mapping (u)	Provide system response consistent with user action
II. Cognitive overload in dealing with short answer question	Bad mapping of formatting controls to their effects	Efficiency (u) Satisfaction (u) Good Mapping (u) Working Memory Load (u) Understandability (a)	Provide meaningful labels to formatting controls

I. Inability to construct consistent mental model about answering multiple-option questions.
Analysis reveals that blind users observe inconsistent system response when answering questions with multiple options. This type of system behavior gives rise to a conflict between user's prior cognition and present observation, resulting in cognitive dissonance (Festenger, 1957). Users feel the need to modify their mental model about answering multiple-option questions. However, repeated dissonance hampers construction of a mental model consistent in multiple instances of this type of question. Users must relearn how the system works in every instance of use. This creates problem in the form of extra steps or cognitive load (Norman, 1991).

The problem is a result of one-to-many correspondence between user action for submitting answer and system response. This represents violation of good mapping principle (Norman, 1988), that requires a system to assist the user in mapping an action to its outcome. Lack of mapping means users must relearn navigating out of multiple-option questions in every instance. This violates memorability principle (Nielsen, 1993), that requires users need not relearn system functionality and navigation items. This is also a violation of consistency principle (Shneiderman & Plaisant, 2004), that requires sequence of user action is consistent in similar situations.

Generally, questions are submitted by activating "Go to Next Question" button on the navigation bar. Sometimes, users can achieve this by pressing Enter on radio button or checkbox corresponding to an option. However, evidence shows that this action sometimes brings up the previous question. To illustrate this inconsistency, we present evidence of S4's experience. S4 hits enter on a radio button corresponding to an option with the goal of answering Question 1. She hits enter again on the selected radio button, this time with the goal of moving to Question 2. The system changes, and brings up the subsequent question. She uses this observation to create a mental model of answering multiple-option questions. According to this, selecting options and submitting answers can be achieved by hitting enter on an option. In Question 2, she hits enter twice on an option with the goal of moving to Question 3. Instead, the system takes her back to Question 1. She gets confused, believing she must have committed an error. Table 3 presents evidence of S4's experience of dissonance.

Table 3. Dissonance experienced by S4

Activity	Verbalizations
Answering Question 1	66: So how do you select...? 67: I'm gonna say you Enter on the one that you want 68: I mean I don't know but I'm gonna try it well. 71: I got it 75: but now, I cant get to the next question 76: Maybe try … Enter? 77: Whoa. (Hearing "Forms mode off. Enter. Out of table") 78: Yes! (Hearing "Confirm question...").
Answering Question 2	163: The answer to...two 164: I think it's that one 165: So I'm gonna do Enter 166: Ah! So I checked that one 167: Alright 170: Then Enter again 171: Oh. (Hearing "Question one of three") 172: Question one. (Responding to "What question are you on?") 173: I need to go to the next — go to question three. 174: Wait. No. 175: I Entered on something I shouldn't have. 176: Go up 177: Well, I went to question one, and I'm tryna get to three.

This problem can be avoided if Web applications are designed for one-to-one correspondence between user action and system response under similar situations. Consistency in presentation of operations and results is important for all users. It is particularly important for blind users who have to memorize hundreds of key commands to carry out operations. If similar operations can be carried out with a single key command, blind users will have more cognitive resources available for decision making.

II. Cognitive overload in dealing with short answer question.

In short-answer question, participants experienced cognitive overload due to a group of text formatting controls interspersed around the input field. They felt disoriented and confused, unsure how to use these in answering the question. One participant confused these as possible answers, just like a multiple-option questions. In general, participants found these controls very distractive, forgetting the question before arriving at the input field. We present evidence of this problem in Table 4.

Table 4. Confusion associated with formatting controls

S1's confusion about the formatting controls	47: I don't understand what this is. 48: I don't really understand what's going on with this part of the question,

	with the internet.
	49: I don't understand why it's saying a whole bunch of superscript, numbering, bullets, indents
S3's confusion about formatting controls	121: Skip visual text box edit buttons
	122: What in the world is this?
S4's confusion about link "Expand"	278: I think expanded is one of the answers
	284: I'm gonna Enter on it.
	289: Gosh!
	290: What the world
	291: I think it was an answer
S5's confusion about the link "Expand"	50: looking at, I am at question 3, and it says expanded.
	51: I think that will allow me to input information.
	52: Pushed the enter key,
	53: Opens up the forms.
	54: Doesn't tell you that.

Evidence shows that this confusion arose as a result of difficulty mapping these controls to their effects. A link called "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. The system provides a link labelled "Skip Visual Text Edit Buttons" to allow the user jump over the proceeding formatting controls. None of our participants used this feature although it could have reduced the problem somewhat. Probably they did not find the label intuitive. If labeling is not intuitive, blind users fail to recognize the purpose of the link, particularly if they are unsure what lies ahead (Leuthold, et al. 2008; Theofanos & Redish, 2003).

Problems due to these formatting controls represent violations of several accessibility and usability principles in LMS assessment environment. These violations are:

a. Efficiency – Participants were unable to answer the question quickly (Nielsen, 1993);
b. Satisfaction- Participants were not happy due to the confusing nature of this aspect of LMS assessment environment (Nielsen, 1993)
c. Good mapping – Participants had difficulty determining relationship between formatting controls and their effect (Norman, 1988)
d. Working memory load – The large number of formatting elements made it difficult for the participant to remember the question (Shneiderman & Plaisant, 2004)
e. Understandability – Participants were unable to understand the purpose of these controls (WCAG, 2008)

This problem can be reduced or eliminated if more meaningful labels are provided, and placing these controls beyond the input area. If blind users observe an input field after question text, they can relate it to a location for providing response. After typing a response, users would look for a button to submit the answer. This can be considerably easier for blind users.

CONCLUSION

The purpose of our study is to develop an understanding about the nature of accessibility and usability problems blind users face during Web interaction. These users interact with Web sites and Web applications to perform a task for achieving some goal. Accordingly, we adopt a task-oriented approach to discover where and why these users face difficulty completing an online task. The context of our investigation was online assessment – a common task in today's academic environment.

We employ verbal protocol analysis to collect evidence of problems 6 blind participants observed and experienced completing a representative assessment over the Blackboard. Our analysis reveals four aspects of Web design that presents accessibility and usability problems for the blind in an online assessment. These problems represent violation of good design principles in multiple ways. The four problems include:

Blind users have difficulty ascertaining their arrival on a new page of an LMS. This is because they receive a feedback about link activation that is inconsistent with their mental model. This accounts for violation of two usability principles – consistent feedback and satisfaction of use. A possible remedy is to program the LMS such that the feedback associated with link activation is complete and consistent with blind user's mental model.

Blind users are susceptible to skipping an assessment question without realizing. This error is induced by positioning of cursor focus on the navigation bar on moving to a new question page. This accounts for violation of two usability principles - error avoidance and visibility. This also accounts for violation of an accessibility criteria that requires providing context and

orientation information. A possible remedy could be to position the cursor focus at the question text on moving to the new question page.

Blind users fail to construct a consistent mental model about answering multiple-answer questions. This happens because of inconsistent system response to user action to submit an answer. This problem reflects a violation of usability criteria including consistency, memorability, and good Mapping. The solution would be to bring about a one-to-one correspondence between user action and system response.

Blind users experience high cognitive load in short-answer questions. This is a consequence of their inability to map formatting controls to their effects. This violates usability criteria like efficiency, satisfaction of use, good mapping, and working Memory Load. It violates accessibility criteria of understandability. This problem can be avoided or reduced by providing more meaningful labels to the formatting controls that communicate their purpose clearly.

The solutions we suggest may be evaluated in future research through an experiment. These findings have implications for design of Web systems used not just for assessments, but also for similar purposes including interactive forms and questionnaires.

Our study makes two important contributions. First, it informs what blind users observe and experience while interacting with online assessment environments. This represents the first step in creating a user profile for this group of Web users, about whom we hardly know anything. This kind of understanding is fundamental to determine accessibility and usability requirements of the Web for the blind. A second contribution of our study is a very effective and feasible technique for subjective evaluation of Web accessibility and usability for the blind. It demonstrates how to trace accessibility and usability problems from blind user's perspective, and characterize these with the help of extant design principles.

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APPENDIX

Screen shots of various steps in completing the assessment task on the Blackboard course management system

Figure 1. Step 1: The user finds the Web Accessibility Quiz under the Assignments section of Blackboard

Figure 2. Step 2: The user begins the quiz by activating the "OK" button
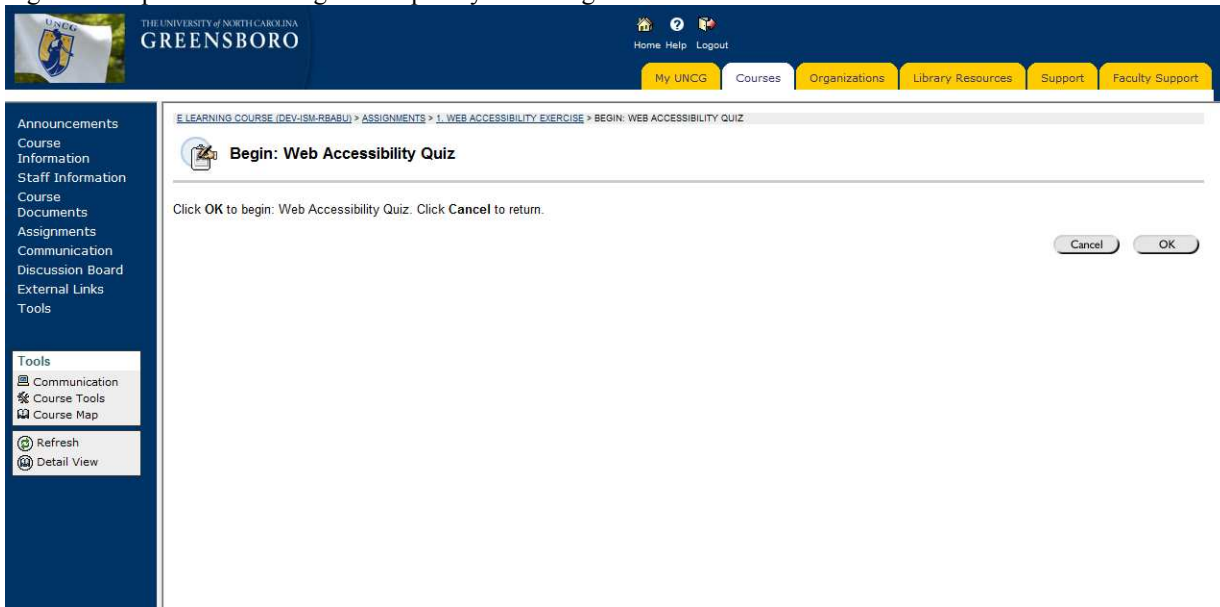
Figure 3. Step 3: The user arrives on the page with the first question
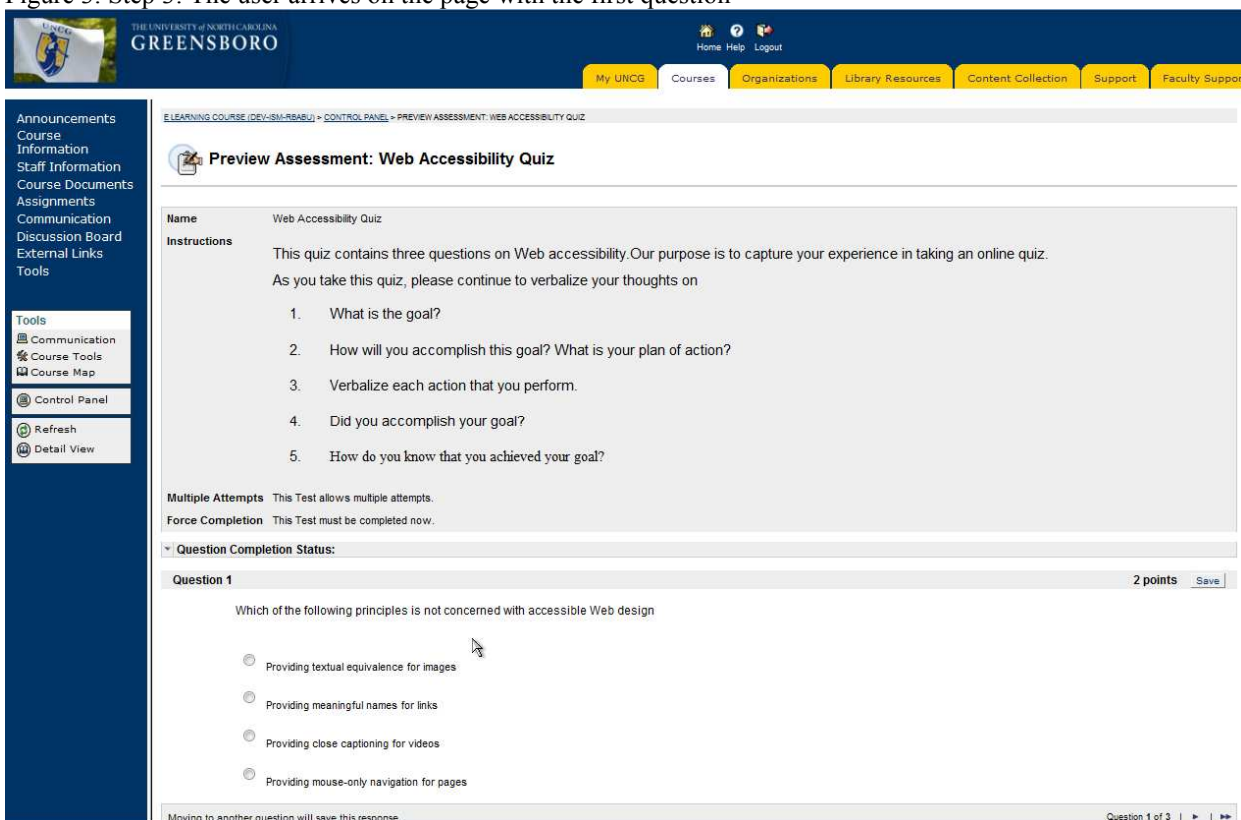
Figure 4. Step 4: The user moves to question 2 after confirming response for question 1.

Figure 5. Step 5: The user types in a short essay response and submits the entire quiz for assessment.