ISSUE 109, June 2014

Accessibility and Computing

A regular publication of the ACM Special Interest Group on Accessible Computing

A Note from the Editor

Dear SIGACCESS member:

Welcome to June 2014 SIGACCESS newsletter. The first article in this issue presents collaborative work by Ravi Kuber, Shaojian Zhu, Yevgeniy Arber, Kirk Norman and Charlotte Magnusson that uses geomagic touch haptic devices to improve the non-visual Web browsing process. The second article by Nic Hollinworth, Kate Allen, Gosia Kwiatkowska, Andy Minnion, and Faustina Hwang discusses a project that engages people with learning disabilities as co-designers in the development of interactive sensory objects. The third article presents the work of Dr. Stephanie Ludi to improve access to math and science lecture material for visually impaired students.

Jinjuan Heidi Feng and Hugo Nicolau

Newsletter editors

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Augmenting the Non-Visual Web Browsing Process using the Geomagic Touch Haptic Device

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Abstract

In this article, we describe an extension to a web browsing tool, designed to support individuals who are blind. The user is able to explore web-based content using the Geomagic Touch device. Both haptic and speech-based cues are presented when alighting over objects (e.g. images, hyperlinks, buttons and textboxes/textareas), replacing much of the structural information which can be difficult to obtain via a traditional screen reader. Findings from an observational study suggest that the tool offers promise to assist users with mapping the layout of objects on a web page. However, further refinements are needed, particularly when encountering smaller-sized objects located in close proximity to one another. In terms of future work, we aim to evaluate the tool with blind web developers who design for sighted audiences, or who work in teams with sighted developers, to determine whether the solution can support target users within the work environment.

Introduction

Although awareness regarding the importance of accessibility has increased in recent years, the process of using a screen reader to browse the Web can still be challenging for individuals who are blind. Research suggests that web pages often contain inaccessible content that is expressed only visually (Borodin et al., 2010). Furthermore, some content can only be accessed using a mouse, which can prove to be frustrating for screen reader users, who mainly use keystrokes for purposes of interaction. The sequential nature of information presented by screen readers can impact the user's mental representation of page layout. The result is that a web page is often visualized as a long sequence of text and objects (Murphy et al., 2008), rather than a range of objects spatially-distributed across the whole screen. While strategies are used to compensate for the constraints of screen reading technologies (Borodin et al., 2010), a need has been identified to replace the missing structural cues and augment the quality of the browsing process.

Haptic technologies have been developed to assist individuals who are blind to interact with graphical user interfaces (Ramstein et al., 1996; O'Modhrain and Gillespie, 1997). Force-feedback is presented to the user's hand as he/she navigates an interface, to communicate the presence of icons, menus and other objects. The feedback enables users to develop an understanding of the layout intended by the designer.

In this article, we describe the design and early evaluation of a haptic web browsing tool. Through a series of iterations, it is envisaged that the tool can provide the assistance needed when performing tasks which are difficult or not possible when using a screen reader.

Related Work

Haptic technologies offer considerable potential to augment the web browsing process. Examples include the 3D environment described by Kaklanis et al. (2010), where haptically-enhanced widgets (hapgets) have been mapped to HTML objects. The solution enables the user to navigate freely around the interface, to obtain an overview of content. Todd et al. (2012) describe the development of a browser, developed using C++, Ogre 3D and various other libraries. HTML code is first extracted using libcurl, and then parsed to extract valid tags within the system. When objects are detected, force-feedback is presented to the user's hand using a low-cost haptic device. A range of test scenarios are described, relating to tasks commonly performed when accessing the Web. These include exploring images and selecting hyperlinks.

Arnab et al. (2011) describe a system where the user explores a 3D ancient city on a web browser using the Novint Falcon device. Haptic cues (e.g. textures, stiffness, friction) are applied to objects, and the user is able to discern between effects presented to map the layout of the virtual environment. Comai and Mazza (2010) suggest that force feedback could be used to provide the user with additional awareness of the function or purpose of objects on a page. For example, the association of 'sticky' feedback with a textbox makes it slightly more difficult for the user to leave that area of the page. This is thought to indirectly convince the user to enter data into the box.

In order to extend our previous work (Kuber et al., 2011), we have focused on developing a solution to enable blind users to explore the layout of web sites using the Geomagic Touch (formerly known as the Phantom Omni device). The tool can be accessed in conjunction with a generic browser (Internet Explorer) to explore live pages. In contrast to assistive tools which require users to access specialized browsers, our solution requires users to access the same browsing software as their sighted colleagues.

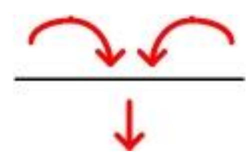
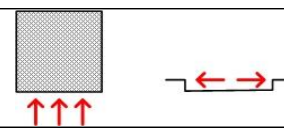
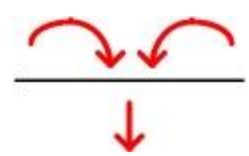
Extension to Browsing Tool

A haptic browser developed by Magnusson et al. (2006) has since been extended to better meet the needs of blind users. In the updated version, the user is able to explore the Web by moving the stylus associated with the Geomagic Touch device (Figure 1) around the interface, perceiving cues when alighting over the objects present on the screen.

Microsoft Active Accessibility (MSAA) has been used to obtain information about the actions performed by the user (e.g. when moving over text, or when moving over/selecting images, hyperlinks, buttons and textboxes/textareas). In the earlier version of the system, haptic cues were arbitrarily selected for integration with a web page (Magnusson et al., 2006). In the updated version, a larger range of effects have been integrated with the browsing solution. These mappings were developed using a participatory-based approach with blind web users to convey more meaningful information when using a force-feedback mouse to browse a web page (Table 1 (Kuber et al., 2011)). These were developed using the H3D API (www.sensegraphics.com). Speech is presented when hovering over text, using the Microsoft Speech SDK. Alternative text associated with images, and the names of hyperlinks are also outputted.

Figure 1: Geomagic Touch (formerly known as the Phantom Omni).

Table 1: HTML Haptic Mappings from Kuber et al. (2011)

Objects	Force-feedback mapping	Diagram of mapping
Hyperlinks	• A spring effect should be used to direct the user towards the relative center of a hyperlink. • Proportional horizontal and vertical springs should be used to direct the user to the relative center of a hyperlink. • A distinctive weak periodic wave effect to alert presence of a hyperlink.	
Images	• A slightly lowered enclosure effect should be used to encase the visual border of the image. • A distinctive strong spatial texture should be applied to the image's interior.	
Textboxes and Textareas	• A lowered enclosure effect should be applied to a textbox/textarea. This would allow the user to move into a box and explore its contents. • To indicate that the user has clicked inside a box, a periodic wave can be used to provide a slight nudge.	
Buttons	• To represent a button, a spring effect should be used to attract the user to the center of the object. • Proportional horizontal and vertical springs should be used to direct the user to the relative center of a button. • No further sensation is required to represent the body of a button.	

Study Design

An evaluation study was conducted to determine whether participants could identify objects, their location, and their proximity to other objects on the interface. Due to the exploratory nature of the study, five blindfolded sighted participants and one congenitally blind participant were recruited. No participants had previous experience of using the Geomagic Touch device.

Each participant was given 15 minutes of training, enabling them to familiarize themselves with using the Geomagic Touch device and interact with the haptic cues described in Table 1. 12 web pages were developed for purposes of the study. Each page contained between 2 to 3 objects, randomly positioned within different regions of the page. Each participant was asked to explore two of these pages. They were asked to position themselves at the starting point (top left of web page), and given three minutes to explore the content while describing the layout. Participants were then asked to diagrammatically represent the layout of the page on a piece of paper. The diagrams were examined to determine whether objects were correctly identified and whether these were positioned correctly.

A grid containing six equally-sized regions was placed on top of each diagrammatic representation (Figure 2). If objects were drawn inside the same region as the physical web page, a score of 1 was awarded to participants. After completion of the task, a questionnaire was presented to solicit opinions on the cues presented, and whether improvements could be made to augment the browsing process.

Results and Discussion

After exploring each of the web pages presented, participants were able to describe the layout of content and represent the layout of each page in diagrammatic format. Findings showed that when using the solution, an awareness could be developed of the spatial relationships between the objects on each page. 19 out of 30 objects were identified correctly, and positioned in the appropriate regions on the diagrams. Hyperlinks (M: 66.6%) and textboxes (M: 71.4%) were identified with the greatest levels of accuracy. Participants suggested that the magnetic effect associated with the hyperlink was noticeable as it assisted the process of targeting, while the border of the textbox alongside the nudging effect provided enough information to differentiate it from other mappings.

Participants did not always explore the entirety of each web page, often favoring to focus on a specific part of the page where content was thought to be located. This was often toward the middle-right of the page, where refreshable content is usually located on a web site. As a result, some objects were missed which may have contributed to the low rates of object identification. Furthermore, when moving quickly around the interface to gain an overview of content, difficulties were sometimes faced perceiving cues. This appeared to be a challenge when objects were smaller in size and located closely to one another on a page.

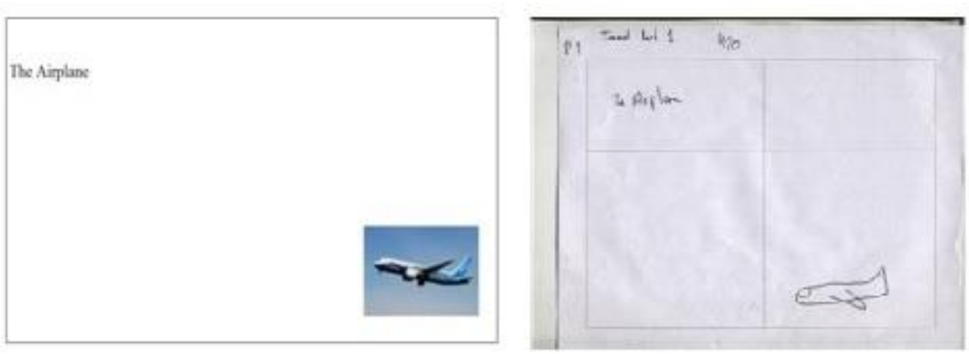


Figure 2: Task including web page to explore (left) and diagrammatic representations of content from participants (right).

Results from the congenitally blind participant were the most encouraging. Although she had no previous experience exploring the Web using a haptic device, she attained a 100% rate of identification and positioning accuracy. She was observed making small controlled movements across the interface, using reference points such as the edges of the browser to help conceptualize the bounds of the web page. The participant was able to recount experiences of where more details relating to the layout of information on a page, would have helped her when performing tasks such as purchasing tickets online. Due to inappropriate coding of web forms, it can be difficult using a screen reader to identify whether secure information (e.g. credit card numbers, passwords) have been entered in the correct textboxes, unless the textboxes associated with the form have been labeled appropriately. The haptic tool could play a role in supporting form entry to reduce input errors.

Design Implications

• Haptic feedback was found to be too subtle, particularly for identifying objects such as images. As a result, a stronger border effect will be implemented. Sjöström (2001) suggests that the user almost always loses contact with the object when moving past a sharp corner. Additional support would need to be provided for corners, possibly through the use of magnetic effects or through the assistance of auditory feedback.

• When moving quickly over a series of objects located in close proximity with one another, difficulties are faced as effects may be occluded from presentation. More time will be spent in training the user to make slow, controlled movements to better conceptualize the layout of content on the page. This issue is not unique to one type of input/output device. It was also identified in our earlier studies when performing browsing tasks using a force-feedback mouse (Kuber et al., 2011). Researchers suggest that enlarging the interaction point can maximize the chance of identifying objects (Sjöström, 2001). However, presenting too many effects within a small section of a web page may also create challenges.

Conclusions and Future Work

In this article, we have described an extension to a browsing tool, developed to support blind users when exploring web-based content. After refining the application to address the issues identified in the study, the next logical step would be to evaluate the solution with a larger sample of blind web users, to better determine the efficacy of the tool. Participants would be asked to access busy pages containing distracters, and complete a series of tasks which are difficult to perform using existing assistive technologies (e.g. filling out forms).

Future work would also address ways to support blind users in the work environment. Research suggests blind web developers encounter difficulties when attempting to check the layout of content when prototyping on-the-fly, or when working in teams with sighted developers (described in Norman et al., 2013). We aim to identify whether our solution which synchronizes the presentation of visual and non-visual feedback, can be used to augment the quality of the collaborative design and prototyping processes.

Additionally, we aim to examine the ways in which haptic feedback can be used to augment web interaction when using touch screens. Although the recent development of touch screen readers (e.g. VoiceOver for the iPhone and TalkBack/Explore by Touch for Android devices) allow users to explore spatial arrangements, further support is needed to maximize interaction potential. Preliminary studies within this area (e.g. Poppinga et al. (2011)) indicate that further research along these lines would be fruitful.

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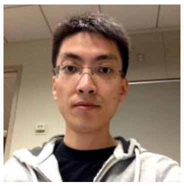

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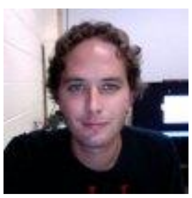

Kirk Norman works as a usability researcher. He is currently pursuing an MS degree in Human-Centered Computing at UMBC. His research interests include developing accessible interfaces and gaming technologies.

Charlotte Magnusson is an Associate Professor at the Department of Design Sciences, Lund University. Charlotte currently has two particular areas of interest. The first is concerned with non-visual interaction design and how senses other than the visual, can be used in applications and services. The second is design and design methodology for persons with and without disabilities.

Interactive Sensory Objects for and by People with Learning Disabilities

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Abstract

This project engages people with learning disabilities as co-researchers and co-designers in the development of multisensory interactive artworks, with the aim of making museums or heritage sites more interesting, meaningful, and fun. This article describes our explorations, within this context, of a range of technologies including squishy circuits, littleBits, and easy-build websites, and presents examples of objects created by the co-researchers such as "sensory boxes" and interactive buckets, baskets, and boots. Public engagement is an important part of the project and includes an annual public event and seminar day, a blog rich with photos and videos of the workshops, and an activities book to give people ideas for creating their own sensory explorations of museums and heritage sites.

Introduction

"Hands-on exhibits bring a space to life, giving a greater understanding and meaning to cultural heritage. This is especially important for people with learning disabilities."

(Lord Rix, President of Mencap, 2005)

The experience of handling artworks enormously enhances our understanding of cultural heritage, and this is especially so for people with learning disabilities. For this group, hands-on experience of cultural objects can be an important approach in promoting an understanding of cultural heritage, and in response, many museums and heritage sites have established 'handling collections'. Yet there are many drawbacks. The materials made accessible to people with learning disabilities as substitutes for the originals are usually chosen by the curators rather than determined by the user group; many materials are deemed by curators too delicate to be handled by the user group; and in some heritage sites, access to the objects is limited because of the complex nature of the site's environment, and the character of the handling collection is sometimes limited to pictures in books.

"Interactive Sensory Objects for and by People with Learning Disabilities" is a three-year (2012-15) research project funded by the UK Arts and Humanities Research Council. The aims are:

- to engage people with learning disabilities as co-researchers in the design of interactive multisensory objects that replicate or respond to museum collections
- to explore what improvements to access and engagement with heritage and museum displays can be achieved for people with learning disabilities, through the use of multisensory objects
- to explore to what extent the experiences of people with learning disabilities can influence the provision of multisensory objects and interactive technologies in museums and heritage sites for the general public

The project brings together artists, human-computer interaction researchers, experts in multimedia advocacy, and people with learning disabilities as co-researchers in the design of multisensory objects that can enhance the museum or heritage site experience. Over the course of the project, we explore the collections at three sites: Speke Hall, a Tudor manor house and a property of the UK's National Trust; the Museum of English Rural Life (MERL), a museum of the University of Reading; and the British Museum which houses one of the world's largest collections of world art and artefacts. We are working with three groups of co-researchers: Mencap Liverpool Access to Heritage Forum, a group set up in 2005 to identify what could be done to make interpretation at heritage venues accessible for people with learning disabilities; Reading College students from the Learners with Learning Difficulties and/or Disabilities department; and the Tower Project, a community-based voluntary sector organization providing a range of services to disabled residents in East London.

Explorations of Technology in Multisensory Workshops

Central to the project is a series of multisensory art workshops, where our co-researchers explore how the different senses can be utilised to augment existing museum artefacts or to create entirely new ones [1]. The workshops are fundamentally experimental and exploratory in character, and this includes investigating the role and use of technology by co-researchers in the research and design process [4].

We aspire to engage our co-researchers in as many stages of research as possible, for example, analysis, design, creation, and reflection, so that their individual experiences and knowledge can be included throughout the research process. To do this, we use a variety of complementary methods within the workshops to support conducting the research and communicating the findings.

People with learning disabilities often have difficulties in communicating their likes and dislikes effectively and without bias from other individuals, so one of the methods we adopted for the workshops was the use of Polaroid cameras (See Figure 1). They were used to take photographs for capturing and communicating preferences, and to photograph which objects from a museum collection were most appealing. The ability to capture the image quickly and to watch their creation develop in their hand was exciting to the co-researchers, and having a physical photo to hold and show to others was important to them. At the end of the photography session, the photographs were laid out on a table, and the co-researchers collaborated by adding smiley stickers (either a smile, neutral or frown) to indicate which object(s) were their favourites. These were then arranged in order to see which objects in the museum were overall favourites for the entire group.

To support reflection about the sounds in a museum and enable the communication of personal preferences, we developed a "sound player" (the small rectangular box with a rotary knob shown in Figure 1) that is designed to be easy for all to use, with little or no instructions. The sound player is pre-loaded with audio files, and a sound can be selected with a dial and played back with a single press of a large button. These devices were used as part of a museum tour, which got the co-researchers thinking about what sounds the items in the museum would make and what sounds they would want their own interactive objects to make.

Figure 1: Two co-researchers from Reading College using a sound box and Polaroid camera. Stick-on smiley faces indicate a preference for a particular image - the more smilies, the greater the preference.

We wanted our co-researchers to appreciate that they could design interactivity into their artwork themselves. We introduced technology to the group in stages, with goals of illustrating to them what was possible in terms of making objects interactive and responsive, empowering them with methods to explore and experiment with a range of methods, and to make and communicate about their own designs.

At both Speke Hall and MERL we began with Squishy Circuits [8] to construct simple electric circuits using conductive dough, batteries, buzzers and LEDs (see Figure 2). The group found the dough very easy to work with, and quickly started making and experimenting with triggering actions.

Figure 2: Co-researchers at Speke Hall and MERL using Squishy Circuits.

As a next step in encouraging autonomy in experimenting with technology, we experimented with littleBits, an electronics kit [8] which consist of small electronic components (a bit like Lego) which snap together with magnets. Our co-researchers really engaged with the simple design and magnetic connections of the kits, but we found that the size of the pieces could sometimes be a problem for our co-researchers, many of whom have limited motor control or manual dexterity. We customized the littleBits components so that they sit on a larger base, which is designed to be more accessible for our co-researchers (see [4]). This work was recognized with an International Design for All Foundation Award 2014 [3].

To capture our co-researchers' reflections, experiences and findings at various stages of the research, we use the inquiry-based, action research method Multimedia Advocacy [7]. Through the use of images, videos, sounds, text and the Talking Mats philosophy we were able to capture thoughts and reflections from most of our co-researchers including those with complex communication needs. Easy Build wikis, a Web 2.0 platform [5], enable our co-researchers to record their thoughts and experiences using pictures, sounds, video and text, and to organise this information on their personal, password protected wiki website. This aids reflection, reinforces memories, and communicates the co-researchers' views.

Interactive Sensory Objects

The creation and design aspects of the research produced a variety of interactive sensory objects. In the first year of the project, co-researchers from Liverpool Mencap Access to Heritage Group developed a "sensory box" as their personalized interpretation of Speke Hall. The idea was that they could send their box to someone who had never visited, thereby sharing with them their sensory version of visit.

The sensory boxes were created over multiple workshop sessions, and included a range of materials (e.g. photographs, fabrics, sticks, stones, biscuits, clay models, soaps, and spices), combined with digital media (e.g. lights and sounds) triggered by electronics.

Figure 3 illustrates one of the boxes created by one of the co-researchers. She has a visual impairment, and in her box she used flickering LED lights that were bright enough to be seen by her as a fire effect. Her box also contained a drawing she had made of the textures of carved wood she had felt, and the sound of clocks ticking and chiming. The sounds were recorded in the Hall using a hand-held sound recorder, and transferred to a microcontroller which was used to trigger the sounds and light.

A box created by another co-researcher focused on the sounds of creaking doors in the Hall. He designed his box to trigger the sound of a creaky door when you lifted the flap of the box. It also contained a selection of soaps and spices to produce smells that he described as "the smell of the middle ages".

Figure 3: A co-researcher demonstrating her "sensory box" which houses a collection of images, textures, smells and sounds that represent her experience of Speke Hall.

In the second year of the project at MERL, we focused on objects that related to the items on display in the museum, and which were based upon English rural life with a focus on farm machinery. Instant cameras were used to find out what took our groups interest, and we introduced ideas of farming and farms through sensory materials, though singing Old Macdonald and by eating a farmer's lunch. For the latter, we asked our co-researchers to consider how the food they were eating was produced.

Continuing the idea of using some kind of container similar to the boxes of Speke Hall, we asked our co-researchers to build artworks using buckets, boots and baskets. One of our co-researchers covered a wellington boot in faux cowhide and painted a picture of Old Macdonald on it, inspired by singing the song. She was very keen on making the sounds of a cow mooing and wanted the boot to respond by making the sound of a cow when it was handled. The prototype of the boot is shown in Figure 4. Using this design, we built a prototype of the boot and added the necessary electronics (contact microphones, a pressure sensor, and microcontroller with sound device) to the boot so that it would moo when the sides of the boot are stroked or when the toe is squeezed. This was tested out on the group to see their reaction, with a view to modifying it where necessary.

Another example is a chicken in a basket which clucks and flaps its wings when an observer moves close to it. The chicken was made by one of the co-researchers and the research team created the mechanics and added the electronics. Other examples of sensory objects that were co-designed during the workshops are: a grass-covered boot that plays rural sounds (e.g. the sound of a tractor) when picked up, pressed, or moved around; a range of buckets containing co-researchers' interpretations of pigs, other farm animals, and even a golf course. We also created a portable "herb in a boot garden" that visitors could smell and taste in the museum

Public Engagement

Public engagement is an important part of the project, and from the project's outset, we had planned several strands of activity.

Open events and seminars

We host an open event at each site, where members of the public can meet the co-researchers and interact with the sensory objects as part of their museum visit. It provides an opportunity for the co-researchers to present their work to the public. At our first event, "Sensory Stories", a one-day event held at Speke Hall in Spring 2013, our group fully-embraced this opportunity and their pride in their work was clear. Additionally, the event was attended by people with a wide range of disabilities, and provided an opportunity for us to see how the interactive objects influenced their visitor experience.

We also host a seminar day which has a more structured programme of talks and activities, and is an opportunity for us to share and reflect on our work with an audience including museum curators, academic researchers and disability experts. Our first seminar was called "Sensory Stories Retold," held at the Museum of Liverpool. We had approximately 60 delegates, and the day provided lively and helpful discussions about the project's impact in its initial year and the future direction of research.

In June 2014, we will host a "Buckets, Baskets and Boots" event at the Museum of English Rural Life, followed by the "Sensory Objects in Progress" seminar at the University of Reading. This year, our events will be part of Universities Week, which is a national campaign to increase public awareness of the wide and varied role of the UK's universities. Being part of this initiative has benefited the project in terms of additional marketing support.

Figure 4: Posters for our events in June 2014.

Project blog

Every session with co-researchers is reported on a project blog [9]. The webpage uses many pictures and videos and is written in clear language. The blog is regularly reviewed with the co-researchers, who seem to very much enjoy seeing themselves on-line. The blog also serves as a resource for staff at Reading College for working with the group outside of our project's workshops.

Book of Sensory Activities

We are in the process of compiling a book of suggestions and resources to help people create their own sensory expeditions to museums and heritage sites. The book includes a number of activities that have been tried and tested in our workshops, illustrated in friendly cartoon format. We are in the process of trialing the activity book with a group of co-researchers from Liverpool Mencaps' Access to Heritage group who were not involved in the original workshops. They are using activities from the book in visits to Sudley House, a Victorian merchant's house in Liverpool. They are reporting their findings in terms of the content, organization, and format of the book and feasibility of the activities (e.g. in terms of resources required), and we will revise and rewrite the book in light of their suggestions.

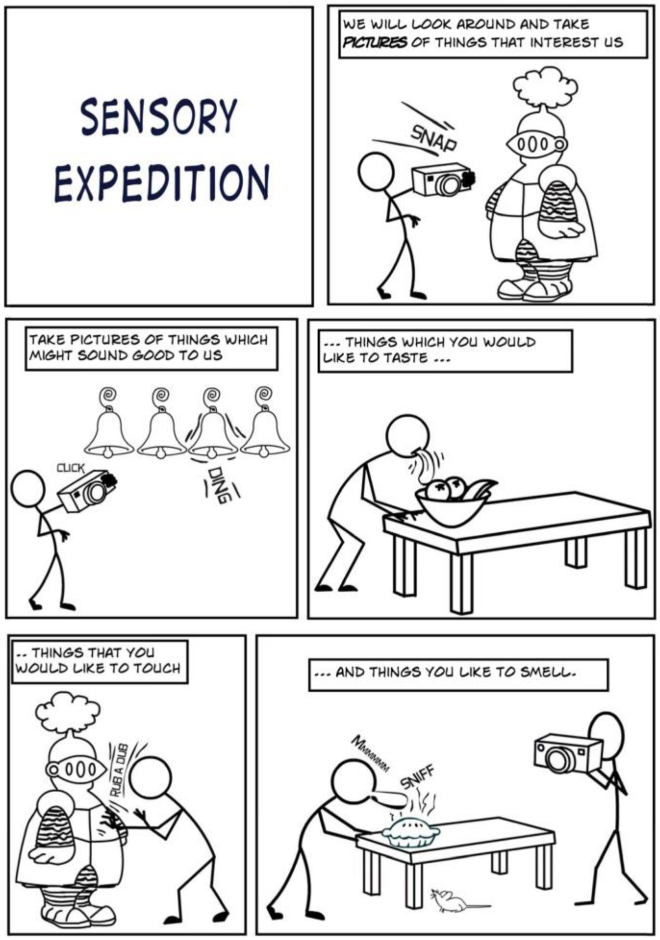

Figure 5: A page from our book of sensory activities.

Future Work

During the next and final year of the project we will continue to develop the book of sensory activities and to add new ideas for workshops. We would be very interested to hear from people who might like to be involved in trialling the book.

The focus of the project moves from MERL in Reading to creating responses to the Enlightenment Gallery at the British Museum in London. We will continue to develop tools to make electronics easier to handle and to understand, in particular, exploring how to make the functions of littleBits more obvious and how to make the controls on the bits larger. We are keen to create opportunities for our co-researchers to bring their own content into the museum by further developing our sound box to include an easy to use sound recorder, and making the whole device compatible with littleBits.

The objects created so far by the project have provided alternative perspectives to museum content, hence potentially shaping others' views and visitor experiences. In addition, these sensory art works become social objects that spark conversations, reflections and direct attention onto the objects rather than the individuals. This enables people with learning disabilities to be more meaningfully involved in the research process and to share their experiences and interpretations of museums and heritage sites.

Acknowledgements

This project is funded by the Arts and Humanities Research Council (AHRC), grant AH/J004987/1. We thank the Mencap Liverpool Access to Heritage Forum, Reading College LLD/D programme, the Tower Group, Speke Hall, Museum Of English Rural Life, and the British Museum. We also thank Ticky Lowe, Director of Making Sense CIC, and our project advisors. littleBits is a trademark of littleBits inc.

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Towards Improving Access to Math and Science Lecture Material for Visually Impaired Students via iOS Support: a Convergence of the Student, Instructor, and Classroom

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Abstract

In this paper we describe a series of exploratory studies conducted as part of the development of AccessLacture, an iOS-based system that is designed to help visually impaired students access math or science lecture material in and out of the classroom. The instructor writes material on the whiteboard, via the Mimio Capture system, using standard whiteboard markers. The lecture material is sent as written strokes that the iOS app displays for the student in real-time. Students can adjust the size and contrast of the material, as well as write notes on the lecture itself for later viewing. The access to lecture provided by the system provides students the ability to follow an active lecture that can facilitate more class participation. In order to support student needs, students, instructors and the classroom environment itself were studied.

1 Overview and Motivation

In a math course, the instructor typically writes on the board and refers to parts of the equations or diagrams as he/she presents the concepts to the class. The students then take notes and ask questions or engage in discussion in order to understand the material. The presentation also typically involves working through examples or homework exercises. The conveyance of the visual representations in conjunction with verbal elaboration or clarification make math courses particularly challenging to visually impaired students.

The bulk of research literature focuses on making math more accessible to blind students, whereas we are focusing on students who are visually impaired, having enough vision to read print that is adequately magnified. To make math more accessible, much research has been done on the creation of tactile or audio-based representations of material, including calculators and tablets that can be used for the study of math and science (Brown & Brewster, 2003; Bonebright et al., 2001; Davison & Walker, 2007; Gardner, 1999; TouchGraphics, 2011; Walker, Lindsay & Godfrey, 2004; Walker & Mauney, 2010). In addition representations of math in speech, haptics, and Nemeth code are studied (Rughooputh & Santally, 2009; Stanley, 2008). The preparation of materials using these techniques can be costly, time consuming and low vision students (who have functional vision) are more focused on visual issues such as magnification.

In American universities, many visually impaired students have a (paid) volunteer who serves as the note taker. The student may be enrolled in the course as well. The note taker provides the notes directly to the student after class or the student retrieves or downloads the notes from the university office that supports students with disabilities. In either case, the result is that students have to wait to get class notes until after class, when it is too late to ask questions during the course of the lecture. The instructor's oral presentation is then disjoint from the written notes. The student often misses or is at a disadvantage during in-class activities that are written on the board or the student may miss written reminders or announcements that are not spoken. The reliance on another student's notes is risky, due to the reliance on the quality and quantity of another student's notes. Some students may use a camera, or CCTV system, but these devices can take up valuable desk space, and can be awkward to follow lecture and take notes at the same time. Also, glare from the board or an obstruction can impact access to viewing the lecture material. The use of a handheld monocular can make the task of watching lecture through a small area and taking notes difficult. Students in middle school (typically ages 11-14) and high school (ages 14-18) have similar access to accommodations though note takers are less prevalent.

The AccessLecture project seeks to address the issue of access to the lecture material being presented on the whiteboard with low latency. Such access would not be limited to in-class viewing, whereby the student can use the system when studying outside of class. The display presents a single view of lecture material and notes, thus reducing the need for the student to shift focus between the board and their written notes.

Via the use of low-cost commercial Mimio hardware, the instructor's written strokes are displayed on the student's iPad. The iPad is portable and has many accessibility features that already make it a good platform for visually impaired students. The other key aspect of AccessLecture is easy set up for both student and teacher. The student need only start the app and connect to the class lecture shell for that day. The instructor set up of the Mimio Capture hardware simply involves affixing a small bar to the board with a magnet and slipping markers into their respective sleeves, allowing for writing to occur without altering the instructor's style.

A related project, Note-Taker, allows a low vision student to view (and record) a lecture as well as take notes (Black & Hayden, 2010; Hayden et al, 2011). The Note-Taker team designed a camera that enables a student to pan and zoom as needed in order to record lecture material. A PC Tablet-style laptop is used to view the video feed as well as take notes. The student can view notes and lecture material at a later time, or rewind lecture to help with an obstructed view of lecture material. We are taking a different approach to the user interface as well as the transmission of the lecture material as strokes sent via Mimio hardware. No issues with glare or obstruction exist. Note taker's camera and software adds contrast and color inversion capabilities. AccessLecture has these features built into the iPad app with low overhead (as is the case with Zoom) as well as the planned features that will enable searching for keywords within notes and across lectures (under the new AccessMath moniker).

2 Exploratory Studies of the Math and Science Classroom

Before the technical work began, the team conducted surveys with visually impaired students, interviews with math and science instructors at both the university and high school levels, and observations of math and science classrooms around campus. These initial studies allowed the team to gain perspective on user needs, experiences, and environmental contexts that need to be considered during system design. Additional information can be found in Ludi, Canter, Ellis & Shrestha, 2012.

Student Surveys

The population of visually impaired students is diverse. Visually impaired students are distributed in low numbers across diverse campuses in the United States. A survey was developed to capture their pre-college and university experience in Math and Science courses. The students' majors were not important given that each student would have had several pre-college Math and Science courses in order to be admitted to university and non-STEM majors require some college level Math and Science courses. This approach provided a wide view of the varied pre-college and university campuses that the students have attended. The online survey was shared with three geographically and socioeconomically diverse US universities, each with a minimum size of 15,000 students. Eleven students (ten being undergraduates) responded to the survey. The students represented a variety of majors including English, Mechanical Engineering, Psychology, and Computer Science.

The student survey revealed that most students own iOS devices, thus impacting the design choice for AccessLecture. In terms of class material access, it is not a surprise that students have difficulty discerning material written or projected onto the board. In order to access material written or projected on the board, students often use in-class note takers at the university level though electronic versions of materials are also used (when provided). Hand held magnifiers, enlarged print, and CCTV systems are also used by some students especially when studying outside of class or when handouts are given in class. In terms of trying a new system, respondents were interested but indicated that at portability is critical (e.g. lightweight, fitting in a backpack), that the system have a long battery life so as to last the school day. Also noted by respondents, especially in the context of pre-college classes is that the system should not make the student stand out from peers. It was also noted that in terms of student experiences, there were sometimes issues with working with an instructor in terms of gaining access to material or other accommodations (both at the pre-college and university levels).

Instructor Interviews and Student Perspectives

Interviews were conducted with eight Math, Science, and Computer Science instructors across the middle school, high school and university level. The student team members contacted their past instructors, in addition to other instructors that they located on departmental website's at those schools. The middle and high school instructors are from the Northeastern US, representing both urban/suburban and rural schools. Only a couple of instructors had experience working with one or two students with low vision over the course of several years.

Interviews were conducted either in-person or over the phone, depending on the instructor's preference. The structured interview focused on key areas of the classroom, use of technology, and presentation style in terms of an instructor's day-to-day experiences. The broad categories are noted in the left-hand column in Table 1.

The interview was structured via primarily open-ended questions to enable the instructors to elaborate on their style, preference, and experience. In addition to the structure of the learning environment, the constraints and factors that impact the students' learning experience in the classroom.

The classroom presentation of material is often dependent on the individual instructor's teaching style. Instructors were asked specifically about their teaching style while students were surveyed about the presentation of class material. Both perspectives were needed as part of user and task analysis, in order capture classroom instructor diversity across the many courses that instructors teach and that students are enrolled in over time. The results of the interviews are presented in Table 1, where pre-college and college results are categorized.

Table 1. Classroom presentation characteristics based on instructor interviews.

Factor	Pre-College Classrooms	College Classrooms
Use of Chalkboard or Whiteboard	The most common means of conveying class information	
Use of Technology	Some teachers use overhead projectors and document projectors, but most write on the board; Some science classes project diagrams; Use of interactive whiteboards is not common in most schools	LCD projects are the most common in order to display any PowerPoint slides or diagrams. Most material is still written on the board. Some Math classes do use PowerPoint slides, but that is not common.
Style of Instruction	Lecture is common; science labs are at designated times	Primary Lecture, labs/recitation are separate meetings; Some instructors have group activities during lecture
Type of Written Material	Textual material and drawn diagrams; Science courses contain more elaborate diagrams, including annotating projected diagrams	
Type of Information Written on Board	Course material, announcements, quiz/lab questions	
Classroom Activities, including Teamwork	When conducted, often integrated in class rather than a separate meeting; the exception of some science class labs	Some instructors have short in-class activities with partners or small teams during class, but many of the group-based activities are kept for special class recitation or lab meetings
Use of PowerPoint and Extent of Slide Sharing	When used, the slides generally not shared with students though instructors were willing to share them with low vision students	When shared, it was often on class websites; either before or after class; willing to accommodate low vision students

The team was surprised by the use of PowerPoint slides in a Math class in addition the fact that overhead projectors are still used in pre-college classrooms. While there were trends in how classes were run, an instructor's style had unique elements especially at the pre-college level. Regardless, nearly all instructors said they would accommodate the needs of students with visual impairments. This did not always match with the student perspective (surveys), but this can be explained by the fact that the instructors who participated in the interviews were self-selected.

Classroom Observations

In addition to eliciting information from student and instructor stakeholders, examples of the classroom setting was explored in order to ascertain issues that we need to address when the system is used. Classroom settings are varied in terms of organizational, logistical and environmental factors. In order to explore these factors, members of the project team observed various classroom configurations and constructs that could impact system set up and use at RIT. Some factors (e.g. chalkboards, use of interactive whiteboards such as Smartboard and document projects such as the ELMO) were added during analysis of the instructor interview data. The classroom characteristics that are of particular importance are presented in Table 1, in the left-hand column.

Due to the diverse nature of classrooms, for pre-college or college use, instructors and students alike were asked about their learning environment in math and science classes. Both perspectives are needed as part of user and task analysis. Each group was questioned separately since the students were unlikely to be enrolled in the courses of the instructors who were interviewed. The results of the interviews are presented in Table 2, where pre-college and college results are categorized.

Table 2. Classroom environment characteristics and examples from student surveys and instructor interviews.

Factor	Middle and High School Classrooms	College Classrooms
Student Capacity	Typically 15-35 students	Often between 15 – 50 students, though some schools may use larger lecture halls
Use & Layout of Chalkboard or Whiteboard	Chalkboards more common in middle school; typically the boards are at the front of the room only; some science classroom boards are vertically moveable;	Some classrooms may have chalkboards, but most have whiteboards; Boards are in front of room and often on at least one side, though use of front boards most common; In science class or large lecture halls, some boards are vertically moveable
Place of Projector or other technology	Usually present in more affluent schools, LCD Projector may be on a cart or mounted to ceiling, Smartboards more common in affluent schools, ELMO's may be present	LCD projector is often present, usually mounted in middle; Smartboards and ELMO's usually not present
Types of Desks	Typically full desks or half desks;	Often depends on size of room or age

Factor	Middle and High School Classrooms	College Classrooms
	some science classes have table seating	of school; lecture halls often have stadium like seating with half-desks or tables; traditional classrooms often have half desks
Place of Instructor Desk	Front of room, to one side; usually a desk, often has an instructor computer; the room is generally the instructor's room	Front of room, typically to one side; is often has a table setup where the instructor can connect a laptop and other equipment; the room is typically shared with other classes
Location of Electrical Outlets	Varies greatly, but usually at front of the room and on some side walls (though may be blocked by furniture)	Varies greatly, at least at the front of the room; sometimes student tables may have their own outlets
Duration of Class Meeting	Depends on course scheduling; most often 1 hour every day or 1.5 -2 hours 3 times per week	Depends on course scheduling; most often either 1 hour 3-4 times per week or 2 hours for 2 times per week
Availability of Wireless for Students	Usually at more affluent schools, though many schools can at least accommodate wireless needs for assistive technology	Usually at least associated with specific buildings, often the science and technology department buildings; many schools are either entirely wireless or increasing coverage

The common use of chalkboards was a surprise to some on the team. While chalkboards are out of scope for the system, it will be considered in future hardware design. The lack of outlets for student use and the duration of classes mean that battery life is critical. Instructors have greater access, which in this case means the Mimio Capture hardware can be plugged in. In terms of wireless connectivity, university level students will have greater access though as time goes on this issue may be less of an issue at the middle and high school levels.

3 Impact on System Features and Quality Attributes

In addition to understanding the prospective users, their needs and tasks, the elicited information directly impacts the system features and constraints by offering a means to map requirements to the gaps uncovered in the studies. The user interface and workflow must meet the student needs in order to be successful.

AccessLecture's high-level features and quality attributes focus on the student's (iPad) interface. Features focus on the real-time access to content in class and to the related note taking/studying tasks that will enable students to independently discern lecture material without standing out from their classmates. The features are mostly stated in a user-focused manner, while the quality attributes are stated in a system-manner. They include:

- The student can follow the current material written on the whiteboard in near real-time (less than 2s latency).
- The student can zoom in and out of the displayed material.
- The student can navigate the view of the whiteboard while zoomed in or not.
- The student can center their view on the currently active part of the written material.
- The whiteboard session is recorded to include the recording of the whiteboard strokes and audio of the instructor.
- The system can snap to the current place where the instructor is writing/erasing on the whiteboard.
- The system enables time shifting during the recording, to enable the student to rewind the material during a lecture.
- The student can add notes during the lecture for viewing afterwards with an onscreen/hardware keyboard, stylus or finger.
- The student can access lecture material and their notes after lecture.
- The student can bookmark a moment in time in a lecture
- The student shall be able to revisit their notes and review the lecture
- The system shall support interfacing with the hardware to allow the same color to be displayed on the iPad as the color that the professor is using.
- The system shall provide consistent user experience, following Apple's iOS Guidelines for user interface design and accessibility.
- The system (including hardware) shall be easily transportable.

While some survey, interview and classroom observation results noted issues such as the occasional use of PowerPoint slides, chalkboards, and Smartboards in the classroom, AccessLecture is not currently designed to address these needs. In the meantime, the system architecture is designed to be flexible in order to add in functionality to address these needs in future.

4 Future work and Conclusions

While each student's classroom experience can vary due to prior history, visual characteristics, and the style of instruction, the study of this variety has been helpful in acquiring a big picture view. The studies offered a more complete view of student diversity, the needs of the educators, and the constraints of the classroom environment.

The user profiles and task analysis has been conducted and continues to be revisited throughout the iterative design and testing process to ensure that the needs of the students are met while not negatively impacting the instructor or classroom environment.

While basic accessibility features and settings (e.g. magnification, contrast adjustment, font sizes for typed notes and settings, enlarged note pins to signify the presence of a note in the lecture) have been implemented to support the lecture viewing workflow, the recently overhauled note taking user interface remains to be tested to assess improvement over this last prototype. Recent work (renamed AccessMath) also seeks to provide more flexible text and graphic notes that are attached to lecture at a time stamp. Additional customizations to notes and lecture navigation features are also being finalized. In future, improved storage for lectures, time shifting for recordings, and the ability to search through notes and lecture (audio and visuals) are planned. The application also needs testing in a classroom. These tasks will provide a more robust solution that can be used by low vision students, as well as other students who need a central means of accessing course material.

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