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# Interaction Design for Teaching Visually Impaired Students

Deryn Graham, Ian Benest, and Peter Nicholl

**Abstract** — This paper reports on the findings for a study on improving interaction design for teaching visually impaired students. The crux of the problem is the ability to draw and understand diagrams. The cognitive issues are often underestimated with insufficient attention being given to the use of metaphors, etc. and "one size fits all solutions" are often the norm. The findings of the original seed funded project have led to design criteria and to an application for a large scale project, to produce generic tools and to enable "multi-modal" teaching and learning, with connotations for the mentally as well as the physically impaired.

**Index Terms** — Cognition, Education, Interaction Design, Visual Impairment

## 1 Introduction

Current interface design for teaching visually impaired students, even when SENDA (Special Educational Needs and Disabilities Act in mainland UK) or SENDO (Special Educational Needs and Disabilities Order in Northern Ireland) compliant, has often neglected the direct involvement of target users in determining the requirements specific for their needs. In particular, there is a lack of awareness of the cognitive issues for the spectrum of users deemed to be visually impaired. A research project funded by the Higher Education Academy (HEA) aimed to determine and produce criteria for the design of interfaces through the participation of target users from the outset, implementing these criteria in teaching exemplars in computer science at Ulster, and in electronics at York. An important constraint was that these criteria would be inclusive; usable by both sighted and partially sighted students as well as those with other impairments. Furthermore, inclusive design should not impede those without impairments. This posed a considerable problem for both the exemplars at York for conveying electronic circuit diagrams and Ulster conveying Unified Modelling Language (UML) diagrams [1], [2].


- *D. Graham is with the School of Computing and Mathematical Sciences, University of Greenwich, 30 Park Row, London. SE10 9LS. E-mail: D.Graham@gre.ac.uk.*
- *I. Benest is with the Department of Computer Science, University of York, Heslington, York. YO10 5DD. E-mail: ian.benest@cs.york.ac.uk.*
- *P. Nicholl is with the School of Computing and Mathematics, University of Ulster, Shore Road, Jordanstown. BT37 0QB. E-mail: p.nicholl@ulster.ac.uk.*


## 2 Methodology

The first activity required is knowledge acquisition. Different authors present methodologies with varying stages of knowledge acquisition, but fundamentally they all involve: the identification and conceptualisation of requirements and problem characteristics, formalising these into some mediating representation scheme, implementation, and final testing and validation [3]. Knowledge acquisition can be machine-aided or human-labour oriented.

Johnson and Johnson's methodology [4], enhanced by Graham [5], proposes a three-stage knowledge acquisition process based around semi-structured interviews. The first phase is to perform a broad, but shallow survey of the domain. This allows the elicitor to become oriented with the domain, so that a more flexible approach can later be taken. This type of horizon broadening is a standard approach in social science research. Once this shallow trawl of the domain has been done, the second phase requires that a more detailed task analysis is performed by the elicitor, focussing on the area of interest. The structure of the interview uses a teachback technique to traverse the domain and validate elicitor understanding with the result that the elicitor progressively refines the model of the expert's competence. This model is qualitatively drawn up and uses a mediating representation, Systemic Grammar Networks (SGNs) [6]. These are a context free, qualitative representation, which can be used as a tool for the systems design, but their use does not imply the final application of any particular knowledge engineering software or methodology. SGNs have been used in many domains including oncology, printed circuit board (PCB) design, and fault diagnosis. The third phase of this approach is to validate the models drawn up from the expert with the wider expert community. The theoretical predictions of the model are presented to the initial community used in the first phase, and then to a further independent population, to check the appropriateness and validity of the model which has been created.

This knowledge acquisition methodology was adopted and tailored to the needs of the project. The first phase, the Broad and Shallow Survey, was achieved by arranging local interviews with clients from the Royal National Institute for the Blind (RNIB) in London and in the University of Ulster, using questionnaires specifically tailored to suit visually impaired interviewees. The second phase, a more detailed task analysis, was achieved through the design of semi-structured interviews with a visually impaired student expert at Ulster. Knowledge synthesis and analysis of interview findings led to design criteria rather than the employment of SGNs which were not considered practical for visually impaired experts. Validation (and verification) was achieved by the evaluation of implemented criteria in exemplars at Ulster and York, for teaching computer science and electronics respectively.

## 3 Results

### 3.1 Results from Phase One

Current interface design for partially sighted and blind users predominantly includes Tactile User Interfaces (TUIs) or Audio User Interfaces (AUIs) [7]; [8].

The Broad and Shallow Survey conducted at Greenwich with the RNIB resulted in the accumulation of a number of relevant publications, materials and links to appropriate sites [9]; [10]. Whilst extremely useful information was gleaned, the solutions offered were not sufficiently inclusive. A prime example was the use of tactile diagrams and graphs aimed at blind and partially sighted people [8], for example "Tactile and large print maps of three London Underground (LU) Stations" using raised lines. These diagrams were in principle very pertinent, because the concept of the London Underground map was based on an electronics circuit and therefore relevant to the York exemplars. It was initially difficult to see how these diagrams could be made computer tractable. T3, prima facie, appeared to be a solution. The T3 [9] is a touch sensitive, multi-sensory device which provides instant audio feedback from tactile images. It enables visually impaired people to access graphical information. The T3 is connected to a standard PC or laptop computer via a USB connection and has a bespoke application to understand the diagrams on the tablet. To activate the system, a T3 tactile diagram overlay is placed on the surface of the device and touched by the operator's finger. The T3 is the European version of the Talking Tactile Tablet (TTT) from Touch Graphics, New York. It requires tactile diagrams (such as the LU maps), so it would be necessary to create every combination and permutation of these for teaching electronics – too numerous to be practical or inclusive. The NCTD [8] states that Tactile Diagrams are useful when:

- The user is print-impaired and has some tactile ability.
- A novel concept not easily described in words, must be conveyed.
- A real object is unavailable for touching.
- The shape/form/pattern is important.
- Needed to illustrate scale and relationship: biology, maps, technology.
- Used as a reference: once, or as reminder.
- It is necessary to enhance educational experience – variety.

Tactile Diagrams are not good:

- For fine detail.
- When extremely large.
- Without training.
- Without support materials.

These factors meant that they were not a suitable solution in the electronics domain. The most difficult hurdle was designing an interface that was both computer-tractable and inclusive. The focus on inclusivity distinguishes this project from others such as: the TeDub system [11], a computer-based tool for visually impaired users, and web-based haptic applications that enable blind people to create virtual graphs [12]. Coping with the number of combinations and permutations for the electronics exemplars also meant that any solution needed to be dynamic.

Guidelines have been suggested by Tiresias [13] on several aspects of computing for varying disabilities, but were highly specific to web accessibility for instance. The most generic advice was the "User Needs Summary" dealing with each disability in turn. Specific to applications software were "Guidelines for Application Software

Accessibility" [14]. These guidelines (two priorities) covered application software running under any operating system or runtime environment. Priority one ensures that the application can be used by most people with impaired mobility, vision, hearing, cognition and language understanding, using their assistive technologies. Priority two makes it easier to use and will include more people with cognitive impairments or multiple disabilities. These guidelines were certainly inclusive.

## 3.2 Results from Phase Two

### Student Expert

The task analysis conducted with the student expert at Ulster proved to be most insightful. The student had had a period of being sighted and therefore was able to offer viewpoints with and without a visual and/or haptic memory of things. For example, the student had a visual memory of a grid, but only a haptic memory of resistors and capacitors. The student was therefore able to discriminate between what was meaningful to a visually impaired student who had a visual and/or haptic memory. This proved to be highly significant in terms of metaphors used. For example, when describing the pointer in a linked-list, a statement such as "might be thought of as a door to", is more insightful (especially for those who have never experienced sight) than the expression adopted by the computing community of "points to".

In relation to the senses utilized by the student expert for using computer interfaces, predictably the main sense used was hearing, however sight was still above smell and taste. For everyday activities, hearing and touch can be interchangeable. The student, perhaps due to the possession of visual memory, still thought in terms of images. The student was able to touch-type (learnt whilst sighted) so used standard QWERTY keyboards for input and GUIs with screen readers such as Dream, for audio output. The student was unable to read Braille; this was considered a great disadvantage as there were major gains to be made from using Braille displays and printouts for checking computer programs for example.

The recommendations from the student for interaction design were that: colour contrast can be of great immediate benefit for many partially sighted people; explanations using terms like "door, room, Lego" were meaningful to all; the best input and output devices were "anything tangible", that is, audio or tactile, with touch for orientation, keyboard for input; "hearing is serial, vision is parallel". The student had used examples of raised maps for aircraft flight safety procedures, which were useful provided a reference point was given as to where the student was located in the aircraft or on the map; by itself the map was meaningless. The student had no visual memory of the symbols used to represent AND/OR/NOT gates. The student had some visual memory of programming, namely Visual Basic, prior to losing his sight.

### Diagrams

A circuit diagram is the result of a design process that begins with a specification and, for analogue circuits, amounts to calculating component values for resistors, capacitors, and so on as appropriate for the selected transistors. By example, students are taught how to analyse and design specific circuits in such a way that they should be able to abstract the analysis and design strategies and then apply them to other circuits. The circuit diagram is central during the teaching and learning process, rather than a supplement or final result. It is used directly during the exposition on how the circuit works, what limits its performance, and how to go about calculating the component values. Analogue circuits are thus an excellent focus for understanding how diagrams can be explained to the visually impaired.

Before students learn to analyse and then design, they need to be able to "see" the artefact on which the exposition is based; for the visually impaired this means that the connectivity must be painted in their mind's eye. A schematic-based circuit (lines interconnecting symbols and annotated with text) is sufficiently semantic to be automatically converted into a form suitable for a circuit simulator. This being so, a high-level oral description ("spoken" by a text-to-speech synthesiser) can also be generated; the question being: how should it be phrased? It is assumed that, in general, authors of course-ware that includes a spoken narrative would not be familiar with the needs of the visually impaired (including all that needs to be said). So, if possible, this extra information would be generated automatically by the computer.

The circuit diagram used is shown in Figure 1; it is more than suitable for illustrating the problems that the visually impaired would have if a computer spoke the description from its internal storage of that diagram. Three descriptions were created "by-hand", two (Figures 2 and 3) as if they had been automatically generated and a third version (Figure 4) created using a set of "humanempathic" rules and thought to be more difficult to generate automatically.

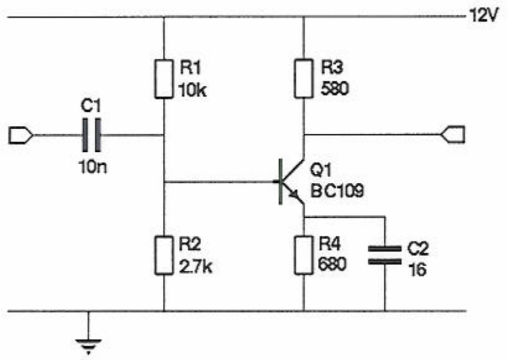


Fig. 1. Circuit diagram

The three descriptions were presented at the task analysis: "Description by Components Top-to-Bottom, Left-to-Right"; "Description by location and node", and; "Description – Human-orientated" (Figures 2 to 4, respectively). Due to the possession of visual memory, the second description was thought to be "more everyday language", the third "more hierarchical".

*This is a common-emitter amplifier consisting of 1 input, 1 output, 2 capacitors, 4 resistors and 1 transistor. There is one power rail and earth. The input is connected to capacitor C1. Capacitor C1 is 10nF and is connected to an input, to resistor R1, to resistor R2 and to the base of transistor Q1. Resistor R1 is 10k ohms and is connected to the 12 volt power rail, to resistor R2 and to the base of transistor Q1. Resistor R2 is 2.7k ohms and is connected to resistor R1, to the base of transistor Q1 and to earth. Transistor Q1 is a BC109. The collector of transistor Q1 is connected to resistor R3 and to an output. The base of transistor Q1 is connected to capacitor C1, to resistor R1 and to resistor R2. The emitter of transistor Q1 is connected to resistor R4 and to capacitor C2. Resistor R3 is 580 ohms and is connected to the collector of transistor Q1, to an output, and to the 12 volt power rail. Resistor R4 is 680 ohms and is connected to earth, to the emitter of transistor Q1 and to capacitor C2. Capacitor C2 is 16uF and is connected to resistor R4, to the emitter of transistor Q1 and to earth. An output is connected to resistor R3 and to the collector of transistor Q1. That's a common-emitter amplifier.*

Fig. 2. Description by Components

*This is a common-emitter amplifier consisting of 1 input, 1 output, 2 capacitors, 4 resistors and 1 transistor. There is one power rail, 12 volts, and earth. On the left is an input connected to C1. On the right is an output connected to R3 and to the collector of Q1. R1 and, to the right, R3 are connected to the power rail at the top. R2, and to the right R4 and C2 are connected to earth at the bottom. R4 and C2 are connected in parallel. On the left is C1 connected to R1, to R2, and to the base of Q1. On the right, R3 is connected to the collector of Q1. R4 is connected to the emitter of Q1. C1 is 10nF, R1 is 10k ohms, R2 is 2.7k ohms, Q1 is a BC109, R3 is 580 ohms, R4 is 680 ohms and C2 is 16uF. That's a common-emitter amplifier.*

Fig. 3. Description by location and node

*This is a common-emitter amplifier consisting of 1 input, 1 output, 2 capacitors, 4 resistors and 1 transistor. There is one power rail and earth. The input is connected through C1, 10nF, to the base of transistor Q1, a BC109. The base of transistor Q1 is biased by the potential divider provided by R1, 10k ohms, and R2, 2.7k ohms. R1 is connected to the power rail (12 volts) and R2 is connected to earth. Q1's collector resistor is R3, 580 ohms, which is connected to the power rail. Q1's emitter resistor is R4, 680 ohms, which is connected to earth. C2, 16uF, is connected in parallel with R4. The output is taken from the collector of Q1. That's a common-emitter amplifier.*

Fig. 4. Human-oriented description

The hierarchical structure was deemed to be an aid to cognition, however, the student chose the second description (Figure 3) which was also the easier to implement. The interview revealed that the student:

- Did not know about AND/OR gates or appreciate what was meant by a table (of data).
- Used his visual memory of a grid to understand the position of AND and OR gates, and truth tables. People without spatial awareness would be unable to do this, and the grid would be meaningless.
- Understood "gate" to be a meaningful term, but an OR gate posed a problem. An everyday physical gate can be visualised, but not a previously unseen OR gate?

- Only had a tactile memory of resistors and capacitors.
- Having had the first schematic diagram description read to him, the student was lost by the 4th stage (i.e. very early on).

**Navigation Advice**

During discussion, the student said that the following information was needed for navigating hyperlinked information (and some of these needs are also applicable for navigating schematics):

- Where are you?
- What can you do?
- When do you know you're there?
- How can you get back (not all pages have a home or back button)?
- Best naming convention for Lecture 15, slide 2 say, would be 15.2.
- Brief reminders of where you are at all times – just when moving on (not FROM WHERE, just TO WHERE), re. naming convention.
- Adopt the Daisy navigation system for the sectioning of books from RNIB.
- Use spoken descriptions in preference to sound (audio icons).
- The speed of the voice should be controllable, such as in Talking books (RNIB), using something like Cont+Alt, though this would not be appropriate for those with physical impairments. For example, it would be impossible for a person who used a mouth stick for typing; instead, a special button box would be needed. Arrow keys might be adopted as an alternative.
- Best to keep speaking tone constant.

With the help of a computer science on-line tutorial the student commented that he found:

- pauses included in the present audio-aided visual presentation were necessary, else the presentation was too fast.
- the presentation could be improved by the use of male and female voices, for example, male for the tutorial facts, female for the details.

### 3.3 Results from Phase Three

For the follow-up meeting (task analysis) with the student it was decided to make use of the T3 device to create an example set of UML diagrams. As previously stated in the electronics example, it would be difficult and time-consuming to prepare all detail and levels associated with use-case and class diagrams. This is partly due to the requirement to "register" every diagram for the T3 device, in order to generate a unique key for each diagram. It was hoped that the student's prolonged use of the T3 device in some key examples in a second year module that adopts UML, and is also used on the third year sandwich placement, would reveal more useful information as to the best way to use this device. An alternative, and more tactile solution, was introduced and was based on Lego. The factors to do with colour, size and board boundaries could allow for a more interactive non-computing solution. Could the student work around a diagram? Could they construct a diagram? If two or more boards were available could it represent levels of hierarchy? It was hoped that the validation and verification of the findings from this work over the next six months would prove the use of a more tactile approach, particularly for non-Braille users.

The validation and verification of the UML exemplars (Duplo blocks) identified the following:

- The blocks that were used to represent different symbols, were distinguishable.
- Blocks provide 3D and fully tangible information.
- The student expert could not distinguish between the primary colours used for the blocks, but colours could aid partially sighted users.

**Electronics Exemplar**

For the purpose of this paper, a teaching object consists of one or more visual slides, each with an accompanying aural narrative that is synchronised with any visual changes that occur. They are not videos of live lectures. Each slide (though not the individual changes) were to be provided as "haptic hardcopies". The validation and verification of the exemplars revealed the following aspects of the design.

Having teaching objects available before the live lecture would be useful, because it would enable the user to "get up to speed" before hand. All students should do this, but most, if not all, do not do it. If they did, they would probably get more out of the live lecture. However, most students do buy the booklet of slides before the start of the module.

It is thought that an mp3 player version would be useful for everyone. Designing the narrative with the visually impaired in mind means that it must also be suitable for sighted people with their mp3 players – they should not need (though they might appreciate) the visual support. So for each visual slide, it is necessary to concatenate all the constituent audio files, with suitable delays inserted between each audio file. The delay is currently set to 1.5 seconds, with 4.5 seconds delay at the end of each slide so that the end can be easily recognized when playing. The result is that each slide is equivalent to an audio track and a complete teaching object (on-line lecture) is equivalent to a musical album. Thus students can skip along the play-list and play the slide they want. Experience at York suggests that a 10 credit module-worth of on-line lectures will occupy no more than approximately 150Mbytes in the mp3 format – well within the capacity of a modern mp3 player. Sleeve notes are automatically created giving the title of each slide and its play-time, as well as the lecture's total play-time and disk occupancy.

Most sighted people feel a need to know how long the slide, and the complete teaching object, will take to play and this information is also needed by the visually impaired. For sighted people this is often provided (thoughtlessly) by a visual ribbon that grows in length as the teaching object plays. Unless the ribbon is tucked out of the way, the movement will distract the eye from the more important animation that is designed to reinforce what is being explained (e.g. how the circuit is drawn to reflect a design). A simple time elapsed/total duration (as with a CD player) placed in a corner somewhere out of the way would be acceptable for sighted people.

For the visually impaired, what are required are temporal directions in the narrative: "I have 5 points to make .... My 4$^{th}$ point is .... My last point is ... " These are equivalent to the visual directions in the narrative such as: "...at the top right of the slide..." used to direct the eye visually or virtually.

It will be necessary to judge how long it is before clock watching begins; slides that last longer than that will need the temporal direction (this is likely to be most cases). Unfortunately this is yet another thing to which authors have to attend and they are not used to it.

The animation on the slide needs to be overtly described to the visually impaired and while sighted people can see what is going on, they may still need to have it explained. So in these circumstances users need to be able to turn off the explanation. This implies that some audio files are always played, while others are not, and the software viewer has to be able to differentiate appropriately. This requirement is in addition to the need to differentiate between the spoken narrative and illustrative audio when the system is used in a live lecture. The narrative must be turned off, but, for example, twenty seconds of Beethoven's symphony might be needed for illustration, or a small part of a great oration ("I have dream...") must be heard in the lecture theatre. The animation should be simply stated for everyone. The "I'll just get rid of clutter" (in the form of a warning to the sighted) is not satisfactory; instead, what is left to view and where that is, needs to be expressed.

The speed with which the narrative is played needs to be variable, but not for the reasons of compensating for a fast or slow lecturer. A fast rate is needed to skim aurally through that material which is already well understood and get (by listening out for keywords) to a position where more attention to detail is required. A slow rate is needed where the user wishes to take notes. For the visually impaired those notes will probably be made on the same computer that is displaying the teaching object. While the use of a pause (in playing the audio) might seem the obvious facility, only if it were foot controlled (for example) would that be acceptable. If, as is the case in the York viewer implementation the space bar is the pause (and pause release), the mouse has to be in the viewer window in order to invoke the pause; the mouse will actually be in the note-taking window. Window swapping will irritate the sighted, and frustrate the visually impaired.

Currently the speed of narration varies from half the original speed (80 to 90 words per minute) to twice the original speed (320 to 360 words per minute) in four steps in either direction. This might be enhanced with experience and feedback from users. The slowest speed must be compatible with a not-very-fast typing rate. Two function keys are used, the left one reduces the speed and the right one increases the speed. It is expected that visually impaired people will count the steps in order to reach their comfortable speed; if the user tries to go beyond the minimum or maximum speeds, a quiet double click is sounded; when arriving back at the originally recorded speed, a single click is heard. The speed can be changed as the system is playing.

In the York viewer the arrow keys move the user forwards or backwards through the linearly organised set of slides (up and down arrow keys are used to step either way through the slide's animation). When the user attempts to go beyond the last slide or back before the first slide, a "bong" is heard. Care must be taken not to over use different sounds in this way, as only the meaning of a few can be easily remembered.

The pause control (space bar) implemented in the York viewer causes the audio to be rolled back to the start of that sentence which was interrupted; so when the pause is released, the audio does not re-start "mid-blurt". The rationale for this is that it quickly reminds the listener of what was being said just before the pause was invoked and that this event would happen when the person was being interrupted by a telephone call or by a colleague. The student expert was adamant that he did not want this roll back and further questioning of the expert is needed; the roll-back feature seems to be an appropriate design decision and currently this is how it has been implemented for all speaking rates. To the authors this mechanism does not appear to impede progress.

Touch is an important sense for the visually impaired and thus should be exploited in order to enhance the system's communication with the user. It is possible to produce "haptic hardcopies" of black and white (no grey) screen dumps. After copying on to special paper and passing it through a heater, the black lines are raised above the surrounding white areas. The black lines can then be felt. Unfortunately the finger's acuity is quite poor so it is difficult to differentiate between, for example an AND gate and a NAND gate by touch alone, as the only difference is a small circle on the output connection. Given that (at York) slides are specified as schematic diagrams in the first place, the symbols can be automatically exchanged for ones that are more haptically visible though still connected in the same position (that is, diagrams are enhanced, not blown up). It must be remembered that an included visually-impaired student must be able to point to haptic diagrams that are readily understood by sighted students, so the exchanged versions must not be radically different.

While the student expert admitted he could read by feeling text, the aesthetically pleasing proportional spaced fonts were more difficult to read (especially if they were "decorated") than mono-spaced fonts. In any case, characters probably have to be almost one centimeter in height. Converting the text to Braille while simple to perform, would cause the slides to become proportionally very large (Braille also has to be read with haptic senses that have low acuity). Practically speaking this rules out such a conversion. Alternatively, it is possible to lay the haptic hardcopy on to a tablet, inform the system what slide it is, and then let the visually impaired person point to the written text. The system would then speak that text; if a symbol were pointed to, it would say what the symbol was. To identify the haptic hardcopy, it would be necessary to annotate (in Braille and outside of the screen dump area) the module acronym/number, lecture number, and slide number. The position of the slide number around the screen dump would vary according to its value. So the number one would be on the far left, while the maximum slide number would be on the far right. The visually impaired would not need to learn Braille, the position of the number would be sufficient for its recognition. However, the number in Braille might encourage Braille to be learnt. When laid onto the tablet, selecting the acronym, lecture number and slide number would let the system recognize what slide it was and therefore what the text was on the screen dump. The slide text would not be changed to Braille so that sighted people would be able to help the visually impaired. Some means of ensuring that the haptic paper does not move on the tablet needs to be provided. The shirt cuff of a visually impaired person might catch the edge of the paper and the movement not be realised.

The tablet would be carried in a laptop case and plugged into the USB port of a PC. Pointing would amount to the tablet sending an (x,y) coordinate to the viewer. If the viewer were aware of which haptic hardcopy it was, it would readily identify to what the user was pointing. While text-to-speech is tedious when played continuously, it would feel less so because the user was interacting with it. This is similar to a telephone conversation where the poor sound quality only has to be listened to for brief moments, before the listener becomes the speaker. Alternatively, all the text on each slide would have to be recorded by the author of the slide and that is unlikely to be very acceptable to that author.

Of course, last minute updates that are so easy to do with electronic documents, would be less so if the haptic hardcopies also had to be changed. But this might encourage authors to get material correct in the first place!

## 4 Conclusions

The distributed cognition of the student expert was mainly acoustic. Understanding diagrams appears to be the crux of the problem.

The old (often misquoted) Chinese proverb: a picture is worth more than ten thousand words succinctly expresses the information content that may be contained in a diagram. Furthermore with the ability of the eyes to move at will (with none of the interference of pointing and clicking) the information can be re-presented to the cognitive processes of the brain for further evaluation. The understanding of the information is still serial but because the eyes provide an ability to "look back" and the brain knows precisely what is to be reviewed and can spot it, sight is said to be "parallel". This is particularly apparent when compared with speech which is inherently serial; it requires physical interaction to move back and forth, and there is no clear indication of where anything is except to rely on a temporal memory of when it occurred. The temporal memory is usually inaccurate, requiring overt physical manipulation, which interferes with the information processing going on in the brain. It is essential that this parallel process of information gathering be accessible in a similar though alternative manner for those who are visually impaired; and this is particularly important where diagrams may be the only reasonable way in which information is conveyed. Learning something like UML for a computer science student would pose a major problem as it involves diagrams and programming code.

Given a haptic interface the hands can provide an alternative to the eyes, although the acuity is quite poor in comparison with normal sight. As the eye would serially follow the connection from a resistor to the collector of a transistor, so would the hands. But while the eye and brain together can quickly recognize symbols such as a resistor, the fingers and brain will be much slower and thus help, in the form of a computer recognizing what the user is touching and expressing what it is, will speed up the user's recognition. For this to be provided automatically requires the diagram to be specified as a schematic in which all the symbols are uniquely named. The haptic help needs to be switch-able (on/off). Adopting a touch tablet for user-interaction provides inclusiveness for the visually impaired.

The criteria identified for interface design for visually impaired students are as follows:

- Solutions should be inclusive (suitable for sighted, partially sighted and blind users).
- Solutions should be computer tractable.

These two criteria above may be diametrically opposite.

- Solutions should be dynamic.
- Metaphors should be meaningful to all ("doors", "rooms", "Lego" not "points to").
- Touch is best for orientation.
- Sound is best for input and output, unlike Braille it is inclusive.
- Colour contrast can help a large range of (but not all) people – different platforms render different colours with different hues and different brightness.
- Inclusion can be aided by multi-modal and multi-media interfaces.
- High-level names which are well understood by all should be adopted, so that an individual's short-term memory limitation (of between five and nine items) are not overly compromised [7]; thus such naming helps to reduce overload [15].
- An emphasis on naming items followed by their use should also help consolidate sighted people's learning.
- Superfluous information or detail needs to be suppressed.

Overall the student expert thought the audio descriptions were "fantastic". Some conclusions on points made:

- The audio narrative of a lecture would be preferable in advance of the lecture.
- The audio description can be provided asynchronously and Podcast.
- Material needs initially to be given serially ("hearing is serial"), but should be randomly accessible after, so as to reinforce learning and/or provide explanation.
- The student expert felt that a gap between oral paragraphs (an oral paragraph is usually between one and four sentences) should be between one and one-and-a-half seconds, though a facility for customizing pace might be useful in addition to the ability to vary the speaking rate. The

danger of course is that the more functions provided, the less likely their position on the keyboard will be remembered; so ideally, pace might change automatically with change in speaking rate.

- For the "haptic hardcopy", the larger version (slightly more than A4) was much better than the A4 version. This implies that the tablet must be large and therefore not very portable. In practice, with the ability to speak the text and help with the diagrams, an A4 size tablet might be acceptable.
- An orientation description of the tactile diagram is required at the start.
- Care must be taken to avoid ambiguity in a description of a diagram that would otherwise be resolved when looking at it.
- Characters in a proportional-spaced font appropriate for reading comfortably in a lecture theatre and printed on to A4 paper cannot be read when felt.
- Ideally, the tablet should be touch sensitive and not require a pen with umbilical chord.
- The student expert was able to follow a haptic slide whilst the audio description was played.
- A haptic diagram adds more information to an audio description.
- Tactile diagrams reduce the cognitive load considerably.
- Blocks could be assigned component descriptions, and with the aid of a board, could enable visually impaired students to construct circuit, UML and other diagrams.
- Generic technology could be built to enable component assignment for any diagrams and the output of tactile hardcopies, with optional audio descriptions.
- The additional information for visually impaired people may help sighted people (reinforce learning through multiple encoding). This could be made an option using a toggle switch.

The final three points listed above are now the focus of a larger research project.

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**Deryn Graham PhD (1991), MSc (1987), MA (2004)** Dr. Graham began as a Computer Programmer for Automotive Products Precision Hydraulics (industrial and commercial programming) before deciding to go into academia. Working at the Animal and Grasslands Research Institute as an MSc placement student in Calorimetry research, and then as a Research Assistant at the University of Nottingham on a Colorectal Cancer research project whilst writing-up her MSc dissertation. This was subsequently followed by a PhD at Brunel University in Artificial Intelligence: Computer Hardware Fault Diagnosis and Repair, a CASE award in conjunction with the Computer Repair Centre Ltd. After completing her PhD at Brunel, she stayed on as a Lecturer, researching in to "Knowledge-Based Image Processing Systems" in relation to bio-assays in collaboration with the National Institute for Biological Standards and Controls, leading to the publication of a book of the same name. In addition, she began her first funded research project into Educational issues. A stint as a Visiting Professor at Mid Sweden University followed, during which partnerships were established for an EU FP5 project on Acoustic Emission applied to mechanically loaded Paper (AEP). Currently she is a Senior Lecturer at the School of Computing and Mathematical Sciences, University of Greenwich, where the AEP project was successfully executed. Deryn Graham in collaboration with the HEA is the organiser, chair and editor for the annual workshop on "e" Teaching and Learning. She is a member of the programme committee/referees for the HEA, and has reviewed papers for IV06, IV07 and the HEA. She has reviewed books for Pearson, Springer-Verlag, Wiley and the British Computer Society (BCS), and is both a reviewer and contributor to the BCS Computer Bulletin ITNOW. She has well over 30 publications on a wide range of topics from vibro-acoustic models to Human-Computer Interaction (HCI), and e-learning. She has given two keynote papers and has twice been an invited speaker. She is a Fellow of the HEA (FHEA) and the BCS (FBCS), as well as a Chartered Engineer (C. Eng) and IT Professional (CITP). This year she became a member of the HCI Disciplinary Commons. In 2004, she was the Institutional Nominee for the University of Greenwich for the ILTHE National Fellowship Scheme, Experienced Staff category. She has held several grants and is presently involved with a bid for an FP7 e-Accessibility Call on Multi-modal Teaching and Learning, founded upon the Higher Education Academy (HEA) seed funding received for research on Interaction Design for Visually Impaired Students. Another FP7 bid has been prepared for the Call on Technology enhanced learning, in e-learning. This project is strongly linked to her recently published work.

**Ian Benest** graduated from the University of Essex with a BA in Computer and Communication Engineering in 1974 and completed an MSc by research and then a PhD in interactive computer-aided circuit design — all at the University of Essex. He then spent five years at the UK Science and Engineering Research Council's Rutherford Appleton Laboratory, latterly in the role of MMI coordinator. He is currently a lecturer in Computer Science at the University of York, teaching hardware design; in the past he has taught user-interface design. He has been the author (or co-author) of more than 70 publications. He is a member of the Advisory Board for the Information and Computer Sciences network of the UK's Higher Education Academy (HEA-ICS) and is a Chartered Engineer through the IET. His research interests include user interfaces to hypermedia systems, with special attention to inclusive design (for those with aural, visual, cognitive and physical impairments); the work is applied to teaching and learning in electronic circuit design.

**Peter Nicholl** Eur Ing Dr Peter Nicholl completed his first degree in 1991 from the University of Ulster in B.Eng. Electronic Systems with a Second Class Honours (Upper Division) and Diploma in Industrial Studies. He then completed his D.Phil. in Computing Science in 1994 from the University of Ulster with a Thesis entitled: "Feature Directed Spiral Image Compression (A New Technique for Lossless Image Compression)". He then started his academic teaching career as a Lecturer in Computing Science, University of Ulster, and completed the Postgraduate Certificate in University Teaching in 1996. He was awarded the 1993 Proctor & Gamble Prize for the best Faculty of Informatics Research Paper published by a Research Student during 1992 and in 2006 was awarded the University Awards Scheme for Leadership in Teaching and Learning Support (Distinguished Learning Support Fellowship: Team Award). Currently, he is seconded 50% of his time to head up the University Progress Files Coordinator role in relation to PhD Personal Development Planning. He has 23 publications and intends to continue research into teaching in relation to the recent SENDO legislation and the dissemination of Disability Guidelines and Tools to support hearing and visually impaired students.