

Department of Electrical & Computer Engineering

**Instructional eLearning Technologies for the Vision
Impaired**

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This thesis is presented for the Degree of

Doctor of Philosophy

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Declaration

This Thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

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- Hollier, S, Murray, I, 2004, The evolution of e-inclusion: Technology in Education for the Vision Impaired. History of Computing in Education 2004, Toulouse, France
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Synopsis

The principal sensory modality employed in learning is vision, and that not only increases the difficulty for vision impaired students from accessing existing educational media but also the new and mostly visiocentric learning materials being offered through on-line delivery mechanisms. Using as a reference Certified Cisco Network Associate (CCNA) and IT Essentials courses, a study has been made of tools that can access such on-line systems and transcribe the materials into a form suitable for vision impaired learning. Modalities employed included haptic, tactile, audio and descriptive text. How such a multi-modal approach can achieve equivalent success for the vision impaired is demonstrated. However, the study also shows the limits of the current understanding of human perception, especially with respect to comprehending two and three dimensional objects and spaces when there is no recourse to vision.

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1. INTRODUCTION

1.1. Introduction

Diderot (1916) asked the congenitally blind man of Puiseaux whether he would be overjoyed if he ever regained the use of his eyes – his reply:

“I would just as soon have long arms: it seems to me that my hands would tell me more about what happens on the moon than you can find out with your eyes and your telescopes; and besides, eyes cease to see sooner than hand to touch. I would be as well off if I perfected the organ I possess, as if I obtained the organ which I am deprived of” (Diderot, 1916:77)

Even though western governments have legislated for equal opportunity for minority groups, including those with disabilities, the vision impaired still do not have equal access to opportunity in a digital world. The pathway to much opportunity is through education. In advanced technical areas, that education is increasingly reliant on visual forms to convey information where this can be images or the visualisation of data in some form. This clearly disadvantages the visually impaired. Further, as the reliance on these forms increases, so the vision impaired become even more disadvantaged. This is especially true for those in developing countries due to the high cost of tactile devices and hard copy tactile graphics.

A particular problem is caused by the revolution that has occurred in most advanced societies over the past decade; the Internet. It offers a wealth of information, access to a wide range of services such as on-line banking and other opportunities that are changing societies in ways that

could not have been imagined. One such service is education. Advanced training in a number of areas has long had the problem of never more than a few potential students in any one physical site making it very expensive to deliver. Delivery via the Internet, removes that constraint. For some though, their disability may be a barrier to such access unless learning materials or instructional media has been tailored to accommodate their specific needs.

Education is an essential key to living a fulfilling and constructive life. Individuals with disabilities encounter lower career success than their peers and are less prone to complete post-secondary education and undertake academic studies in science, technology and engineering (Burgstahler and Ladner, 2006). These, though, are the growth areas in advanced and developing nations. This lack of opportunity increases the demand on government services of all kinds by the visually impaired. Further, it isolates them from the community and that lack of contact and participation results in a range of health issues.

A recognised human right is equal access to education (United Nations, 2007). Clearly, there is a need for research to allow people with disabilities to access education commensurate with their intellectual abilities and subsequent employment in line with their sighted counterparts. In particular, there is a distinct need for research that allows the person with a disability to access Internet-based educational training programs. The obvious solution of tailoring training packages for the disabled is unrealistic; there is a wide range of disabilities that need to be catered for and even though the numbers with disabilities is significant, it is uneconomic to meet their needs in advanced fields by this approach.

The overall aim of this research is to build a framework to ensure on-line teaching materials can be made fully accessible to the vision impaired. In

order to achieve this goal it is necessary to understand the characteristics of disability and its effects on opportunities for education within today's society.

1.2. The Demographics of Disability

Disability is a term that covers a wide range of conditions and combinations of conditions (Noonan, 1999) and this is recognised in regulations throughout the world. The US Access Board (Access Board, 1999), for example, is responsible for ensuring that Electronic and Information Technology Access standards are applied in a wide range of services including those used for communication, duplication, computing, storage, presentation, control, transport and production of information. This Board creates its standards according to the following categories of disability;

- visual disabilities (e.g., blindness, low vision and lack of colour perception)
- hearing disabilities (e.g., hard of hearing, deafness)
- physical disabilities (e.g., limited strength, reach or manipulation, tremor, lack of sensation)
- speech disabilities
- language, learning or cognitive disabilities (e.g., reading disabilities, thinking, remembering, sequencing disabilities)
- other disabilities (e.g., epilepsy, short stature), and
- any combination of these disabling conditions (e.g., deaf-blindness).

In the 2003 Survey of Disability Ageing and Carers (SDAC) conducted by Australian Bureau of Statistics (ABS, 2004), one in five people throughout Australia had a reported disability. In terms of raw numbers, 3,958,300

(out of a total of 19,791,500 of Australia's population recorded for statistical purposes in 2003) suffer some form of disability. The gender distribution of disability is even with 19.8% of the male population and 20.1% of the female population reporting a disability. Disability was defined as, "any limitation, restriction or impairment, which has lasted, or is likely to last, for at least six months and restricts everyday activities". Examples range from hearing loss requiring the use of a hearing aid, difficulty dressing due to arthritis, to advanced dementia requiring constant help and supervision. After removing the effects of different age structures, there was little change in the disability rate between 20.1% in 1998 and 20.0% in 2003. The rate of profound or severe core-activity limitation also showed little change between 6.4% in 1998 and 6.3% in 2003.

Statistics from the SDAC report relating to employment are of particular interest. Of persons aged between 15 years and 64 years with a reported disability living in households, only 30% had completed year 12 of schooling and 13% a bachelors degree or higher. The proportions for those with no disability and therefore better opportunities were 49% and 20% respectively. The labour force participation rate of persons with a disability was 53% and the unemployment rate was 8.6%. Corresponding rates for those without a disability were 81% and 5.0%. The median gross personal income per week of persons aged between 15 years and 64 years with a reported disability living in households was \$255, compared to \$501 for those without a disability. Median gross personal income per week decreased with increasing severity of disability. The report shows that median gross personal income per week was lowest, \$200 per week, for those with a profound core-activity limitation.

These figures clearly show that people with a disability are less likely to have the same levels of education, employment and income as their sighted counterparts.

There are nearly 650 million people throughout the world experiencing disabilities of various types (WHO, 2008). 180 million people have a visual disability and approximately 50 million are blind and cannot walk unaided (Resnikoff et al, 2004). The World Health Organisation anticipates that with normal population growth, the number of blind people will double within the next 25 years.

1.3. Improving access to eLearning resources for the vision impaired

This thesis examines the issue of providing tools so that the vision impaired may access Internet-based learning materials targeted at an advanced training level in such a way they suffer no educational disadvantage. In the past, separate versions of curricula were maintained, one for the able bodied students, another for those with access difficulties. This led to a common situation of the “accessible” version not being maintained and updated less frequently than the “mainstream” version. As the focus for this thesis is on accessing learning materials in a meaningful way by the vision impaired and methods of access rarely change, the vision impaired are always in a position to access the most recent training programs.

The scope of this research was as follows. The focus group were taken as those with severe visual impairment. In the context of this research ‘severe visual impairment’ includes those who had no perception of light at all through to those who while able to sense some light had no visual

perception. This group was chosen as they are clearly the most disadvantaged with regard to visual-centric on-line training schemes.

To build the intended framework, a vehicle for the study and development of accessible on-line courses was needed. A suitable available curricula was the Cisco training programs offered to educational institutions via the Cisco Network Academy Program. There were several reasons for this choice. First, they are in the Information Technology (IT) area and this is, in many respects, an ideal area for the vision impaired to seek employment and a very large employer in general. Second, this is an area noted for its rapid change and so one where individuals frequently undergo advanced training. More specifically, Cisco training is important in a number of key areas of IT and the Cisco training relies heavily on on-line programs. The programs, although only English was used in this research¹, have been extensively tested both with native and non-native speakers in a wide range of cultures by other organisation delivering the curriculum in their local languages. In educational terms, they are known to be effective because they have been subject to extensive test and review.

The totally blind will benefit from this project in the following ways:

- Building skills and knowledge they would not have the opportunity to gain otherwise
- Inclusion in an IT driven society
- Ability to contribute to this IT driven society

¹ The Cisco programs are offered in all six of the United Nations official languages. Languages other than English were considered out of the scope of this thesis.

- Developing relevant skills and proficiencies, i.e. computer network skills are in demand in the workplace
- Expanding opportunities for employment
- Expanding opportunities for further education

In an abstract form an on-line training program is a multimedia presentation. That is to say, it is comprised of some set of text fragments, possibly audio fragments, images of all kinds including pictures, drawings, sketches, schematics and charts, animations, videos and possibly supportive software such as applets or simulation packages. In the future this may extend to virtual reality classrooms, such as those being developed at Ohio University's Second Life campus (Second Life development, 2008). At the time of writing, Second Life was inaccessible to people with severe vision impairment although some efforts are made to allow access by people with mobility disabilities and low vision. Trewin et al (2008) demonstrated that virtual worlds could be made accessible, as implemented in the game "Power Up" by IBM and TryScience/New York Hall of Science (<http://www.powerupthegame.org/home.html>).

In terms of function, it is of course, attempting to educate a set of learners in some topic. As such, there are educational outcomes that have been defined leading to a curriculum and then a set of learning experiences that will achieve those outcomes. The on-line system is merely the delivery mode although its influence on learning should not be discounted.

This research focussed on how to maximise accessibility to the information of each of the components of these learning experiences. An important question addressed was *is this sufficient to ensure that a visually impaired individual could be educated to the same degree as others?* If not, then it raises the deeper issue of how to modify the learning

experiences so as to achieve that same outcome. The question revolves around the provision of suitable tools. In technical terms, the opportunity exists for that tool to act statically – the learning materials are transformed before use – or dynamically – they are transformed during use. An on-line program is normally provided remotely hence access to it is limited for the former. Therefore, this research assumed only the latter was feasible.

This raises an important issue. Tools that function dynamically on on-line programs are going to be software tools of some form. They assume that extracting information is the role of a tool. However, it is conceivable that tools could be used that have nothing to do with any element of the training program itself but provide an equivalent educational experience. For example, some form of mechanical device such as the pegboard described in section 4.5.2. Equally, it can be envisaged that situations could arise where combinations of such tools may prove to be optimum. Thus an objective of this research was to identify the circumstances where such alternatives might be fruitfully developed or where combinations of tools may prove of maximum benefit.

A further issue that arises is whether there are multiple possible tools and if so what are their forms, their virtues, their limitations as well as issues such as the degree of difficulty in implementing them. Hence another question listed for examination was *can guidelines be framed in any way that point to the probable optimal solution?* A specific sub-objective of this was *can the range of existing guidelines covering various aspects of assistive technologies be consolidated or refined so that they better relate to educational applications?*

The development of assistive technologies for people with a disability has a long history and much has been learned on their utility and necessary

characteristics. In the context of this thesis, then, some potential tools were ignored as they are already in wide use. For example, text to speech conversion is generally provided quite easily and is very effective. The focus here was on areas where there is significant uncertainty. An image is a two dimensional entity and the issue of how to extract its core information and any other needed to promote learning is not at all clear. Undertaking this was deemed a core objective of this research. An even more difficult situation is animations or three dimensional graphics. Given what is currently known with respect to images alone, tackling these topics was seen as too ambitious.

A possible outcome sought for this research was improvements to guidelines for the development of assistive technologies. In a more general sense, though, what is required is a model of the impaired learner of a similar form to models of learners widely used in education. Clearly, as human beings they would share many similarities, but their impairments would mean this model has to take account of a translated sensory experience. Hence a further objective of this work was to advance the understanding of the framework for such a model.

1.4. Achievements of the research

This research established that relatively simple tools to access on-line training programs are sufficient to educate vision impaired individuals to the same level as sighted students. Undoubtedly there are circumstances where this is not true but none were encountered in this research. Hence it seems a minor concern.

As mentioned, a particular focus of this research was on tools to access imagery, as these present a significant challenge. For example, pictures in

broad terms have a foreground and background where the latter does much to place the former in context. Conveying these interrelationships to the vision impaired learner is exceedingly difficult. This is also true of simpler visual objects such as charts. Research that has been done to date has established that transforming images into some form of auditory experience does not adequately portray the information content of that image and in particular such linkages. For that reason, many have expressed their enthusiasm for a tactile experience based on some form of haptic device, the most popular form being a tactile experience of surfaces and shapes. This research, however, has established that while haptics have a significant role in assistive technologies, they have severe limitations as a means of interpreting images in this way. It is therefore difficult to recommend them except in limited circumstances.

It was found that using a combination of tools was a very effective means of accessing on-line programs. A particularly effective combination was a computer based tool providing primary access backed by a separate support tool offering a tactile experience. However, an unresolved issue is defining a systematic way of developing this support. Rather, its production relies on insight by a qualified instructor not only of the program but of the issues facing people with disabilities.

Developing a model of the disabled learner proved, as expected a difficult task. However, useful progress has been made as the range of disability guidelines now available in most countries make it easier for course developers to create programs suitable for both the able-bodied and the disabled.

1.5. Structure of Thesis

The increase in the logical ability of computers has seen a significant rise in interest in assistive technologies in recent years. Chapter 2 reviews current thinking in the field and reports the significant conclusions. Chapter 3 of the thesis then examines the research focus more closely and in particular some of its more technical details. Similarly, chapter 4 outlines the methods used to gain data to support the research objectives. Chapter 5 analyses that data, both in its simple and holistic forms, and frames some quantitative outcomes. Then chapter 6 draws the significant conclusions of this research plus foreshadows research directions that may prove useful.

2. AN EXAMINATION OF ELEARNING AND ASSISTIVE TECHNOLOGY FOR PEOPLE WITH VISION IMPAIRMENT

2.1. Introduction

Given that those with a disability are a minority and that they have a diversity of conditions, meeting their technological needs has never been in the forefront of research. Nevertheless, studies have been made into three areas of particular concern to this thesis; Blindness and Low Vision, Human Computer Interaction, and e-Learning relating to the Vision Impaired.

2.2. Human Sensory Perception

2.2.1. Rate of Perception

Of the five normal perception sensors, sight is considered the primary sense because that is how most people use to gain information, particularly about their immediate environment. Blind and partially sighted people have to compensate their vision impairment by relying on their other senses. Each sense has its own advantages and disadvantages that should be acknowledged and considered when designing a non-visual user interface. One clear difference between the five senses is the speed with which humans can assimilate information. In computing, the information transfer speed is frequently called bandwidth. This is a term that can be extended to apply to the five human senses. Vision is the strongest sense in this regard; an estimate has put its bandwidth at around 10^6 bits per second (Kokjer, 1987). Information bandwidth for the ear and skin were given at 10^4 and 10^2 bits per second respectively. However, this last value was obtained for vibrotactile stimulation (as of a vibrating pin) that may not give an indication of the tactile sense's full

potential. In addition, other research has put this value at no more than 10 bits per second (Way and Barner, 1997a). On the other hand, Mandic, Harvey and Kolonic (Mandic et al., 2000) argued that the maximum information flow of the tactile sense is in fact around 10^6 bits per second at the receptor level and around 50 bits per second at the cognitive level, and can in fact be greater than that of the ear.

Perhaps a more definitive comparison of the capabilities of the senses could be achieved through comparison of respective reading rates. Although not the most efficient way of utilising each sense, reading is an example of a task that requires one's full attention. Users commonly achieve Braille reading rates of around 100 words per minute (Way and Barner, 1997a). This can be compared to an average visual reading rate of around 250 words per minute and preferred rates of around 200 words per minute of synthetic speech. Experienced synthetic speech users often may prefer higher rates. These values could be converted to around 60, 150 and 120 bits per second respectively.

While these examples give only an indication to the full capacity of the senses, it does provide a comparative measure of comprehension speeds. A surprising result of this analysis is that the differences between input rates do not seem as large as expected. Therefore, one could conclude, major differences in computer access speeds must be due largely to user interface design.

2.2.2. Cognition

It is well known that upon being presented with a new scene, the visual system of a human first concentrates on the whole then responds to specific detail. This breadth – then - depth search approach applies

equally to both the visual and tactile senses, and also to the auditory sense in a slightly lesser degree. Roth and Colleagues (Roth et al., 1999) term this two-stage approach macro-analysis or “where” stage and then a microanalysis or “what” stage to gain more detail. The serial approach to information created by the use of screen readers inhibits this two-stage search process.

The acuteness of haptic and auditory senses of blind people in comparison to those of the general population has been questioned (Molyneux Question, cited in Paterson, 2006). If this is true then there is a common misconception that the other senses to some extent compensate for blindness. It is true, however, that blind people make better use of their other senses. A large amount of anecdotal evidence suggests that blind people often learn to extract more information from their haptic and auditory senses. For example, sighted people may find it very difficult to distinguish the patterns of dots that form Braille code, but many blind people can read Braille very easily. Blind people may also have learned to rely more on their memory than sighted people and thus may have better recall abilities.

2.2.3. Tactile and Haptic perception

The word “haptic” is generally used to mean a combination of the sensing capabilities of the skin and the information about position and movement of the body. Oakley (Oakley et al., 2000) provide a comprehensive summary of terms relating to haptic perception and an excerpt follows in Table 2.1. Oakley defines that “haptic” is used to indicate a combination of tactile and kinaesthetic capabilities and gives some information about the way in which haptic information is perceived including; some basic parameters of the haptic sense, the stages of perception involved, its

resolution and recognition capabilities, and the way the sense is affected by the number of contact points.

Table 2.1 Definition of Terms Relating to Haptic Perception

Term	Definition
Proprioceptive	Relating to sensory information about the state of the body (including cutaneous and kinaesthetic sensations).
Haptic	Relating to the sense of touch
Cutaneous	Pertaining to the skin itself or the skin as a sense organ
Tactile	Pertaining to touch (cutaneous)
Kinaesthetic	Meaning the feeling of motion. Refers to sensations originating in muscles, tendons and joints.

The haptic sense is hampered by a comparatively low rate of information perception. The scope of haptic human-computer interaction is mostly limited to the pressure sensors in the fingertips and the kinaesthetic receptors in the hands and forearms. Generally, tactile perception has been found to vary little from person to person (Way and Barner, 1997a). Persons with diabetes, a common cause of blindness, sometimes experience reduced tactile sensitivity. Table 2.2 provides a summary of parameters relevant to tactile perception adapted from work published by Way and Barner (1997a).

Table 2.2 Summary of Parameters Relevant to Tactile Perception

Factor	Parameters
Ratio of tactual to visual bandwidths	1:10000
Minimum discernible separation of two points (static)	About 2.5mm
Minimum discernible displacement of a point on a smooth surface	0.002 mm
Height of Braille dot	0.2-0.5mm
Minimum discernible separation of grooves in grating (dynamic)	1.0mm
Resolution of expanded microcapsule paper	1-5 capsules/mm
Displacement of expanded microcapsule paper	0.2-1.0 mm
Resolution of human fingertip	About 1 dot/mm
Best size for tactile image	3-5in to a side

According to Way and Barner (1997a) the haptic recognition task can be divided into four stages: detection, discrimination, identification and comprehension. As discussed in an earlier section, these four stages are an example of a specific instance of the breadth-then-depth search.

The detection and discrimination stages form the breadth aspect of search are achieved by identifying the presence of an object and its independence from other objects. The second aspect of search, depth, consists of identifying the object and then understanding what it means.

Due to the low bandwidth and resolution of tactile perception, it is important to avoid information overload on this sense. If many objects are

presented for tactile exploration, a person may easily forget the earlier objects due to the time taken to explore them all. The low bandwidth causes objects to be explored in an almost serial manner. This can cause difficulties in comparing dimensions or relative positions of objects (Magnusson et al., 2003). It also puts a larger demand on memory, as an understanding of a complex object must be constructed from serial understanding of its parts. The low resolution puts limits on the amount of detail that can be comprehended in a tactile manner. Higher resolution may provide too much detail with the tactile image being difficult to understand and much information may be lost (Way and Barner, 1997b).

When a three-dimensional object is explored haptically, usually all the fingers or even both hands are used to increase the bandwidth experienced. Unfortunately, most haptic human-computer interaction devices have restricted the user to a single point of contact, such as a fingertip or stylus. It has been shown that this restriction results in higher exploration times and error rates when exploring objects haptically (Kirkpatrick and Douglas, 2000). It should be borne in mind, however, only eight to ten tactile patterns can be easily distinguished at one time (Challis, 2000). These considerations should strongly influence the design of possible haptic icons in an interface.

Dulin (2007) suggests that in the tactile exploration, and the perception of the raised line materials, a high level of expertise in congenitally and early blind people may compensate for the impairment in spatial representation often resulting from lack of visual experience. His experiments involved simplistic diagrams and examined rotation, displacement (of a moving spot) and length estimation. Results showed that raised line drawings improved the accessibility and may increase the spatial abilities of blind people. An observational case study by D'Angiulli (2007) supported the notion that the “identification of raised-line pictures is based on principles of the perception of the shape of objects, independent of tactile beliefs”.

Results showed relatively poor recognition rates of simple objects, 4 of 8 correctly identified with 3 of 8 items able to be drawn as a reasonable facsimile of the original. It should be noted that the study included only a single subject and may not be representative of the blind community.

However, identification of raised line pictures is not innate and significant training is required to achieve a reasonable level of competence.

2.2.4. Auditory Perception

A major advantage of the human auditory sense is that it is inherently parallel and omni-directional. A change in auditory stimulus is noticed regardless of direction and attention. Current use of audio in non-visual user interfaces uses synthetic speech almost exclusively. It is not practical to listen to and comprehend more than one stream of synthetic speech at once. However, while listening to speech it is possible to notice a non-speech alert and decide whether to respond, without losing the sense of the speech. This demonstrates a parallelism of the auditory sense that is not currently exploited in auditory user interfaces (Mynatt, 1995).

Sound has three basic components: pitch, intensity and timbre. Pitch is related to frequency. Intensity is the amplitude or volume of the sound. The shape of sound's waveform determines timbre. Timbre is the quality that allows people to distinguish between different musical instruments. A complex sound such as that created by a musical instrument consists of many frequencies. The lowest frequency wave is referred to the fundamental frequency and this is related to pitch. In a complex sound, the frequencies are all harmonics of the pitch. If, however, the fundamental frequency is removed, the perception of pitch does not change and is somehow inferred by the listener (Brewster, 1991).

The relationship between pitch and frequency is non-linear. Pitch can also be affected by intensity. The pitch resolution of the human auditory system also varies with frequency. Brewster, (1991) gave the approximation that a human can hear frequency changes of less than 1% at low frequencies, and that this resolution increases as frequency changes towards higher frequencies.

Sound frequency is measured in Hertz (Hz) but more commonly kilohertz (kHz) as the normal range of hearing is about 20 Hz to 16kHz. Sound intensity is measured in decibels (dB) where this is the logarithmic ratio of sound air pressure to a reference. That reference is the quietest sound the average human can hear in ideal conditions, and this 0dB intensity level occurs at about 3kHz. The quietest sound that can be heard is at the frequency range 1kHz. The intensity range of human hearing varies from 6.5dB through to 120dB. A 10dB increase in intensity of a sound causes its perceived volume to double.

Frequency also changes the perceived loudness of sounds. At frequencies lower than 100Hz, intensities of 20dB and more are required for the sound to be heard. Frequency perception also varies with age. A good range for sounds to be used as interface elements might be between 200Hz and 5kHz.

It is also possible to determine the direction of a source of a sound, which forms a fourth basic parameter to the sound. Perceived direction is generally on the horizontal plane and is perceived due to a combination of the difference in intensity and delay between the two ears. However, this is also dependent on frequency and can be ineffective at around frequencies of between 1.5kHz and 2kHz (Stevens and Newman, 1991, as cited in

Brewster, 1991) and it can be difficult for the listener to tell if a sound source is directly behind or in front of them.

The pinnae, the external part of the ear, enables a listener to determine the vertical height of a sound source. The vertical height of a sound source can be measured in the form of a Head-Related Transfer Function (HTRF) which is then used to simulate vertical positioning (Roth et al., 2000). Software libraries that include generalised HRTFs are available from Intel and Microsoft and these have been used with some success. Unfortunately, these functions are dependant on the individual user's head shape and thus it could be difficult to use this effect in a commercial software package.

Pitch can be used to represent vertical position. Mansur et al. (1991) found that people naturally perceive a higher pitch to come from a spatially higher source. Researchers (Kamel et al., 2001; Yu and Brewster, 2002) have used this relationship between pitch and perceived height to add a third dimension to artificial sound.

Different sounds will tend to be grouped by the listener into different 'sources'. Brewster (1991) lists the parameters by which listeners distinguish sounds as: fundamental frequency, location, rhythm, and musical key. Perhaps the most powerful distinguishing parameter is the spatial location of the sound. The well-known "cocktail party effect" is based on this premise; a person can very effectively concentrate on one conversation in a noisy room with many conversations.

The human auditory sense is very temporally sensitive. Responses to auditory stimuli are often faster than those of any other sense. This is

aided by the omnidirectional nature of sound, in that a person will notice a sound even if their attention is elsewhere. Small changes in frequency are easily noticed, provided the change is abrupt. Changes in rhythm are also very noticeable.

There are many facets of sound, all of which can give different messages to the listener. The auditory system allows for specific attention focus, fast reaction time, and a parallelism that allows a listener to respond concurrently to different stimuli. Only a very small part of these abilities are used when listening to synthetic speech.

2.3. Braille - A Written Communications System

2.3.1. Properties of the Braille System

Braille is a system of embossed (raised) signs, which are formed by six dots arranged as shown in Figure 2.1. Eight dot Braille is also in limited use in the computer application area and is used in the display of text attributes. Each dot can be set or cleared giving 2^6 (64) possible characters in the code. As can be seen from this available number of combinations, not all characters may be represented directly by this system. (ie. 26 upper case letters +26 lower case letter +10 numerals + punctuation marks greatly exceeds 64) Therefore, a system of contractions and abbreviations for words and letter combinations exists. This is commonly termed grade 2 or literary Braille. Each of these cells (Braille characters) is context sensitive, depending on absence/existence of previous, following and symbol characters in the string being read.

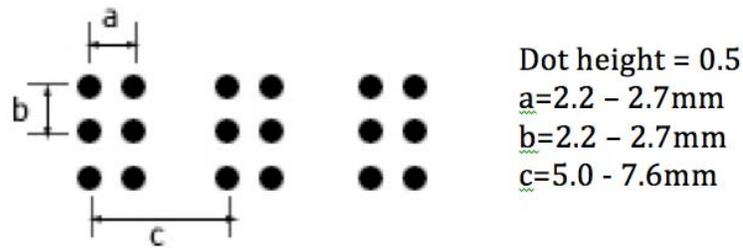


Figure 2.1: Braille cell dimensions

The majority of Braille producing countries have standards for Braille cell dimensions and spacing, for the most part based on the cells produced by the Perkins mechanical Braille writer (Gardner, 2005).

Separate Braille codes may be used for notation systems other than natural languages, such as music, mathematics and computer programming, and even for highly specialised pursuits such as chess. The basis of such codes remains an association between the 64 possible Braille characters, or distinct sequences of such characters, and the symbols and other notational elements of interest.

2.3.2. Braille Literacy in Education and Employment

It is often believed amongst educators involved the teaching of vision impaired students that Braille literacy is a crucial skill that should be mastered at an early age. Much of the literature relating to Braille literacy is in the form of qualitative studies and position statements without substantial quantitative data to substantiate this belief. Ryles (1996) examined the relationship between Braille reading skills and employment, income, education and reading habits. Her study included only those congenitally legally blind between ages of 18 to 55 with no other disabilities. Participants (n=74) were divided into two groups; those who learned Braille as their original primary medium (referred to as the BR

group, n=43) and those who learned to read print as their original primary medium (referred to as the PR group, n=31). It is of particular interest that of those eligible for the study 32% completed bachelor degrees and 23% had post graduate qualifications. 13 (30%) of the BR group completed graduate degrees whereas only 4 (13%) of the PR group had completed graduate degrees. Additionally only two of the subjects completed doctoral degrees, both from the BR group. Participants were also questioned on their perceptions of their past and present reading ability, with 35 of the 43 (81%) in the BR group stating that they read as quickly and fluently as their high school classmates, whereas 9 out of 31 (29%) in the PR group reported the same fluency as their classmates. Ryles also found that those who had learned to read Braille at an early age and used it extensively were employed at a significantly higher rate.

Whilst the Ryles study points to Braille literacy as beneficial in employment and education, Braille literacy has been falling in recent times due, in part, to the increased availability of speech and audio products for the vision impaired (screen readers, audio note takers, digital talking books etc). The National Federation of the Blind in the United States of America estimates that Braille literacy of school age children is now at 12% compared to 50% in 1960. (NFB, 2006) Halliday (1998) proposed arguments both for and against the use of Braille when compared to speech, which he summed up as “the debate is actually over which medium is the best alternative to sight”. He reported that among people who use both Braille and speech equally, many find that speech is a more efficient form for reading and reviewing text but as documents become more complex, either in format or content, Braille becomes preferable. Speech is linear in nature so there is no inherent spatial characteristics that reflect the layout of the text in print or Braille format. Halliday also points out “there are fundamental cognitive and mechanical differences between being read to and reading”. Reading Braille is similar

in many ways to that of reading print. Readers adjust the speed and repetitions of phrases to match the comprehension of the material being read. Speech rates may be adjusted and phrases repeated but not automatically by the user, it requires conscious steps to stop the audio stream, rewind and/or adjust the playback speed. In the case of computer languages, mathematics and numbers ambiguity may exist, particularly when no context exists to aid recognition. Differentiating between consonants (T, E, C and D for example) is dependant on the acuity of the users hearing. Braille has significantly less ambiguity.² When compared to speech, Braille may be preferable

The evidence tends to show that Braille literacy, whilst falling, continues to be beneficial in education and particularly for those technical areas.

2.4. Human Computer Interaction

Effective communication demands that information is transferred between at least two entities and while technology provides many enabling devices vision impaired technology users often require purpose designed communication output devices rather than purpose designed input devices. As one would expect in a rapidly evolving product market where profit directs development, research into the manner of interaction between humans and computing devices tends to focus on the majority of users with less attention devoted to special needs minority groups.

² Ambiguity does exist in Braille, for example the Braille symbol for | and \ are the same.

Barber (1997) discusses the importance of considering the term 'HCI' to relate to human computer *interaction* in preference to human computer *interface*. Human computer interface tends to focus on a requirement for users to possess an ability to see a screen to enable effective communications with that computing device. Barber (1997) considers and discusses three primary implications of this perspective on interaction rather than interface. First, the physical activity for most computing users is reduced to entering information as the end product of cognition whereas an interaction perspective demands a dynamic process of communication. Whilst this may have been true for early systems, for example data entry in batch processing systems, it does not hold true for modern computer applications. It may be considered that a major use of computers nowadays is that of information retrieval, workflow management and facilitating workplace procedures rather than that of data entry.

Secondly, by adopting the interaction perspective one may then consider activity with devices as tool use. Thirdly, the use of a tool would normally imply that the activity is directed towards achieving an objective through purposeful behaviour. Barber (1997) concludes that human computer interaction must therefore be grounded in work practice. This attitude would see the focus move from being on devices used to communicate with computers to where computing interaction devices become central as the tools to mediate achieving communication objectives. The physical appearance of computing interaction devices can suggest to users an interpretation of permissible user actions. The implication is that a device is task specific serving as a tool to mediate a human activity. The user's interaction with a computing device occurs in real time with the user's performance being guided by various types of interaction feedback. Types of interaction feedback range from kinaesthetic limb movement and related information to data requiring translation and interpretation before being presented as information to the user.

Barber (1997) explains the difference between interaction and interface with examples such as the computer mouse (interface device) which is easier to use to select an onscreen object and initiate an activity than it is to remember a series of typed commands (interaction). Whilst this may be true for the majority of users, it is not true for all. The obvious exception is those who use text to speech (TTS) as the display modality. When utilising a screen reader with TTS output is serialised i.e. all information is read as a single dimension sequential list unlike a standard visual display where information is displayed in two dimensions but randomly accessed. For a screen reader user, it is much easier to use a series of typed commands than to navigate a graphical arrangement of objects. A comparison of these “display” techniques will be explored in greater detail in later sections of this thesis.

The difference between interface and interaction might be considered as only a subtle change in one’s point of view because at times authors tend to use these two words interchangeably.

Raskin (2000), when discussing the concept of the “Humane Interface” proposes that humans can only consciously do one thing well at a time, providing the example and explanation that most people can walk and speak with a companion simultaneously because the conversation is the only conscious task being undertaken. Raskin suggests that after an initial learning phase, all interaction with the “Humane Interface” should become habitual and an unconscious activity because it has become an automated interaction. Raskin further suggests guidelines to promote computing commands becoming habitual more quickly:

- All modes should be eliminated.
- The system should always react in the same way to a command.
- Generate user modes errors.

Raskin (2000) explains that modes are differing types of responses based on context and that receiving unexpected or different responses is undesirable. All responses should be predictable and based on context and the user should not have to pay attention to the system's current mode. The user should only have to pay attention to their content and be alerted by the system to any user mode errors. Raskin also recommends monotony and non-multiple command paths. The monotony of performing tasks in the same manner more quickly leads to habitual and therefore unconscious interactions. Also, that the regularly provided multiple command paths to achieve computing tasks requires users to disengage from actual work to decide the manner in which they will operate tools. This is particularly true for screen reader users as they generally rely on memorised series of commands to perform tasks. It is not efficient to explore menus and dialog boxes, as a sighted user would do, if searching for a particular command. This is due to the serialised output (or display) of TTS.

Barber (1997) concludes that simple tasks should always be simple to perform and that design should be based on "universal psychological facts" rather than "industry standards". Methods deploying devices for communicating between humans and computers in order to accomplish complex computing tasks maybe thought of as being assistive technologies.

2.5. Assistive Technologies

2.5.1. Human Senses and Assistive Technology

Most humans enjoy the full use of two types of sense, exteroceptive and interoceptive. There are six exteroceptive senses, better known individually as; sight, taste, smell, touch, hearing, and balance. It is the interoceptive sense that informs us of the relative positions of our body parts in relation to each other. Proprioception is a sensory modality that informs us of the status of internal body parts. Assistive technologies are those technologies that promote better communications between humans with impaired exteroceptive senses perception and computing devices.

In this study, primary consideration addresses the needs of the sight impaired. Technologies that are considered assistive to the sight impaired concentrate on two senses, touch and sound, to compensate for limitations with sight. Assistive technologies focussing on sound are referred to as auditory devices, while those focussing on touch are haptic and tactile devices. Human computer interaction developments and implementation of auditory and haptic devices are strongly influenced by user demand in the computing entertainment and gaming arena.

2.5.2. An Historical Perspective on Assistive Technology

Prior to the mid-1970s, the rights of people with disabilities were very limited, until the World Health Organisation (WHO) published official definitions for the terms disability, impairment and handicap in 1980. It also show-cased some of the prototype accessible technology during the International Year of Disabled Persons. One of the more significant items on display at this time was the SYNTE2, one of the first microprocessor-

based and portable speech synthesizers in the world. (Hollier and Murray, 2004)

During the 1970s and 1980s countries such as the United States of America, the United Kingdom and Australia developed a legislative framework to provide more opportunities and facilities for people with disabilities. The development of these policies increased societal acceptance of people with disabilities as equals as well as access to education.

The development of computer technology at that time provided additional educational opportunities for these people and the emergence of assistive technologies, mainly for the blind. Data in electronic format was easily output in an accessible format. Many of the early assistive technologies focused on assisting people who were blind or had vision impairment via speech synthesizers based on the Votrax speech synthesis chipset. Examples of these synthesizers included the Brother Caiku, Eke, Humanica and Task. Over the course of the 1980s, other products were made to assist people with different types of disabilities through the use of light pens for people with mobility impairments, and on-screen alerts for people with hearing impairments. (Hollier and Murray, 2004)

However computing technology developed at a much faster rate than the assistive technologies and few mainstream firms, with the exception of IBM, included accessibility issues in their release of products. Specialist companies then began producing assistive technologies, resulting in expensive products that were out of the financial reach of their target users. In a world that was becoming technology dependent the gap of inequity for those with disabilities became more noticeable.

The mid to late 1980s provided many benefits for people with disabilities, with a reduction in the price of assistive technologies as the existing technologies became more established. The IBM PC platform provided a firm base for assistive technologies due to its popularity by the business and education sectors. Another advantage of the IBM PC was that the interaction was purely text-based, allowing assistive technologies such as speech synthesizers to easily interpret the information (Lemmetty, 2004).

However, the lack of direction from government policy posed problems for the application of assistive technologies in education environments. Educational institutions determined the best technological solutions for their students, but the small client base made it difficult to justify the economic outlay. The platform upon which the assistive technologies would operate also needed to be determined. For example, the Epson HX-20 (see Figure 2.2) was considered by many Australian educators to be a vital tool for developers in the early to mid-1980s for blind and vision impaired people. The reason for this selection was due to its portability, built-in screen, and relative affordability at approximately \$4,000AUD. However, software speech synthesis could be better handled by popular 8-bit machines such as the Commodore 64 and, in the mid- to late-1980s, the Commodore Amiga range of computers. Furthermore computers such as these also had support for light pen technology that would assist people with mobility issues. Additionally, machines such as the Apple II were cheaper and already had a significantly larger user base than the Epson HX-20 (Hollier and Murray, 2004). The Eurika A4 (see Figure 2.2) from Robotron was a highly successful note taker and computing platform available from the late 1980's to mid 1990's. It incorporated a large number of features including database, telephone dialling, word processing and music composition software. However it was still relatively expensive at \$4,200 for the "professional" model.



Figure 2.2: Early speech capable computers, Epson HX-20 (Circa 1981) left and Robotron Eurika A4 (Circa 1988) right

By the end of the 1980s individuals with disabilities were finally getting greater access to information and legislators, particularly in the United States, were strengthening their disability laws. Although the evolution of technology still seemed to be volatile for specific IT-based legislation for people with disabilities, the ongoing public education of the needs of people with disabilities strengthened during this time (Bricout, 2001).

Late in the 1980s the Graphical User Interface (GUI) emerged. Gaining significant popularity from the commercial success of the Apple Macintosh released in 1984, numerous platforms began to focus on GUI implementation. 16-bit systems such as the Commodore Amiga and the Atari ST were developed as GUI operating platforms. Even older 8-bit platforms such as the Commodore 64 received a GUI overhaul from programs such as GEOS being built into the sale of 8-bit machines. The fading CP/M operating system and the popular MS-DOS operating system were now making way for newly developed operating systems by Microsoft and IBM on the IBM PC platform.

Two GUI products on the PC platform gained popularity towards the end of the 1980s - Microsoft Windows 2.0 and IBM's OS/2 1.1. Both products still incorporated text-based DOS functionality (which was accessible by the then current assistive technologies) but the dominance of the GUI was evident. Although IBM endeavoured to provide accessibility features in OS/2 with a degree of success, most of the large corporations did not implement accessibility features into the new interface. This left much of the assistive technology useless. In the rush of competition and innovation, people with disabilities were once again faced with the likelihood of trying to catch up to the able-bodied population in an attempt to embrace technological equality.

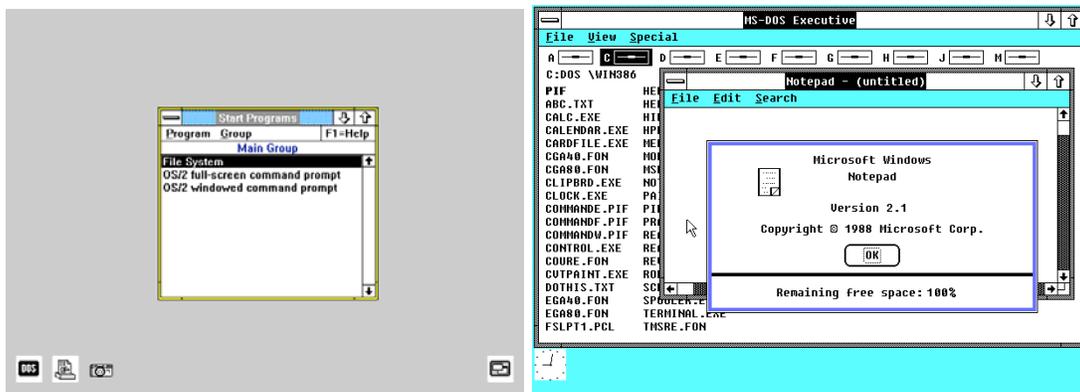


Figure 2.3: Screen captures of early GUI systems. OS2 1.1 left, and Microsoft Windows 2.1, right. (source: <http://pages.prodigy.net/michaln/history/os211/index.html>)

The concentration of graphics and images in software applications has increased over the past two decades, with frequent utilisation of colour, shading, 3D images, rotation, animation and dynamic movement. Assistive technologies do not currently have the capacity to interpret and deliver these features to vision impaired users. The most common assistive technologies utilised by legally blind students currently are

screen reading software, screen enlargement software, Braille Display units and swell paper printouts (for example PIAF hardcopy).

2.6. Haptic Devices

2.6.1. Haptics and perception

Haptic relates to perception and manipulation of objects using the senses of touch and proprioception. In a technical sense, the term Haptic, an adjective of Greek origins, relates to the sense of touch and when applied to human computer interaction refers to touch related sensory devices and sensations.

Yu et al. (2000) state that while touch is considered a secondary sensory medium to sighted people, the sight impaired consider touch as being crucial and to be their primary sensory feedback.

Haptic devices allow users to interact with computing interfaces utilising the user's sense of touch by means of either force feedback or tactile devices. Brewster and Murray-Smith (2000), state that this type of interface has the potential to significantly alter the way users interact with systems and pose the questions;

- What are haptics good for?
- What kind of information can be successfully presented by touch?
- Do haptics actually improve efficiency, effectiveness and user satisfaction?

To better consider these questions in relation to the application of haptics to an e-learning environment in computing for the vision impaired further examination of haptics is worthwhile.

2.6.2. Haptic Receptors

Cutaneous and kinaesthetic are the two main types of haptic receptors located throughout the human body. Cutaneous haptic receptors reside beneath the surface of the skin and respond to pressure, pain and temperature. Kinaesthetic haptic receptors are located in muscles, tendon and joints, and correspond to the position of limbs and their movement in space (Klatzky and Lederman, 1999; McGee et al., 2000). McGee and others (McGee et al., 2000), define the human haptic system to consist of the entire sensory, motor and cognitive components of the body-brain system. They further explain that in relation to haptic sensations, ‘tactile’ pertains more specifically to pressure sensations rather than temperature or pain in cutaneous receptors and that forced feedback is associated through kinaesthetic receptors because the mechanical production of information communicates to muscles, tendons and joints. Cutaneous and kinaesthetic haptic receptors assist a person to determine the shape, texture, and other physical attributes of an object.

In determining shape, Kirkpatrick and Douglas (2000) describe a benchmark for evaluating the usability of haptic environments for a shape perception task. This work examines how well participants recognise a set of shapes, cup, saddle, ridge, rut, and cap. It is impractical to expect the vision impaired to recognise or to determine complex shapes when they have no concept of what the shape looks like.

Fundamental to accurate human recognition of physical objects is, according to McGee et al. (2000), an object’s surface texture. Perceiving

information relating to the texture of an object greatly improves the opportunity to accurately identify that object.

Other attributes determined by haptic receptors to assist object identification would include feeling an object's weight. To communicate haptic sensation to humans, various computing devices are employed.

2.6.3. Haptic Device Types

There are limitations to the types of computer output devices suitable for incorporation of a haptic device. The commonly used mouse has been subjected to considerable effort in the endeavour to incorporate haptic feedback. Examples include the vibrating mouse that reflects sounds in multimedia applications but is primarily intended to enhance the experience of a sighted user. The types of haptic mouse can be separated into two categories: the haptic mouse with tactile displays mounted on them, and the force-feedback mouse that simulates objects and textures using forces.

An example of the force-feedback mouse is the product ScreenRover from Betacom Corporation Inc. ScreenRover is a motorised mouse that uses force-feedback to help the user explore the 'screen'. This mouse system generates a variety of pull-push effects to distinguish icons, controls and text. It also guides the user to the active area of windows and its elements, allows the user to position and size jpeg and bitmap formatted images, distinguishes frames on websites and multiple windows, and reads any text on the user's screen. (Screen Rover, 2006)

Sjöström (1999) discusses another force-feedback mouse, the Virtual Reality Mouse, released in 1995, that consisted of a mouse attached to a force generator by a bar at the front, where the cord usually is, allowing an output of up to 1kg of force. The Virtual Reality Mouse was designed to work with the Microsoft Windows 95 and 3.x operating systems haptically rendering Microsoft Windows screen display elements and was compatible with several common screen readers and magnification programs.

The Feelit mouse, a product by Immersion Corporation, was an attempt at haptically enhancing Microsoft Windows screen displays by directly representing all display elements via a force-feedback mouse on a mouse-pad sized workspace. A disadvantage of the Feelit mouse is that it has a small workspace and low force capability, this is countered because it is intended for the general market and is thus made more affordable. The concept behind the development of the Feelit mouse was taken over and commercialised by Logitech and released for distribution as the Wingman force feedback mouse as shown in Figure 2.4



Figure 2.4: Logitech Wingman force feedback mouse

Source: <http://www.amazon.com/Logitech-WingMan-Force-Feedback-Mouse/dp/B00001W01Z>

O'Modhrain and Gillespie (1997) constructed a prototype force-feedback mouse for user interface display to the blind called the Moose. With the Moose, Microsoft Windows elements are represented using variable resistance to create haptic icons. The created haptic icons became known as 'hapticons'. The hapticons presented individual force characteristics that identify the element. Actions such as the commonly used 'drag-and-drop' can be represented haptically. With the 'drag-and-drop' instance, the puck seems heavier when an item is being dragged. The mouse is perpendicularly connected to a workspace tablet by a flexible spring steel allowing an effective workspace of 3cm square.

An early example of placing a tactile display on top of a mouse was developed by Terry and Hsiao (1988). A small pin, mounted on the top of a mouse, vibrated when the cursor was over a predefined screen target. Experimentation showed that the tactile feedback slightly reduced targeting time when used as a supplement to visual targeting tasks.

The Virtac system, designed by Jubinski (1992), provided tactile access to the entire screen of an IBM PC by attaching a rectangular array of Braille-like pins to the top of a mouse allowing the user to explore the whole screen a bit at a time. Virtac was designed to eavesdrop on the visual memory of the computer without adding any extra load to the CPU. Because no mention of optical character recognition was made it was assumed that it would not be possible to read text using this system, unless the text was large enough for its pictorial representation to be recognised.

Another example is a VirTouch Ltd product, the VTPlayer, a tactile mouse also capable of screen navigation, see Figure 2.5, that looks like a normal mouse except it has two 16-pin displays, similar to those on a refreshable

Braille display. The Braille display is mounted where the user's first two fingers sit on top of the mouse and form a tactile representation of the screen environment under the cursor while the input functions as found on a normal mouse are still available. Prior to the VTPlayer, the VirTouch Mouse using 32 pins under each of 3 fingertips gave a better resolution and set the original design principles as the predecessor of the VTPlayer.



Figure 2.5: VirTouch Ltd, VTPlayer

Source: <http://hcil.cs.umd.edu/trs/2004-36/2004-36.html>

2.6.4. Haptics Research

Wies et al. (2000) discusses research that attempts to use a force-feedback mouse to improve introductory understanding of electric field theory with promising results where project testers reported that their understanding was significantly improved by the program.

Sjöström (1999), using the FeelIt mouse prototype, extended its basic graphic-to-tactile conversion to improve haptic modality. Sjöström proposed several virtual haptic search tools to resolve the difficulty of finding isolated objects, such as icons on a desktop. Sjöström implemented a search tool in the form of a virtual cross that provided

feedback when the cursor was horizontally or vertically lined up with an object. Users found the tool helpful, but found the small workspace of the Feelit mouse very difficult. Other proposed search tools included; a magnet-style tool, which pulls the cursor towards a nearby object, and, a 'ball' tool that allows users to feel objects at a distance but with less detail.

Both the Feelit and Wingman mouse were designed to enhance a visual interface interaction. Advertising material suggests that users will find games more enjoyable and work easier by using a haptic feedback device. Research based on the suggestion that work would be easier lead to confirmatory results when Oakely et al. (2000) conducted usability testing on haptically-enhanced scrollbars and buttons using the product known as Phantom. Results indicated that users found effort and frustration were significantly reduced when using a device offering a haptic recess effect.

Yu and Brewster (2002) used standard interface methods on the Phantom and Logitech Wingman mouse to render line graphs. They added optical scanning and image filtering software to enable blind users to explore conversions of printed graphs. The line was represented as a groove in the back wall of the Phantom's workspace and as a 'sticky' line for the Wingman mouse. Yu and Brewster noted that although the rendering was quite different, the devices required the same data input. The input data consisted of; the start, the end, and the intermediate points of the lines.

2.6.5. Three-dimensional haptic devices

2.6.5.1. Devices and overview

Three-dimensional haptic devices have proved very attractive to researchers due to the flexibility implied by the use of three dimensions

and enabling them to present all possibilities of virtual haptic environments for investigation. The PHANToM and Impulse engine are the most commonly-used devices in this type of research. Although three-dimensional haptic devices were originally expensive and costs hindered widespread user access, recent developments indicate increased user access will result from reducing costs with tools such as the SensAble Technologies product PHANToM Omni model, see Figure 2.6. The PHANToM Omni model is a robotic device that provides one-point force-feedback in three dimensions. Three motors provide applied forces based on the manipulandum position to give the effect of a solid object in 3D space. The PHANToM Omni model workspace volume is 13 x 18 x 25 cm with a position resolution of less than 1 mm. Optical sensors monitor the user's movements so that the information can be used to calculate feedback. The feedback is given by a manipulandum attached to the end of the robot arm via a freely rotatable gimble. The manipulandii provided are a stylus and a thimble.



Figure 2.6: The PHANToM (left), the PHANToM Omni (right) Source :

<http://www.inition.com/inition/>

The PHANToM has proven to be a useful hardware device in a number of research projects conducting studies into virtual haptic devices and their

application. As no software was provided with the first version of the PHANToM device, this encouragement large scope haptic programming research. Since that time, several commercial software development kits for the PHANToM have been developed; including OpenHaptics and Ghost SDK, permitting more and easier experimentation of the hardware device.

Wall and Brewster (2003) state, “Research has shown that the PHANToM is effective at displaying graphical information to blind people, but the techniques so far have been very simple. The ‘point interaction’ nature of devices such as the PHANToM further exasperates the problem by limiting the cutaneous feedback available to the user. The rich, spatially distributed nature of visual cues is not available; hence, users must successfully integrate “temporally varying” cues as they traverse the objects or surfaces. For large or complex data, this places considerable short-term memory demands on the user, thus reducing performance, and comprehension of the data” (Wall and Brewster, 2003, pp 858).

One of the earliest significant researchers who used the PHANToM was Minsky (1995) who wrote programs to simulate complex virtual textures such as sandpaper. Numerous researchers have since investigated other virtual textures. Extensive research, programming and usability testing with the PHANToM have been conducted by Sjöström (1999, 2002) and colleagues at the Certec rehabilitation research centre at Sweden’s Lund University of Technology. Fritz and Barner (1999), investigated textures, force fields and mathematical plots, whereas Oakley et al. (2000) researched 3D haptic augmentations to a graphical user interface.

Fritz and Barner (1999), aimed to make mathematical graphs accessible to blind people. They considered one, two and three dimensional data and provided a detailed description of the mathematical process required to translate an idea into a force profile suitable for implementation on the

PHANToM. This work included force vector derivation, texture, and resolution. Fritz and Barner (1999) also considered the modelling of objects with the use of a line of attractive force to render a line. This attractive force is similar to that which would be felt if the line was an iron wire and the manipulandum a magnet. Three dimensional vector fields were represented directly as force fields. These are useful to aid in the understanding of subjects such as electrical fields, fluid dynamics and gradients.

In the basic PHANToM toolkit, 3D surfaces can be modelled but they all have the same 'slippery' surface texture. The basic Phantom model does not provide any information about data values on a mathematical surface graph and it can be easy to slip off the surface. Fritz and Barner (1999) continued by suggesting grid lines or tick marks to provide a frame of reference in a haptic graph. Data values could be estimated using these marks or presented in a different way, for example speech. Surface friction can be used to improve users' adherence to the surface or to represent other information such as emulate physical resistance in a fluid. Fritz and Barner also consider various methods for creating virtual texture. These textures can be used to give a sense of colour depth, a smooth texture indicating a light colour and a rough texture indicating darker areas. When implementing lines and surfaces to represent mathematical equations, Fritz and Barner used virtual walls to make it easier for a user to find the relevant part of space.

Oakley et al. (2000) utilised the PHANToM to investigate the use of touch as a way to reduce visual overload on conventional user interfaces. They represented a screen by using the 'back wall' of the PHANToM's operating space. This was used in conjunction with an adjacent visual monitor. The experiment was concerned with enhancing standard user interface buttons using haptics to decrease error rates and increase usability. Four

effects were used to augment the buttons: texture (a ripple pattern), friction, recessing (or engraving) and gravity.

Oakley et al. (2000) conducted usability testing on their button enhancements, measuring task time, error rates, and subjective workload via a modified version of the NASA Task Load Index (Hart & Staveland, 1988). They found that the gravity effect significantly reduced user errors when compared to the control (no haptic effect), while the texture effect actually increased errors. Correspondingly, the gravity effect reduced subjective workload measures, while the texture effect increased workload.

In a second experiment, conducted by Oakley et al. (2000), the objective was to measure the usability of the gravity condition in a more realistic task. A gravity and recess enhanced scrollbar was tested in an experiment designed to simulate normal operation, where a scrollbar is frequently needed but the visual focus is elsewhere on the screen (in the text area). The authors found that the haptic enhancement decreased perceived effort and frustration, but had no significant effect on fatigue or mental demand.

Sjöström (1999, 2002) and colleagues at the Certec research centre spent many years on rehabilitation engineering research and used the Phantom in numerous tests and evaluations to clarify the extent to which a virtual environment is understandable and useful to blind people. These have involved programs for games, mathematics, drawing and navigating. The programs are also seen as investigatory steps on the way to a future complete haptic interface called Touch Windows.

One of Sjöström's (1999) first programs was called the Memory House. This was an array of buttons embossed on the 'back wall' of the workspace that made a sound when pressed. The object of the game was to eliminate

buttons by pressing buttons with matching sounds, similar to the game ‘Concentration’. Tests conducted on the Memory House showed that almost all blind users were able to complete the game. Two out of the nine were unable to finish, although they did find some pairs. These users may have benefited from more practice with the device and/or a tutorial on its use. It is especially interesting to note that several blind users finished the game using a similar number of button presses to that of a sighted group of test subjects using a mouse. This, along with the fact that seven users finished the game, would seem to show that it is possible to understand and remember a reasonably complex virtual haptic environment.

Table 2.3: Applications Developed and Tested by Sjöström (1999, 2002)

Application	Description
Submarines	A haptic version of the Battleships game
Paint with your fingers	Simple drawing program
Early mathematics program	Simple mathematical curve representation, using a ridge or groove
The Memory House	Spatial and memory game
Haptics in Collaborative Virtual Environments	Collaborative haptic manipulation
Radial Haptic Menus	A menu organised like a clock face
Virtual Haptic Search Tools	A ‘cross’ that gives feedback when the cursor is in line with a screen object
Mathematics – Herbivores and Carnivores	Mathematical simulation of population relationships
Textures	Simulation of textures such as sandpaper, corduroy and wood

Line Drawings	Monochrome line drawings
Floor Plans	Raised floor plans of building interiors: rooms and corridors
Geometrical Objects	Recognition of cubes, cylinders, spheres.
VRML Objects	Recognition of complex realistic objects
Traffic Environment	Training and game with buildings, roads, cars.
Sound Memory Game	Haptic and audio sound matching game
Mathematical Surface	Graphing program where equations can be entered as text

These programs were conducted testing both blind and sighted users. Attention was paid to the user's actions, ideas and feelings rather than objective measures (eg task completion time) in order to improve the perceived usability of the applications and tools. The results from these tests are presented in the form of guidelines for haptic interaction design, and are presented in a later chapter.

Penn et al (2000) experimented on roughness perception using the PHANToM and concluded that there was a negative relationship between groove width and perceived roughness; that is, the surface seemed rougher as groove width decreased. This is contrary to experiments with real textures that have been proven to have a positive relationship. This result is a demonstration of how different narrow one-point interaction can be from conventional means of haptic exploration. Penn et al (2000) also found that the thimble created greater 'sensitivity' than the stylus. Perhaps this was due to the users expecting one-point interaction when

holding a pen-like object, but being accustomed to an area of sensations when using a fingertip.

Yu et al. (2000) investigated two simple line graphs using the PHANToM. The lines were modelled as embossed cylinders, using 'sticky' or 'slippery' effects to distinguish between them. Blind and sighted participants tested the graphs, with mixed results. Participants confused the lines, found it difficult to keep the pointer on the line (especially at corners and ends) and many could not understand the intersection points between the lines. However, most users were able to distinguish between the textures used and gain some impression of the shape of the graph.

Gridlines were not very effective and added further confusion. It was found to be very difficult to provide estimates of coordinates, for example, maximum or intersection points. Yu et al. (2000) recommended that additional information be available; for example, a speech output of the current cursor position available on request. The results made it clear that the embossing technique is not suitable for force feedback devices. Yu and others suggested the use of a groove instead, and additional features such as selective display of lines could also be helpful. A non-speech audio 'overview' feature was proposed.

The PHANToM can be used to construct very complex virtual environments. It has been used for scientific visualisation of complex models (Hollerbach, 2000). Ruspini et al. (1997) used polygonal rendering techniques with the PHANToM to construct complex haptic models. For instance, a virtual AT-AT walker consisted of 11088 polygons, and a very realistic-looking teapot was constructed from 3416 polygons.

The Immersion Impulse Engine, see Figure 2.7, consists of a pen-like probe which can move in three dimensions. This device, as discussed by Colwell et al. (1998), provides up to about 8 Newtons of force-feedback depending on the position of the probe.

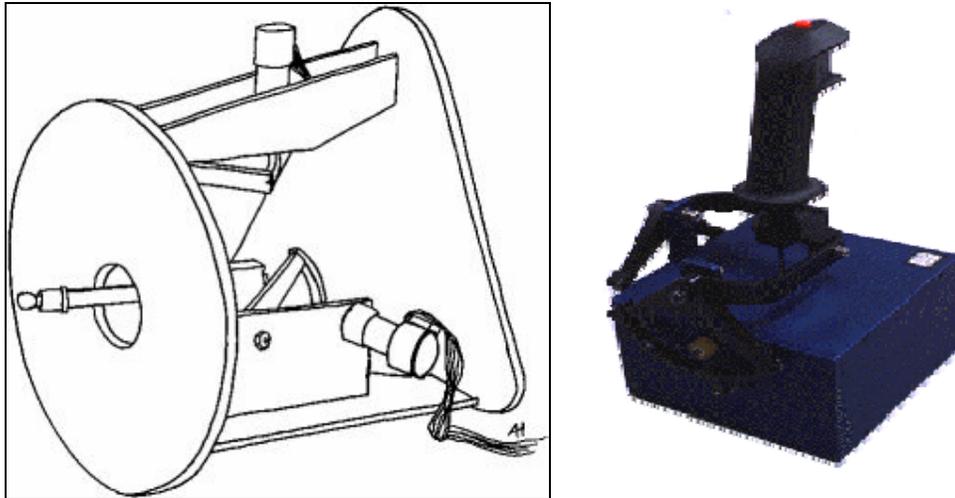


Figure 2.7: Immersion Impulse Engine

Source: <http://ldt.stanford.edu/~yasukato/portfolio/class/cs147/as8/>

Colwell (1998) used the Impulse Engine to investigate users' perception of virtual textures and 3D objects. A similar experiment to that of Penn et al (2000) was conducted to determine relationships between perceived roughness and simulated groove width of a sinusoidal texture. Colwell et al. (1998) found that some people perceived a negative relationship and some a positive. This would seem to be a caution to researchers that not all people respond the same way to virtual environments.

Colwell et al. (1998) also conducted experiments on size and angles of virtual objects. They found that haptic size estimation was approximately correct from the outside of the object, but sizes were significantly

overestimated when the inside of the object was presented. Colwell and fellow researchers nicknamed this observation, the 'Tardis' effect.

2.6.5.2. Tablets

Tactile graphics tablets have created interest with researchers and as a consequence have received much attention because they are seen as the most direct way to represent the information on a visual monitor. Tactile graphics tablets are frequently comprised of a large rectangular set of pins that can be raised and lowered like those in a refreshable Braille display. Other approaches have seen the use of vibrating pins or plastic bumps.

An important benefit of tactile tablets is that they often support multipoint interactions like those in the real world in that objects can be felt with all fingers of both hands, rather than with the point of one stylus or by the movement of a mouse. This allows maximum use of the small bandwidth capabilities of the sense of touch. Although this would seem to be a very promising means of tactile display, commercialisation of this type of device has been severely hindered by the large cost associated with manufacturing the displays. Research has been conducted in the creation of different types of display, however only the pioneering device, Optacon (see Figure 2.8) was made commercially and it suffered business related challenges. The Optacon name is derived from the first few letters of each word in the phrase **O**ptical **T**actile **C**onverter.

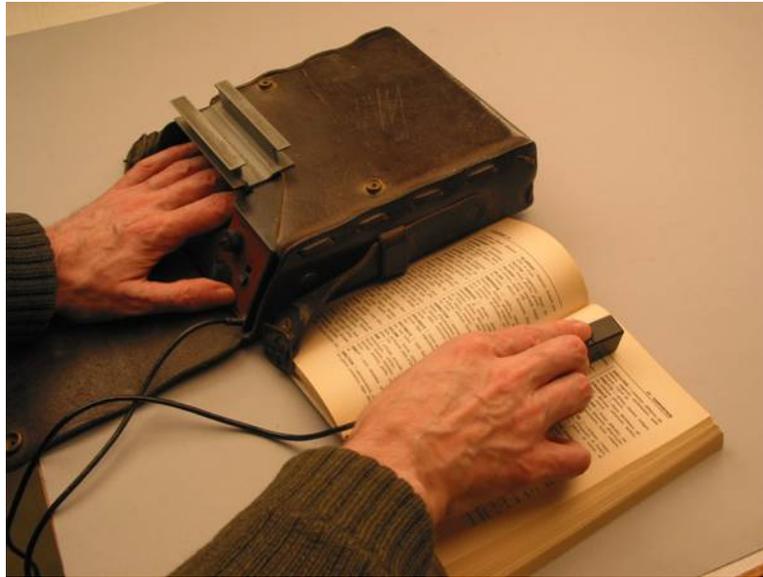


Figure 2.8: Optacon

Source: <http://www.upgrade-cepis.org/issues/2007/2/upgrade-vol-VIII-2.html>

The Optacon has a vibrotactile display that was designed to allow access to printed text. It consists of an optical scanner and an array of pins that vibrate according to light and dark areas under the scanner. According to Way and Barner (1997b) it is possible to read normal text using the Optacon, but reading speeds are very slow and although the vibration can temporarily reduce sensation in the user's finger this occurs after much continuous use. Way and Barner (1997b) also noted that many blind people have found the portable Optacon to be invaluable for activities such as reading labels on supermarket items.

Vanderheiden (1992) discuss System 3, a product including a graphics tablet that was used with a special puck with a set of 100 vibrating pins on top. Its position on screen was directly related to its position on the tablet. System 3 provided direct access to the whole screen and also had

the capacity to zoom into portions of the display screen. Despite its potential, the idea behind this hardware device was not developed further.

Shaped memory alloys have also been used in the construction of tactile graphics displays. Two major disadvantages of this approach are that the metal is activated by heat and reacts in a non-linear manner. Howe et al. (1995) created a tactile display with a pneumatic cooling system and feed forward derivative sensing and position sensing to improve accuracy. This allowed the display to be used accurately at 6Hz; their goal (based on research on tactile perception) was 10Hz. They proposed that this could be achieved through liquid cooling and improved control models.

Wagner et al. (2002) constructed a 6 x 6 array of pins that could be mechanically raised to between 0 and 2mm. Resolution was around 3mm. This implementation required the array to be mounted on a reasonably large column of motors (around 15cm tall), and this box increased if resolution or array size were increased, making the device very bulky. It achieved their aims, though, of relatively low cost and large vertical displacement.

Shinohara et al. (1998) developed a prototype tactile tablet that could present three-dimensional objects. Its 64 x 64 array of pins could each be raised in 0.1mm steps to a maximum height of 10mm. The third dimension can be used to represent shade in a monochrome image. They found that blind testers could recognise particular parts of the brain on an image of the cerebral cortex which was represented on the prototype. The high level of complexity in this device has led to its bulky sized and high cost.

Fricke and Baehring (1994) recognised that tactile tablets had great potential but that the costs of electromechanical tablets were prohibitive for the average user. Their research concentrated on a tablet consisting of a board with small circular channels. The ends of these channels were closed by an elastic membrane that could be raised by the activation of an electrorheological fluid in the channels. They believed that this method could be used to create a comparatively low cost tactile array with no failure prone mechanical pins. An estimate gives a total cost of less than twice the price of an 80-character Braille display. In addition, a better resolution could be achieved without the mechanical elements.

They proposed that a blind person could use the tablet to mark areas of text and graphics on a display for character recognition. This approach has been largely outdated by the provision of software interfaces such as Microsoft Active Accessibility, but could still be useful for the numerous times when text is provided embedded in an image. The tablet could also be used for presenting mathematical formulae.

Taylor et al. (1997) also researched an electrorheological fluid based tactile array. Their array was 5 x 5 with a vertical force of around 150 grams. Each cell was activated by pressure using a stylus or similar, implying that the array could also detect the user's movements. However, each cell was large: 11mm square. The principles they used could conceivably be applied to much smaller cells and larger arrays, and it is anticipated that this type of display could be comparatively robust and inexpensive due to the small number of mechanical parts. Yobas et al. (2001) have developed a miniature pneumatic valve that can deliver sufficient air pressure under a polyurethane sheet to emulate a Braille dot.

Watanabe and Kobayashi (2002) developed a tactile tablet that was designed to allow blind people to draw and erase raised lines. A matrix of 768 pins 3mm apart could be raised or lowered electronically, according to the movement of a stylus attached to a 2-axis positioning arm. The tablet acted simultaneously as an input and output device, as the user could draw using the stylus in one hand and feel the result using the other. This could enable direct manipulation in the user interface such as drag-and-drop tasks. Watanabe and Kobayashi (2002), report that user trials indicated the tablet had good potential, but the pins were too far apart to accurately represent a line. In addition, a left-handed user found the stylus difficult to use due to the structure of the positioning arm.

2.6.5.3. Static displays

Yu et al. (2000) discuss that graphs and diagrams are often presented using static means, for example using Braille and raised lines on microcapsule paper, also known as swell paper, and that the problems with this include the small proportion of Braille literacy, dynamic data cannot be displayed, it is impossible to change the data and a new sheet must be constructed, along with the issues associated with low resolution and accuracy of the displays.

Kociolek et al. (1999) developed a method of printing Braille on memory shape plastic films. These could be embossed and also erased using heat of around 40 degrees Celsius. This would provide a way for blind people to draw and erase lines. Although this provides a static display, it may be worth investigating a similar material for a dynamic display.

Way and Barner (1997) developed a method for automatic production of comprehensible tactile images. They used various image processing techniques to reduce detail in an image such as a photograph to make it suitable for tactile perception. This image could then be printed on swell paper. Way and Barner (1997) also provided specifications for microcapsule paper and its applications.

Challis and Edwards (2001) developed an application to improve the accessibility of music notation. Conventional non-visual music notation (eg. Braille music and Talking Scores) is almost serial. This means that it is not easy to ignore irrelevant information, for example other musical lines. In addition, they form a different mental model to that of graphical music notation, which makes communication between sighted and blind musicians difficult. This project, dubbed Weasel by its authors, used vacuum-formed PVC overlays that were designed to correspond with their visual counterparts. Different heights were used to convey different information. The overlay was placed on a touchpad that could provide audio descriptions of elements and a control section at the bottom to change settings. User assessment was by a group of six competent musicians, five sighted and blindfolded and one blind. The group was trained using five introductory overlays then asked to describe the information given in a new overlay and use the control section to change some settings. The tests were assessed in a subjective manner to gain information about users' understanding and ease of use of the Weasel system.

Challis and Edwards (2001) concluded that the following principles should be used when designing a static tactile display:

- Consistency of mapping between visual and non-visual displays
- Use tactile representation for static data only

- Height should be used to discriminate between information types
- An excess of empty space should be avoided
- A tactile representation identical to its visual equivalent can cause difficulties
- The design should encourage a specific exploration strategy
- Double-clicking is inappropriate without haptic feedback, i.e. in static displays
- A display should be sized appropriately. A suitable maximum size is A4 in landscape orientation
- 'Tactile objects should be simple'

The overlays were changed to meet those criteria. These principles, however, do apply to the group who took part in the testing. If the tests had been conducted with a group of people who were more accustomed to using tactile input, such as blind people and not necessarily musicians, different results may have been achieved. For example, Challis and Edwards (2001) found that people 'got lost' in large areas of empty space. It is expected that this would also apply to blind people but perhaps to a lesser extent.

2.6.5.4. Other forms of tactile display

The Tactile Vision Substitution System, developed in the 1970s, was an early commercial tactile device (Way and Barner, 1997a). This was similar in principle to the Optacon, except on a larger scale: the vibrating image was displayed on the user's back.

The TASO (Tactile Acoustic Screen Orientation), another tactile exploration device, was available from Frank Audiodata (2006). This was designed to explore a character-based text screen and consisted of a vertical and a horizontal sliding key to indicate the cursor's position, along with non-speech audio augmentation of the position information. It then used synthesised speech to present the text at the current position.

A recently developed material, Ionic Conducting Polymer gel Film, was used by Konyo et al. (2000) to produce a tactile display capable of subtle changes in surface texture. The film changes shape in electric fields, and high-frequency vibration of shape can give subtle surface differences. In this manner it is possible to recognisably represent the feel of different types of cloth, such as carpet, denim, and linen. This method of tactile display could have great potential, but unfortunately it is presently expensive rendering it unaffordable to many of those people that would most benefit.

Experiments have been conducted on electrical stimulation of fingertips and other areas of the body such as the abdomen. One example is given by Kaczmarek et al. (1997) who proved that simple geometrical patterns can be identified from mild electrical stimulation of the fingertip. However, pattern recognition was more accurate with embossed Braille-like mechanical stimulation. In addition to this, more than half of the possible test subjects were excluded because of high skin resistance or a small comfortable current range that would suggest that this approach is not useful to all people.

A serious problem with electro stimulation is the widely varying resistance of skin. The resistance of skin to electro stimulation is related to its moisture content that varies from person to person and on environmental

conditions. A system that circumvents this difficulty is the Tongue Display Unit (TDU) (Kaczmarek, 1998). The human tongue is very sensitive, with many nerve endings, and saliva is always present to provide electrical conductivity. The TDU consists of 144 gold electrodes that deliver a small electric current to the tongue. This is attached to a camera that can be worn on the forehead. Test users found that, with practice, the TDU could enable them to navigate virtual mazes and real environments.

2.6.6. Use of haptic Devices

Ruspini et al. (1997) state that for haptic systems to be of practical use, they must be capable of modelling environments with the same depth and detail as graphic systems. They developed a haptic rendering system that uses a high level framework to model contact constraints, surface shading, friction and texture. Open haptic application programming interface (API), a source code interface used by computer operating systems, or an application library, to support computer program requests for application services, offers similar capabilities. Ruspini and fellow researchers developed a haptic interface library, also referred to in abbreviated form as "HL", to hasten the process of incorporating haptic environments into graphics applications. This type of graphic desktop systems, in 1997, was capable of rendering graphics at over 20,000 shaded and/or textured polygons at 30Hz, interactive rate (Ruspini et al., 1997).

Jansson and Ivas (2000) argue that an ideal user interface should allow users to interact with the system with little or no training. Further, an ideal user interface should require of the user little or no specialised practice to understand the information being presented by the interface. Visual and auditory displays usually meet requirements with well

designed interfaces. Haptic interfaces, however, are more difficult to design and normally require more specialised practice to understand the information being presented (Jansson and Ivas, 2000).

“Compared with the visual and auditory domains, the capabilities of haptic devices and our understanding of human haptics are quite limited. A comprehensive program to develop a variety of haptic interfaces for VEs and teleoperation needs to include research in three major areas: (1) human haptics, (2) technology development, and (3) matching the performance of humans and haptic devices.” (Durlach and Mayer, 1995:181)

2.6.7. Haptic Device Summary

Various hardware devices have been developed to enable haptic human-computer interaction. These devices can loosely be classified into mouse, three-dimensional devices, tablets, static displays, and others. An ideal user interface should allow users to interact with the system with little or no training, understanding the information presented by the interface without specific practice. For visual and auditory displays, this is usually the case with well designed interfaces, however in the case of haptic interfaces, this requirement is much more difficult to achieve (Jansson and Ivas, 2000). High developmental and manufacturing costs render most of these devices unaffordable to the majority of vision impaired computer users. Only the Wingman force-feedback mouse and the static display methods are considered reasonably affordable. The large body of research that has been conducted on all forms of hardware has dramatically improved understanding of haptic human-computer access, and leads to an optimistic view for useful and affordable future developments.

2.7. Auditory Devices

2.7.1. The use of the human auditory system

Of the various auditory devices, synthesised speech generated by a screen reader is currently the most common method of non-visual computer access. This approach takes a long time to deliver interface information and much of the information on the computing device can not be converted into synthesised speech.

Synthesised speech is, however, not the only method of auditory output of which a computer is capable. Numerous researchers have investigated the use of non-speech sounds to assist or replace speech in delivering interface information. This would take better advantage of both the capabilities of computer output and the human auditory sense. And while synthesised speech usually takes too long to deliver an interface message, it is unambiguous and the meaning does not have to be learned. There is a strong argument for presenting synthesised speech messages as an optional addition to the interface where the speech output can aid new users in their learning of an auditory environment.

Another aspect of the auditory system is that it is very sensitive to changes in status. In particular, a listener can become accustomed to a noise and ignore it; however, it is a noticeable event when it stops (Brewster 1991; Brewster, Wright and Edwards 1995a; Raman 1997). This encourages the use of continuous sounds for monitoring nonstop processes such as an Internet download.

Brewster et al. (1995a) suggested that sound could be used to represent otherwise hidden information, even in GUIs intended for sighted users. There are a number of situations where information might be hidden. Information might be hidden because it is not available on the display due to screen size or other hardware constraints. Information might be hidden because it requires an action to access it. Information might also be hidden because it is ignored because the visual channel is overloaded, or it may not be noticed because the user's attention is elsewhere on the screen. Brewster and others also suggest that sound feedback could reduce user errors, particularly when the user's attention is elsewhere. This frequently occurs, for example, when scrolling through a document, or if a button is clicked and the visual focus quickly changes to another area of the screen.

Navigation in a purely auditory interface is often found very difficult, and some tools have been developed to aid screen navigation. The following sections will examine and describe some of the research that has been conducted on auditory human-computer interfaces. Firstly, individual applications that have been developed with auditory interfaces will be considered followed by a summary of some methods and techniques that can be used in auditory interfaces and finally some developments designed to enhance a GUI with auditory output.

Frauenberger (2003) developed a virtual audio reality (VAR) system which allows computer users to explore a virtual environment only by their sense of hearing. The binaural audio rendering implements directional hearing and room acoustics via headphones to provide an authentic simulation of a real room. Users can freely move around using a joystick. The application programming interface (API) is intended to ease the development of user applications for this VAR system, with a C++ interface

to the audio rendering layer. The signal processing is performed by a digital signal processor (DSP).

Because of the sequential nature of commonly used technologies, it was found to be essential to develop a new interaction mode to increase the information flow between user and computer. While tactile devices like Braille lines can only provide a limited amount of information per time, audio has the capability to provide a lot more information at once if made surrounding and spatial. Furthermore, hearing is a sense that allows different levels of intensity of perception, where the range reaches from background sound to speech. This allows a person to adjust the priority of information to the desired attention of the user. It also allows one to explore computers as they would explore a room where the user himself represents the computing pointer device and is thereby capable of movement and actions within the computing environment. Intuitive movements can be achieved by using a joystick, but experiments with the prototype showed that especially congenitally blind people do have problems with a joystick. They have no clear imagination of the implementation of movements when using the joystick. A touch board device might satisfy the requirements better. There are some key issues when creating a virtual audio reality and these include; directional encoding, reflections of the sound in the enclosing room and reverberation modelling.

Roth et al. (2000) developed several tools that would enable a computer user to access the internet by way of using a 3D audio system. Their software is used in conjunction with a touch screen or graphic tablet to give spatial meaning to input. The system can then adjust the location of its feedback according to the user's finger position on the tablet. Different sound characteristics of the feedback, for example pitch and timbre, are used to indicate different user interface elements or HTML tags. The authors have used a software library based on Head Related Transfer

Functions to simulate the vertical dimension of the 3D sound. The Ambisonic algorithm is based on the matching of interfering sound waves produced by a loudspeaker array and the original sound wave to be recreated at a certain listening point.

Roth et al. (2000) also produced several sonic games to provide a learning tool for the computer system. The games take the form of identifying locations and sequences, join-the-dots, and memory concentration, where a user has to pair auditory representations of geometric shapes. Another of their developments was an audio drawing tool that made continuous sounds that changed when the cursor was on a line or inside a closed element.

Brewster (1991) provided an overview of Soundtrack, a word processing application with an auditory interface. The initial screen of Soundtrack was divided into a 4x2 grid. Operated using a mouse, the interface produced a different tone when the cursor entered each area. A warning sound indicated the edge of the screen, and if the user 'got lost' at any time, a click would read the name of the object under the cursor. A double-click was used to execute a command or open a menu. Although Soundtrack was one application and thus did not allow access to an entire user interface, it demonstrated that it is possible to understand and navigate in a purely auditory interface. It also demonstrated the feasibility of the mouse as an input device to non-visual user interfaces.

An application described by Edwards et al. (1995) and discussed by Drake (2003), consisted of two tools that can help blind people with mathematics. Mathtalk enables meaningful access to algebraic equations, using structured speech to present the notation in a way that can be explored and repeated, and also allows manipulation of the equations.

Soundgraph is a simple auditory graphing program that allows reading and creation of simple line graphs. Partially sighted users have also found Soundgraph useful, as the screen display is supplemented by the audio output.

Drewes et al. (2000) created an audio-only game with a detective theme. They carefully considered the difficulties of an audio environment, particularly in regard to the amount of detail communicated. The game was structured like rooms in a house, with footsteps, turning sounds and a collision sound for navigation. Ambient noise provided a means of identifying the room, and dialogue provided information about the non-player characters in each room. User testing revealed that subjects enjoyed the game, but found that it was difficult to identify the rooms. It seems that this was due to sounds having unclear meanings, rather than a lack of information. Every subject reported using the collision sound to find walls, which emphasises the need for navigational reference points.

2.7.2. Methods of audio presentation

A large amount of research on auditory interface development has concentrated on different ways to sonically represent user interface elements such as buttons, menus and scrollbars. Auditory icons and earcons are the two most common approaches to the solution of this problem.

Auditory icons were used as early as 1986 (Gaver, 1986 cited in Brewster, 1991). Previous work on everyday sound recognition showed accuracies of as much as 95% suggesting that everyday sounds can, through various properties, convey information about the object that made the sound. An important property of everyday sounds is that they can convey

multidimensional data. When a door slams, for example, a listener may hear and understand additional information such as the size and material of the door, the force that was used; and the size of room (Brewster, 1991). Brewster suggests that similar properties could be employed to give detailed information about user interface elements.

Earcons are abstract musical tones that are used to sonically represent messages. They can vary by timbre, register, pitch, rhythm, duration, intensity, and directional locations. Guidelines based on research (Brewster, 1991; Brewster et al., 1995a) recommend the following for earcons:

- Timbres should be from distinctly different instruments to aid recognition. Timbres should have multiple harmonics producing reasonably complex sound.
- Pitch and register cannot be relied upon to distinguish earcons. Large differences, for example two octaves, can be sufficient for absolute recognition, and smaller differences forming a tune can be used for relative recognition.
- Very different rhythms make earcons more readily distinguishable and easier to tell apart from other earcons.
- They should be short so that they can keep up with system events and user interaction.
- Intensity should be kept to a small range so that users can control the volume without losing any information.
- Spatial stereo location of earcons can be particularly helpful if they are played in parallel.

Brewster et al. (1995a) noted that earcons take approximately between 1.30 and 2.60 seconds to play and that this was considered to be too slow to allow users to keep up with the user interaction. They proposed parallel

earcons as a solution where two earcons of sufficient difference can be played at the same time.

Gerth (1995) argues that previous research had shown that playing two sounds at once did not significantly reduce recognition rates, but playing three or more sounds did reduce recognition rates. Blattner et al. (1992:448), state, “Our awareness and comprehension of the auditory world around us for the most part is done in parallel”. This supports the suggestion that parallel earcons could use the natural ability of the human auditory system. Gerth (1995) experimented to see if listeners could recognise changes in sounds when several were presented at once and found that as the density of sound, that is the degree of polyphony or number of sounds playing simultaneously, increased recognition rates fell but remained at a level approximating 90% correctness.

Brewster (1994) discusses how recognition rates fall significantly when three sounds are presented. These sounds are more complex than the sounds Gerth used so that combinations may be more difficult to recognise than when only two are to be played in parallel. Brewster’s work (1994), suggests this may mean that two can be played in parallel without loss of recognition and perhaps it is practicable to use a total of four different sounding earcons where two earcons are played in parallel but on either left or right side locations, especially if user training was provided. Wright and Edwards (discussed in Brewster et al., 1995b), conducted tests to confirm Brewster’s hypothesis. Statistical analysis of their results indicated that the parallel earcons were recognised just as well as their serial equivalent. There was a significant increase in recognition rates when the test was repeated, due to the increased experience of the subjects. Three participants were discarded from the testing because they did not reach required recognition levels in the training phase. Two of these reached the required level after more

training, but the other did not. Wright and Edwards (Brewster et al., 1995b), suggest that this may be due to tone-deafness. Tone-deafness therefore is an important consideration when designing an auditory interface to be used without visual backup. Of the results from the accepted participants, there was no significant difference between musically trained people and non-musically trained.

A strong argument for earcons is their structured composition. In this way, they show similarities between elements or events. This is particularly valuable when learning the interface, as for example a newly encountered error noise will sound similar to other errors and thus will be interpreted as an error, even if the user does not yet know what type. Brewster (1991) proposed that the strongly structured and rhythmic composition of earcons would also aid the user's memory when learning the earcons.

The debate amongst researchers continues as to whether earcons or auditory icons are preferable for use in auditory interfaces. Auditory icons are easier to learn, but according to Sikora et al. (cited in Bussemakers and de Haan, 2000), can become annoying. Brewster (1991:26) states "some interface actions and objects have no obvious representation in sound." Earcons are abstract sounds and thus can take longer to learn, but have the advantage of a firm structure which can group similar elements or events conceptually and in the interface and, user interface concepts are largely abstract and thus may be suited to the more abstract tones.

Brewster (2002a) suggests that earcons and auditory icons could be used simultaneously. For instance, if auditory icons were used to represent interface elements that are unstructured and have an easily associated

real-world sound, while earcons were used to represent the more structured components of a user interface, for example a scrollbar, the advantages of both approaches could be exploited. Brewster did not mention that this flexible approach could also be of benefit when adapting the interface to beginner or expert users.

Gaver et al. (1991 cited in Mynatt, 1997) suggest that an interface sound can be altered to give information about the properties of that object. These modifications are termed filters and Mynatt used both low-pass and high-pass filters to give the effects of muffling and thinning respectively. Muffling is a useful technique because it can give the impression of an object being unavailable without removing it and changing the layout; just as objects can be 'greyed out' in a graphical user interface. Thinning was used in this case to indicate that an object is selected, which is also a very important piece of information. Mynatt also modified the sounds of objects such as menu items and buttons to indicate their position in a list.

Ramloll et al. (2000) tested comprehension of tabular data using synthetic speech output with and without pitch feedback. The pitch output was relative to the value in the current table cell, and was played in stereo depending on the current x position in the table. Use of the NASA task load index indicated that the addition of pitch dependent on the value of the table cell significantly decreased mental demand, frustration and overall workload. Accuracy was also significantly increased.

Petrie et al. (1997) constructed a prototype auditory interface, DAHNI, to meet the multimedia access requirements they researched and defined. 'Buttons' for navigation and other functions were grouped in the shape of a sideways placed letter 'H'. These buttons could be accessed using a keyboard, joystick, or touch tablet with tactile overlay. The interface was

tested with blind users in a sample hypermedia environment. They found it easy to use and particularly easy to learn.

2.7.3. Audio feedback as a supplement to a visual interface

The SonicFinder (Gaver, 1989) was an auditory enhancement to the graphical Finder tool on an Apple Macintosh developed by Brewster (1991). It used auditory icons such as tapping noises when something was selected. The tone of the sound, either paper, wood, or metal, gave the type of object, and the deepness indicated its approximate size. Copying was given the sound of pouring liquid into a receptacle and when the copying was finished the receptacle sounded full. Other sounds were added to represent delete, dragging, scrolling and zoom actions.

Gaver et al. (1991) created and tested auditory enhancements to the interface to the control of a bottling plant. They found that auditory queues were very useful in monitoring continuous processes, and that the auditory feedback enabled users to monitor the many machines in the plant simultaneously. However, sometimes users did not notice that a machine had stopped working because its noise had simply stopped. Gaver et al. (1991, cited in Brewster, 1991) also found that users moved quickly to stop failure sounds that were demanding without firstly considering their cause, and this could result in delayed attention to the cause and possibly more serious problems.

An earcon-enhanced scrollbar was constructed by Brewster et al. (Brewster, 1995), using the guidelines presented by Brewster (1991) where the scrollbar was tested using two tasks; a search task, to find a significant feature in a document, and a navigation task to find a particular point in the document. A visual-only scrollbar was also tested

as a control. Total task time and number of errors were recorded, as was subjective workload using the NASA Task Load Index. This requires participants to estimate the mental demand, physical demand, time pressure, effort expended, performance level achieved and frustration experienced. Brewster et al. (1995) added a seventh measure: annoyance, since this is a common concern with auditory interfaces. They also asked participants to rate which scrollbar they preferred overall.

The participants' responses, and it is important not to forget their subjective nature, produced results that showed there was a significant decrease in mental demand using the auditory-enhanced scrollbar as opposed to the purely visual case. The mental demand placed on participants was also rated the highest of the seven workload areas measured. There was no significant difference in the other task load measures and this would indicate that the auditory scrollbar was not found significantly more annoying than the purely visual one. Overall the auditory scrollbar was rated as significantly better.

The earcon enhanced scrollbar experiment was valuable in its own right, but in this context it formed an example of how to apply the guidelines presented in the Brewster et al. (1995) paper, in addition to showing how to test auditory enhanced interfaces. Although Brewster and Colleagues concentrated on auditory feedback as an enhancement to a visual interface; the guidelines would also apply to audio haptic or purely auditory interfaces. The feedback required would obviously be more detailed, but the principles of earcon design presented here can be applied to any audio component of an interface.

In summary, both Gaver and Brewster (Brewster, 1991; Gaver et al., 1991) showed that different real-world sounds (auditory icons) could be used to

represent complex attributes of abstract objects. It is however, important that sounds are not more demanding than is merited; additionally, demanding error sounds should automatically cease after a short period so that users' attention can be focussed on solving the problem. Auditory implementations of abstract user interface objects can also use earcons to beneficial effect.

2.7.4. Auditory navigation tools

Kamel et al. (2001) investigated the use of 3D audio to provide meaningful spatial representations in the use of non-speech audio. They used stereo sound to represent geometrical shapes including triangles, squares and circles. The stereo effect was deemed to be sufficient to represent the horizontal plane, whereas the stereo effect representing the vertical plane was recognised by increasing or decreasing the frequency of the sound. Beeps were added to represent line junctions and corners.

To achieve this stereo effect an input tablet was used. Each shape was given a unique physical position and could be activated by touching that area with a stylus. The stylus was a pen like pointing instrument. An audio grid was then added to the interface. The interface was constructed by using different musical timbres to represent horizontal and vertical axes. In the 3 by 3 grid, two consecutive notes were used to represent crossing a grid line. Different consecutive notes denoted different lines and where dependant on the particular line crossed. For example, crossing the line from (1,1) to (1,2) gave a clarinet tone of 'C', then 'G', and crossing from (1,2) to (1,3) gave a clarinet tone of 'G' then high 'C'. The presentation of the geometric shapes were available over the whole tablet, with their sounds getting softer as the user moves away, and at the loudest when the stylus is in the centre of the shape.

Test participants were asked to explore the virtual environment (which contained the three shapes and one of the three test cases – no feedback, grid or shapes) and then locate one of the shapes. Overall, the grid condition was found to be best in terms of exploration and relocation tasks, user confidence, and accuracy. The authors therefore concluded that it is beneficial to partition work space into subsections to aid navigation.

An interesting idea proposed by Gaver et al. (1991), is that of "soundholders". These function like a sonic bookmark. The soundholder could be placed anywhere and constantly produce a simple noise. The noise increased in volume, getting louder, as the interaction point moves closer to the soundholder. Gaver (1991) suggested that environmental noises such as a bird call or burbling stream could be used in this way. Regardless of which sound is used, soundholders could provide a novel navigational aid in an auditory environment.

It can be seen through observation of the use of the current 'speech only' interfaces that navigation is extremely difficult. A number of researchers have attempted to improve this problem by implementing different navigational tools. However, in a user interface it is important that the non-visual implementation corresponds to the graphical version to enable collaboration between blind and sighted co-workers. This would not be possible in a grid-oriented interface like that proposed by Kamel et al. (2001) or as used by Edwards (1991) in Soundtrack. One technique that does not appear to have been well investigated is the possibility of a sound that changes continuously in pitch and stereo position as the mouse cursor moves across the screen.

2.8. Challenges in HCI: The Digital Divide

2.8.1. Usability: Comprehension of Graphics

Charts, diagrams, and other data visualisations play an important role in the presentation of business and educational information (Schnotz and Kulhavy, 1994). Scientific and technical data representations are used to model increasingly complex data sets in an efficient manner. Visualisations of complex data sets often lead to restrictions on the accessibility of this type and style of information and in turn means that the vision impaired are restricted from participating fully in technical and scientific professions. The manner of displaying computerised complex data sets may be considered ethically wrong and society is probably disadvantaged by the loss of capable people being able to contribute to work in these fields. Schnotz and Kulhavy (1994) state that the comprehension of graphics is still an area that is not well researched. Gyselink and Tardieu (1994) experimented with the mental model of textual description using two groups as subjects. The two phase tests commenced firstly with both groups reading a text dealing with cellular division followed secondly with one group again reading the text while the other group received drawings to illustrate the cellular division process. Testing of the two groups produced similar results allowing the conclusion to be drawn that the mental model has to reach a sufficient level of elaboration before illustrations can reinforce reading text alone. This result reinforces classroom observations showing that it is not necessary to have graphical representations to achieve learning outcomes.

2.8.2. Traditional Methods of Graphical Data Representation to Vision Impaired

The vision impaired traditionally have graphs and diagrams presented in Braille. The raised dots are formed in lines on swell paper and or thermoform. Yu et al. (2000) state that these methods have poor “granularity” and that touch, when used in this manner does not have the resolution necessary to gain an understanding of the finer details of the graphic. While this statement is true, it does, however, give the student an overall view and a conceptual idea of the material being presented. The static nature of these documents means that it is not possible to display dynamic data in a convenient manner and as discussed in an earlier section there are issues relating to how the user remembers the amount of detail being presented.

2.8.3. The Haptic User Interface

As can be surmised from the previous discussion on haptics, the development of haptic user interfaces to address the accessibility problems faced by the vision impaired is still in its infancy. The number of effective devices that are affordable to the blind are few in number. The device with the greatest potential is the PHANTOM haptic pen as it has the ability in theory to provide a mechanism for blind users to access details presented in graphs and shapes. E-learning in IT and engineering is populated with this type of information. It was decided to use the PHANTOM haptic pen in experiments with the blind students to ascertain their ability to gain an understanding of the technical and visual information being portrayed. A description of the testing and results are discussed later in the thesis.

2.8.4. Audio Desktop or Audio User Interface

Mynatt (1992) developed a system called Mercator that provided mapping between X based GUI's and an auditory interface in a transparent manner.

Blind and vision impaired users have little trouble accessing text based systems as the textual output to the screen was also stored in the computers frame buffer. Screen readers can directly access frame buffers and it is a simply process to copy that output to the assistive technology device such as a Braille display or to a speech synthesiser. With GUI's it is, however, necessary to intercept the application output prior to it being converted to pixel data and communicated to the screen. This method becomes the basis for an "off-screen" model of the user interface. The information in the off-screen model becomes the basis to create an alternative accessible interface. The method adopted by different operating systems varies slightly to produce the same effect.

Mynatt (1995) discusses the extent to which communications can mimic the standard GUI. One such system of communication is 'Outspoken' which can use either the mouse or numeric pad. When the "mouse cursor" moves over an icon 'Outspoken' reads the label. Mynatt (1995) translated the GUI at the level of interface objects rather than pixel by pixel. This was also the method adopted and used in the Outspoken's method. This method allows the modelling of the structural features of the interface rather than the graphical representation that appears on screen.

Table 2.4: Samples of GUI Representative Communications

Attribute	AIC	Filtgear	Description
Selected	all buttons	animation	Produces a more lively sound by accenting frequency variations
unavailable	all buttons	muffled	A low pass filter produces a duller sound has sub-menu menu buttons inflection Adding an upward inflection at the end of an auditory icon suggests more information
relative location	lists, menus	pitch	Map frequency (pitch) to relative location (high to low)
complexity	containers	pitch, reverberation	Map frequency and reverberation to complexity. Low to large, complex AICS and high to small, simple AICS

2.8.5. Speech Interfaces and Screen Readers

A screen reader is a software application that renders the displayed information in a user interface, (GUI or CLI) in a format accessible to people with vision or print disabilities. There are two common output methods, being synthesised text to speech or refreshable Braille display. In the case of TTS, the output method may be either a hardware synthesiser or, more commonly nowadays, software synthesis. The more common screen readers are summarised in Table 2.5.

Table 2.5: Common Screen Readers

Operating System	Screen Reader	TTS Method	Vendor
Windows	Window Eyes	Hardware software	or GW Micro
	JAWS (Job Access with Speech)	Hardware software	or Freedom Scientific
	HAL	Hardware software	or Dolphin Systems
	NVDA (Non Visual Desktop Access)	Hardware software	or Open Source
Apple OSX	Voice Over	Software	Apple Corp
Linux	Speakup	Hardware	Open Source
	Gnopernicus	Hardware software	or Open Source
	ORCA	Hardware software	or Open Source
	LSR ³	Hardware software	or Open Source
	EmacsSpeak	Hardware	Open Source

³ Support and development for this application appears to have ceased at the time of writing

Figure 2.9 illustrates an example hardware speech synthesis device, the SingleTalk, developed by the author and S. Mokroous.

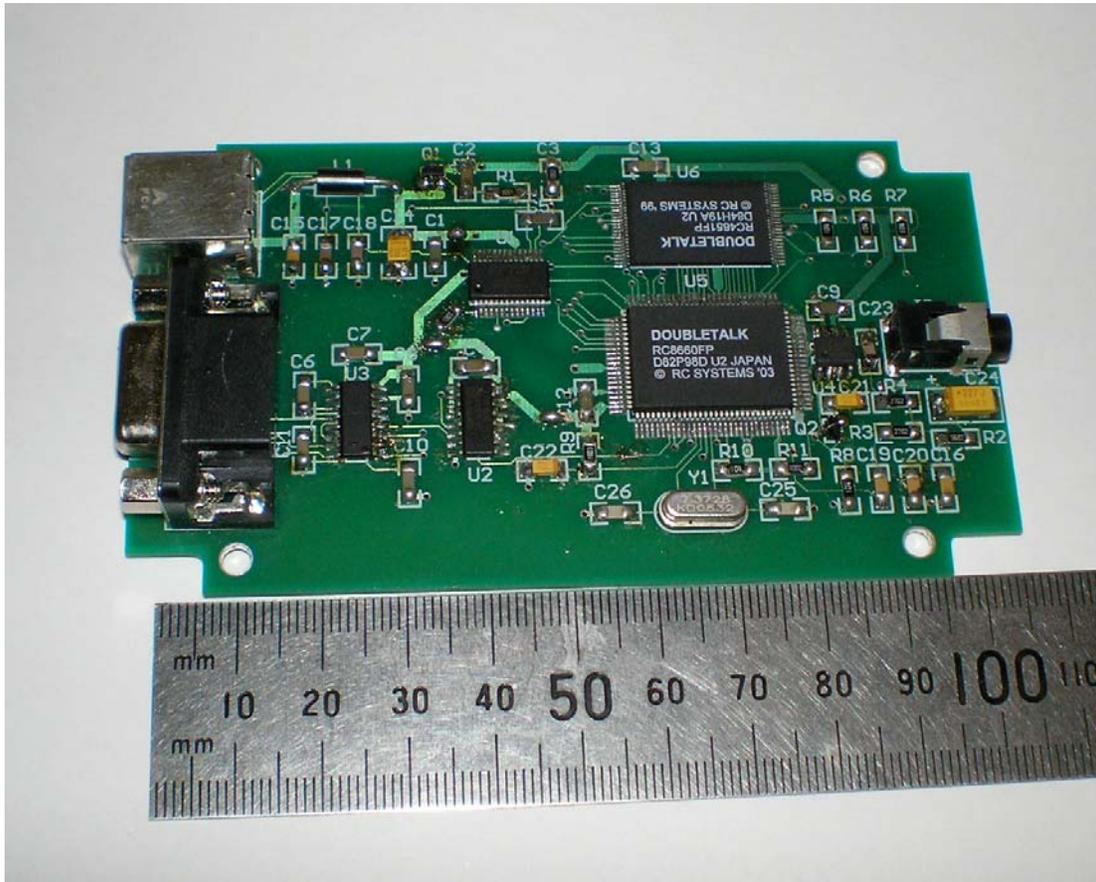


Figure 2.9: Hardware TTS device, the SingleTalk

Roth et al (2000) point out that a major problem with screen readers is their linear nature. Graphical user interfaces are presented in a non-linear, two-dimensional manner. Barnicle (2000) examined the techniques used by screen readers to locate specific controls and objects within an application and found that significant time and effort was involved in reviewing long menus and dialog box information.

Another problem with screen readers is that they do not function well with non-standard application interfaces. A particularly good example of this is

the way Apple's Voice Over interacts with the operating system. If a developer creates custom objects (such as buttons) Voice Over is unable to determine information about this object and thus will not interact with it without the developer investing significant effort in accessibility.

2.9. Combining Modalities in HCI

With the awakening to the specialised computing accessibility needs by a small number of users there has been an increase in the availability and improvement in the quality of auditory and haptic interaction devices that incorporate modalities in interfaces that were previously unavailable because the devices catered to the requirements of a visual population.

McGee et al. (2000) propose a system of "Integration of Information" incorporating a keyboard and mouse arrangement as an important dimension of haptic-audio interaction. They use a combination of haptics augmented by audio to increase the range of resolution in the haptic interface.

Harris (2006:10) states the "the combination of Assistive Technology and Information Technology sometimes delivers a flawed end user experience. This is particularly disappointing to technologically savvy users who expect a seamless IT integration experience." Harris discusses the problems faced by engineers integrating the two and concludes that there is no silver bullet and the need to develop unique user interfaces for each I/O modality will continue.

2.10. e-Learning and the Vision Impaired

2.10.1. The Vision Impaired Learner

In relation to the manner in which the vision impaired learn, it is important to recognise that there are different forms of vision impairment and that not all with vision impairment are completely without some degree of sight. Neither is it necessarily the case that they have been vision impaired since birth. These differences tend to result in those with vision impairment having different requirements to assist their learning.

The difference between temporary or partially sighted students and permanently blind students is considerable, particularly with relation to student expectations and staff support as the two groups exhibit different study patterns and difficulties (Shepherd, 2001). Table 2.6 is adapted from a University of Edinburgh handout on student disability and is presented by Shepherd (2001). It provides a simple guide to the differences between totally blind and partially sighted students.

Table 2.6: Differences between Blind and Partially Sighted Students

Blind	Partially Sighted
Unlikely to be able to use print without some adaptation	Can see in certain conditions
Unlikely to be able to produce handwritten work	May be able to cope with print but take longer to read it
Likely to have difficulty in note-taking	May be able to produce handwritten work
Likely to have difficulty producing written assignments	Has probably been educated in mainstream schools
Likely to have particular mobility difficulties	May be able to use low-vision aids in classroom settings
Likely to have to rely on listening rather than watching	Will probably not use Braille
May have problems with spelling and specialist vocabulary	
May have problems in group discussions	
May use Braille	

Of more concern to teaching staff in specialist fields such as information technology and engineering are the effects of the impairment on the student's ability to comprehend essential parts of the curriculum, normally taught using visual means. Specific conditions relating to vision impairment and their effect in a visuo-centric learning environment are summarised in Table 2.7 (Mann, 1999). Although Mann (1999) developed

this list for disciplines involving fieldwork, the majority of these conditions also impact learning in a computing and engineering environment.

Table 2.7: Impact of Vision Impairment Conditions (Mann, 1999)

Condition	Impact
Ocular Albinism	Difficulties with scanning, tracking, depth perception, rapidly shifting visual points, reading
Cataracts	Wide variation in visual acuity (though full visual field usually maintained) and near and far vision often adversely affected
Diabetic Retinopathy	Fluctuating visual acuity, distortion of vision, and possible impairment of visual field
Glaucoma	Progressive loss of visual field, poor visual acuity, impaired peripheral and night vision, and difficulty in adapting between light and dark
Macular Degeneration	Loss of central vision (hence reliance on eccentric or sideways looking), difficulty in discerning fine detail and reading, and problems in colour discrimination (especially reds and greens)
Nystagmus	Blurred vision, difficulty in scanning and tracking, and problems with depth perception

Optic Atrophy	Variable loss of vision and/or total blindness
Retinitis Pigmentosa	Night blindness, narrowed field of vision (resulting in tunnel vision)

In summary, medical conditions resulting in vision impairment are likely to affect the following visual capabilities of students:

- Ability to see details
- Contrast sensitivity
- Colour vision
- Accommodation to changing light levels
- Width of visual field
- Changing focus
- Seeing moving images
- Sensitivity to glare.

The effects of visual capabilities directly influence a student's learning abilities and in turn demand different student requirements are met.

2.10.2. Vision in Learning

Vision is the most significant physical sense used by the learner. The hierarchy of the senses developed in ancient Greece places vision as the primary sense (Jay, 1994). For all learners, vision is the primary sense within learning and development (Kelly et al., 2000; Levtzion-Korach et al.,

2000), with approximately 70% of the brain's sensory capacity dedicated to processing visual information (Shepherd, 2001). Where there is conflict between several sensory inputs vision either dominates or modifies the percept from other modalities (Shore and Klein, 2001). However, many learners rely on input from other senses because they have little or no vision.

Research by Revesz (1950) suggests that a mental process of integration and synthesis is needed to develop a unitary image of objects. The ability of blind or low vision students to build a conceptualization or mental representation of complex theory in the form of images will affect their rate and depth of learning. The conceptualization built by vision impaired students will frame their understanding of those theories, where these views may or may not reflect the true nature intended.

Pockets of research into the spatial ability of the blind and the sense of vision have occurred across the globe. Although the research involving blindness is predominantly focused on geographical spatial ability (Jacobson et al., 1998; Kitchin et al., 1997; Kitchin and Jacobson, 1997) the classification of past theory is highly applicable to spatial imagery and blindness in other disciplines. The most concise three groupings are as follows (Andrews, 1983; Kitchin et al., 1997, Kitchin and Jacobson, 1997):

1. Deficiency theory - Vision is the spatial sense *par excellence* and congenitally blind individuals are incapable of spatial thought because they have never experienced the visual process necessary to understand spatial arrangements,
2. Inefficiency theory - Vision impaired people can understand and mentally manipulate spatial concepts, but this understanding is 'inferior' because it is based upon auditory and haptic cues, and

3. Difference theory - Vision impaired people possess the same abilities to process and understand spatial concepts, with differences explained by intervening variables (such as access to information, experience or stress).

Although there are conflicting opinions on the spatial ability of vision impaired individuals, the majority of recent research concludes there are differences in the mental imagery of the congenitally blind, later blindness and the sighted, particularly when dealing with 3-D concepts and the integration of multiple images in memory at the higher cognitive level (Arditi et al, 1988; Cornoldi and Vecchi, 2003; Monegato et al, 2007; Vecchi et al, 2004). The predominant findings are that blind individuals assimilate in a linear way and repetition is important to remembering information.

As students with vision impairment tend to utilise memory capacity to a greater extent than their sighted counterparts, practical experience in a learning environment is even more important. Students learn by processing materials via different lanes to the brain (Sprenger 1999), and these include not only pathways through the physical senses but also include motor reinforcement by practical application together with the emotions attached to the experience. Repeated use of procedures in a practical setting increases the skill and confidence of vision impaired users, who do not have the constant visual reminders to prompt them. Repetition and experimenting in a familiar and trusted environment allows vision-impaired students to learn more quickly by using multiple pathways to the brain. (Bishop, 2004)

2.10.3. The Move to e-Learning

Traditional learning environments have been the model for the conventional classroom with teachers presenting information to students via blackboards and whiteboards supplemented by manual learning materials and aids. This conventional approach has dominated since the 1930's (Goh and Fraser 1998) and has been the focus of research for more than 25 years (McRobbie et al, 1998; Tobins and Fraser 1998). On-line and e-learning are modern approaches designed to increase the speed and accessibility to learning materials. Although much of the learning materials are now presented vision in an on-line mode, programs taught in traditional face-to-face mode also use computer-based information as an adjunct to teaching and learning.

One of the features of e-learning presentation is the move away from the predominance of textual material to visual content and modes of delivery. With up to 80% of traditional materials being presented in visual formats, students with acute vision impairment are unable to access information easily accessible to sighted students (Levtzion-Korach et al., 2000; Ross et al., 2001). Access to crucial information is a common hurdle for blind learners. Complex information is frequently presented via high-resolution graphics in the form of tables, graphs, diagrams and images, and visual techniques are used to navigate around structured information. The methods available for presenting information non-visually are restricted and are slower and more cumbersome than the vision-centered methods. This lack of access to a set of learning materials on a given topic results in vision impaired learners having a different conceptualization and understanding of phenomena based upon incomplete or inaccurate information.

While computer-based learning has opened opportunities for many students with disabilities, it remains primarily vision dependent. Students or potential students with vision impairment are thus doubly disadvantaged, as even programs taught in traditional face-to-face mode use computer-based information as an adjunct to teaching and learning.

One of the main deprivations caused by blindness is the problem of access to information. Visualisation is an increasingly important method for people to understand complex information, and is presented using tables, graphs, diagrams and images. Visual techniques are also used to navigate around structured information. Computer-based visualization techniques, however, depend almost entirely on high-resolution graphics and for vision-impaired users the problems of using complex visual displays are great. There are currently only limited methods for presenting information non-visually and these do not provide an equivalent speed and ease of use to their graphical counterparts. This means it is impossible for blind people to use visualization techniques, depriving them even further. Hence techniques and technologies need to be developed to allow users to feel and hear instructional materials .

The Western Australian Government (Department of Training and Employment, 2000) reported that vision impaired students in the tertiary education sector were failing to achieve certification in their chosen course of study, due to an inability of the sector to adapt the training and assessment framework to meet their needs. Although students with vision impairment appeared to be equitably represented in the tertiary education sector in Western Australia, lack of staff awareness of issues related to vision impairment and difficulties in adapting the training directly have hampered completion rates (Lewis et al, 2004). The area of information technology was singled out as being problematic and recommendations included the need for professional development for lecturers and

development of improved access to information technology and electronic educational materials.

Ward (2004) reports that 3 in 10 persons with learning difficulties also have a visual impairment; 4 in 10 have a hearing impairment; and some have both sight and hearing difficulties. Teachers providing information for people with learning difficulties need to present information so that it is accessible to those who have additional impairments. Although assistive technologies tend to be expensive in comparison with mainstream products, most methods to help people with learning difficulties and visual impairments are affordable to educational institutions but advanced planning is necessary.

Among those with visual impairments some will have different needs and will prefer information presented in different formats. Many with visual impairments can read large print if it is written clearly and boldly, while others prefer information on tape or CD. Some will need more than one format, perhaps one for reading and another to keep for reference. They may desire short documents, such as a memo, in print or Braille, but they may prefer longer documents, like minutes of a meeting, on tape or CD. Instead they might want a summary of a long document such as minutes; others will want information on audiotape. A key issue for the developer is to plan in advance and ask disabled people what they need. It is much more difficult to make material accessible at a later stage.

The way information is presented can certainly help vision impaired people. Words and pictures need to be laid out in a way that is easy to see, read and follow. Galitz (1997) shows that one font and one print size will

not suit everyone, though 14 point print or larger is a must, and according to Arditi of Lighthouse International, people with low vision find open, san-serif fonts such as Arial, the best font for everyday use and more readable for people with visual impairment. Arditi also suggests that a combination of upper-and lowercase letting is preferable to ALL CAPS. Over the past decade the number of publications on recommended formats and techniques for accessibility of Web-sites and learning materials has increased dramatically, indicating that lack of accessibility is a concern.

2.10.4. Technology and the Computing Curriculum

Technical and electronic devices are key aspects of our daily lives. Accessibility issues arose on the birth of the graphical user interface (GUI) on PCs. Information technology is an integral part of today's education and employment environments and the Internet and Web have become major drivers of communications in the Western world. The inaccessibility of the majority of Web-based material and industry standard computer applications to users with disabilities (motor, print, etc) has been the subject of numerous research projects. Sighted users find it considerably easier than vision impaired users and theoretically accessible information in industry standard operating systems and applications have been found to have links which were inaccessible to the assistive technologies being used (Burgstahler et al, 2004; Coyne and Nielsen, 2001).

While e-learning and web-based applications have opened opportunities for many students with disabilities, these remain primarily vision dependent, with increasing levels of inaccessibility for blind and low vision students (Kelly et al, 2000). In particular, diagrams, images and visual

cues are inaccessible by blind and vision impaired students (Harper et al, 2001; Ross et al, 2001).

The nature of computing education curricula contributes added hurdles for the vision-impaired. Education in computing at tertiary level requires comprehension of theory in addition to practical application and hands-on exercises in order to develop a sound knowledge base. Computing theory is a combination of logical and physical abstractions, invariably taught to students using conceptual diagrams or figures containing shapes of different sizes together with other visual effects such as shading, colour and sequence (Armstrong and Murray, 2007). The more complex the model, the more complex the visual effects used, requiring spatial abilities to interpret motion and 3D images. Vision-impaired students are at a severe disadvantage in this type of learning environment, particularly those who have been blind from birth or an early age.

2.10.5. Levels of Learning Success for the Vision Impaired

According to Coyne and Nielsen (2001), users with disabilities were about three times less likely to succeed than users without disabilities in carrying out routine tasks such as Web activities searching for information and making purchases. The Royal National Institute of the Blind (RNIB) reports that students with impaired vision using Web-based educational materials spend only around 30 per cent of their time actually using the materials; the rest of their time is spent searching and navigating for pages and options. Meister (1998) found that university students from 15 universities in Germany required two to five times as much time to learn the syllabus and prepare and revise lectures than their sighted counterparts. They also required more breaks and had less leisure time than the sighted students, however this varied with the type and

severity of their impairment. The level of achievement of vision impaired individuals appears to be equivalent to that of sighted individuals. In their study of Polish university students Klinkosz, Sekowski and Brambring found the level of academic achievement of vision impaired students and sighted students to be the same (Klinkosz et al, 2006).

2.11. Discussion on the Advantages and Disadvantages of Methodologies and Modes in Assistive Technology

People with disabilities face many problems effectively assimilating in today's society. They are less likely to gain tertiary or further education, or full-time employment equivalent to their sighted counterparts. In a digitally driven society the vision impaired must rely upon assistive technologies to use computers and the Internet. As noted in the literature review, these assistive technologies lack sophistication and are limited in their application. The complex nature of learning materials in the information technology and engineering fields, and the reliance upon images to present concepts and information, present vision impaired students with additional difficulties.

Way and Barner (1997a) reported vision has the greatest bandwidth of the five senses. If a learner has no usable vision, other modes of input must be utilised and by providing more than one channel of input, greater utilisation of remaining senses is possible. However there are severe limitations on other senses when direct translation from vision based images to audio and tactile forms is undertaken. If audio is utilised, care must be taken that the auditory sense is not overloaded. Brewster (1991) discussed the "cocktail party" effect when multiple sounds are mixed with speech and found this methodology was not suitable in many

applications. Alert sounds were shown to be acceptable to attract a users attention, as a person will notice a sound (or even the absences of a sound) even if their attention is elsewhere. There also appears contradictory evidence in the literature on the suitability of non speech audio as an alternative access method. Researchers involved in the field of haptic interaction for people with vision impairments generally hold a positive outlook for future of this technology. However the cost of hardware and complexity in developing applications for haptic devices is cause for reservations in places too greater reliance the promise of haptic human computer interfaces. Traditional methods of creating learning materials for the vision impaired are under represented in the literature with much of the available information being in the form of case studies or guidelines for producing material. Ryles (1996), however, illustrated the use of Braille in education, particularly when ambiguity exists in speech output.

Research in the area of assistive technologies is still lagging when compared to the advances made in computing and human computer interaction, due in large part on the relatively small user base and low socio economic demographic. Haptic and audio devices developed so far need substantial enhancement before commercialisation can offer these devices as effective and affordable to the vision impaired.

Alternative methods are clearly needed in order for blind learners to access and comprehend e-learning and Web-based instructional materials. In a computing discipline experimentation and practical application are vital to the learning process for the vision impaired. There is a need for practical and cost-effective solutions to accessibility via e-

learning in the quest to ensure the vision impaired have equal access to education and employment.

The reviewed literature has confirmed the e-learning modalities and vision impaired research situation, and highlighted the need for greater accessibility to on-line learning environments for the vision impaired. It has also been established that multi modal assistive devices may improve cognition and rate of information transfer, making the best use of remaining senses. Chapter 3 will examine the manner in which this research project was undertaken and includes discussion on the methodology applied.

3. Test Framework and the Experimental Design

3.1. Objectives in the Experimental Design

The research outcomes reported here relate to an established set of courses on data network architecture and IT support and configuration and were gained by exploring what tools and combinations of tools were required to make this an accessible and effective e-learning environment for the acutely vision impaired. The key elements of that research focussed on questions such as:

- What tools are needed?
- What makes them effective?
- What makes the training program accessible?
- What makes the result better than other training options.

An important goal sought in undertaking this research was the construction of a conceptual model to guide the transformation of any e-learning course to cater for the severely vision impaired.

3.2. Scope of Implementation and Demographics of the Target

Audience

The target audience of the research was the totally blind, who have different requirements for accessibility than those who have some vision. The objective was not to develop a new set of curricula, but to use an industry standard set of courses, already proven with able-bodied students. Hence four Cisco courses were chosen as the carriers for the accessibility transformation: IT Essentials 1 and 2, and Cisco Certified

Network Associate 1 and 2. There are several reasons for selecting this approach:

1. The chosen courses have been offered to sighted students in an online environment for several years and have gained international recognition as industry standard training.
2. The transformed curriculum can be validated by ensuring the vision impaired students gain similar results to those of their sighted counterparts.
3. It provides an opportunity to create new learning experiences that fit the specific needs of the blind in a relevant and contemporary skill area.
4. It is more economical to transform stable, proven curriculum than to develop a totally new curriculum for the vision impaired.
5. The course materials for the vision impaired can be kept up-to-date with new releases posted at the same time as those for the sighted students.

3.3. Accessibility, Efficiency and Effectiveness

In the context of this research the term ‘severe vision impairment’ means totally blind or having no useful vision. Students with such an acute vision disability are often not able to access and interact with e-learning systems developed for the sighted.

Accessibility in this context means all parts of an e-learning course are obtainable and presented in a format that severely vision impaired students can comprehend. Vision impaired individuals interact with the learning content through the use of assistive technologies. In many instances, the limitations inherent in this technology requires changes in the delivery and assessment of curriculum designed for able-bodied learners. As a result, technology is at the heart of accessibility, for without

it those with acute vision impairment have no way of accessing the learning materials.

In the process of building an accessible learning environment the research will investigate if there are technical alternatives for the delivery of the content, and how effective these alternatives are. For example; are haptic and force-feedback devices effective for presenting currently inaccessible graphical learning materials? What are the most effective means of employing technology to deliver learning materials to the vision impaired? How do technical approaches to delivering educational materials compare to traditional or alternative approaches?

Just as learning environments for the sighted seek to be effective in achieving the learning goals and efficient in the use of resources, so must an accessible learning environment be effective and efficient. Effectiveness is “measured by evaluating how well the end product achieves the stated objectives” (Armstrong & Jayaratna, 2005:5). Effectiveness in this context means meeting the same outcomes, that is, can blind students studying the transformed e-learning courses achieve the same outcomes as able-bodied students studying the original courses designed for the sighted?

The accessible learning environment must also be efficient in its use of available resources. Efficiency is “measured by studying the result of increases or decreases in the level of given resources used for achieving the objectives” (Armstrong & Jayaratna, 2005:5). Efficiency in this context would be confirmed if the difference in the cost of resources for teaching methods and tools between the vision impaired accessible environment and the traditional e-learning environment for the sighted is minimal for the same level of output.

3.4. Approaches to Instructional Design

It is important to choose an appropriate instructional design model to guide the research at hand to ensure meaningful and valid results. Two models/methodologies stand out as being appropriate for this research, the Systems Approach Model for Instructional Design (Dick & Carey, 1996) and the IEEE Reference Guide for Instructional Design and Development (IEEE, 2001). The second approach uses the Dick and Carey model as its base.

Dick and Carey (1996) present the Systems Approach Model for instructional design based upon a systematic point of view. The main properties of a system have been discussed extensively in the literature and Skyttner (2001) summarises these based upon the works of major systems thinkers of the time (predominantly von Bertalanffy 1969 and Litterer 1969). The main properties are; an objective or goal, interactive components, inputs, processing of the inputs into outputs, an environment plus a feedback mechanism for management and control. Dick and Carey's application of systems thinking to systems of instruction are summarized as follows:

1. The main objective of the instructional system must be defined in relation to the problem it is intended to solve within the larger environment.
2. The purpose of the instructional system is to bring about learning.
3. The components of this system are the learners, the instructors, the instructional materials, and the learning environment.
4. These components interact in order to achieve the goal.
5. A feedback and control mechanism based upon progress monitoring and adjustment actions to ensure the goals are being met.

The inputs to the system feed into a process which are carried out by the integration of the components, producing outputs that contribute to the purpose of the system. These outputs are then compared with the goals and adjustment action is taken where necessary.

The steps in the Dick and Carey Systems Approach model are illustrated in Figure 3.1 and are described as:

- Assess needs to identify goals: This stage defines what the instructor wants the learners to be able to do when they have completed the course of instruction, and this is the instructional goal.
- Conduct instructional analysis: This stage details what people should be doing when they perform the goal, and defines any entry requirement or behaviours required by the learner in order to begin the instruction.
- Analyse Learners and Contexts: This stage details a parallel analysis of the learners, the context in which they learn the skills, and the context within which they will use those skills. The present skills, preferences and attitudes of learners, and the instructional environment are also identified.
- Write performance objectives: This stage defines what the learners should be able to do on completion of the instruction. This includes skills, any conditions and the criteria for successful performance of those skills.
- Develop assessment instruments: This stage builds assessments to measure the ability of the learner to perform what is described in the objectives.

- Develop instructional strategy: This stage details the strategy to be used to reach the objectives and using the previous five steps as a base.
- Develop and select instructional materials: This stage includes the development of a learner’s manual, all forms of instructional materials, and tests.
- Design and conduct formative evaluation of instruction: This stage entails the collection of evaluation data to determine how the instruction could be improved.
- Revise instruction: This is the first step in the repetition cycle, and using feedback data enables an identification of difficulties faced by the learners in achieving the goals, plus any deficiencies in the system.
- Design and conduct Summative Evaluation: This stage occurs after the formative evaluation and revisions to meet the requirements of the designer.

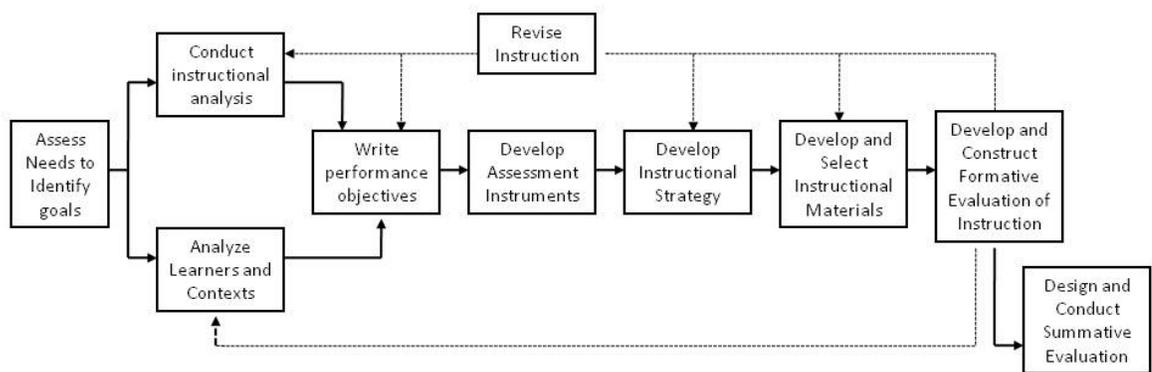


Figure 3.1: Systems Approach to Instructional Design (Source: Dick and Casey, 1996:71)

The I.E.E.E. used the Dick and Carey model as the foundation for its Reference Guide for Instructional Design and Development (I.E.E.E., 2001). The I.E.E.E. approach is illustrated in Figure 3.2 and takes the following form:

- Assess instructional needs. This involves identifying the gap between what is and what needs to be. I.E.E.E. suggests this stage requires answering the following questions:
 - Who are the potential learners, what prerequisite knowledge or skills do they need and what is the instructional goal?
 - Determine if existing curricula or certification requirements exist
 - Ascertain the availability of required media, any technical requirements and facilities available.
- Analyse learners. This requires considering several characteristics of the learners and the learning context including:
 - Cognitive characteristics – e.g. learning aptitude, learning styles and prior knowledge of the topic.
 - Psychosocial characteristics – e.g. motivation, attitudes, anxiety levels, confidence, and socioeconomics.
 - Physiological characteristics – e.g. sensory perception (visual, auditory, tactile, acuity), general health, age, race, ethnicity, cultural and linguistic background.
 - Contextual characteristics – relevance to learners, learning preferences, heterogeneity of learners, appropriateness of physical environment (light, sound, seating, etc), compliance with disability legislation and standards, appropriate technology and support, curricula or certification requirements and community or organizational issues.

- Write learning objectives. This includes determining the goals of the learning activity in the form of the terminal objective, the enabling objectives (what the learners must demonstrate), and objectives relating to skills, tasks or knowledge.
- Select an instructional strategy. This stage is based upon Gagne's (1987) nine events of instruction: gain attention, inform learners of objectives, stimulate recall of prior learning, present the content, provide learner guidance, elicit learning/practice, provide feedback, assess learning and enhance retention and transfer. These events are used as a guide for moulding to given courses.
- Develop materials. These include any materials and tools used in the instructional process, e.g. student manual, instructional materials, pre- and post-tests, and instructor's manual in forms such as worksheets, handouts, job aids, computer-based training, the Internet, laboratory work, learning objects, learning portals or audio\video material. Delivery modes must be taken into consideration. Instructional materials may be adapted from already existing material or be newly developed.
- Evaluate instruction. Careful differentiation is made between assessment and evaluation. Evaluation involves an examination of the entire instructional unit, whereas assessment concentrates on learner learning. This evaluation may take place throughout the development and delivery process by formative evaluation and by summative evaluation after the delivery of the instructional unit.
- Suggested criteria for evaluation are:
 - Materials are appropriate for defined performance objectives
 - Materials include adequate instruction for required skills
 - Material is sequenced logically and chunked meaningfully
 - Materials are clear and understandable

- Materials are relevant to the learners’ needs
- Media employed encourages efficient management
- Materials allow adequate opportunity for practice and constructive feedback
- Assessment items are relevant to performance objectives; test items test required behaviors.

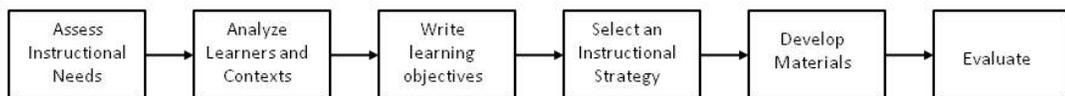


Figure 3.2: The I.E.E.E. Model for Instructional Design and Development (constructed from I.E.E.E. textual descriptions in I.E.E.E., 2001)

The I.E.E.E. Model for Instructional Design and Development was designed to be applied to situations akin to the area under study. For example, this approach is purely focused on the design and development of instructional curriculum, with a concentration on technology and engineering environments. Additionally it considers the needs of the students early in the process, and undertakes an evaluation phase once development is completed to determine how well those needs were met.

It is also of interest to consider the “transmediation paradigm” when considering the conversion of the instructional material to accessible formats. Transformation of graphical information to tactile, audio or text is akin to the transmediation of literary educational works to multimedia formats and therefore has some relevance to this study.

Using a systems theory based approach indirectly gives the research at hand an added dimension. The systems components of this research are:

1. The main goal of the proposed educational 'system' in its broadest sense is to provide an e-learning environment that is totally accessible to vision impaired students in order that they may have the same educational opportunity as sighted students and gain industry certifications upon successful completion of the courses.
2. The purpose of the proposed accessible instructional system is to bring about learning so that vision impaired students may gain skills and knowledge relevant to their disability equivalent to that available to the sighted students enrolled in the same courses.
3. The components of this system are: the vision impaired learners, the vision impaired and sighted instructors, the accessible instructional and assessment materials, teaching aids, the assistive technologies and the accessible computer hardware and software, plus technical and non-technical delivery mechanisms; which are all essential components in the desired learning environment.
4. These components must interact in order to produce an accessible e-learning environment for the vision impaired to receive an equivalent educational opportunity.
5. The feedback and control mechanism comprising accessible quizzes, interactive activities, tests and examinations. Survey results from students and instructors provide additional information on progress and potential problems.

3.5. Steps in the Research Program

Using the I.E.E.E. model to guide the research, the steps in the project are detailed below and illustrated in Figure 3.3:

- Assess instructional needs. The gap identified is the absence of e-learning materials for vision impaired students to gain education and qualifications in relevant disciplines.
 - The potential learners are vision impaired individuals who wish to gain skills and industry certification in IT studies. These learners do not require prior knowledge in IT, but a familiarity with a personal computer and assistive technologies for the blind was desirable. The instructional goal is for students with a vision disability to access e-learning materials already available to sighted students.
 - Existing curricula for sighted students is available in an e-learning mode, however, this is not accessible to the vision impaired students. A new set of accessible materials fulfilling the same curriculum goals needs to be developed.
 - The media required for delivery of these accessible learning materials needs to be reviewed and appropriate mechanisms designed and developed to ensure equivalent delivery to the vision disabled group. The accessible curriculum must be able to be rendered in the correct format by current assistive technologies and computing environments.
- Analyse learners. Characteristics of the learners and the learning context is summarized as follows:
 - Cognitive characteristics: learning aptitudes and learning styles of the vision impaired students are the same as for sighted students. The learning aptitudes could be viewed as 'normal' unless the student has an additional disability related to learning.
 - Psychosocial characteristics: motivation of vision impaired students was expected to be slightly higher than sighted

students, as opportunities to gain industry certifications are minimal. Attitudes of the vision impaired students were expected to be similar to those of sighted students. Anxiety levels were anticipated to be higher as more effort would be required to achieve similar outcomes. Confidence levels of vision impaired students were expected to be lower based upon their learned cautiousness. The vision impaired tend to be of lower socioeconomic level generally due to their limited ability to earn equivalent wages to that of sighted people.

- Physiological characteristics: Lack of visual perception was assumed to be the main limitation of these students; however, some consideration must be given to the possibility of multiple disabilities or general health setbacks which are common occurrences with the blind. Linguistic backgrounds are assumed to be English speaking.
- Contextual characteristics: skills in advanced IT are highly relevant to the vision impaired due to their lack of mobility and the logical nature of the work. The physical environment needed monitoring for health and safety issues to ensure the safety of the students and compliance with all disability legislation and standards. The technological aspects needed careful consideration as the means of delivering the courses to these students relied upon accessible equipment and applications.
- Write learning objectives. The terminal objective of the learning activity is to provide an e-learning environment accessible to the vision impaired that provides equivalent learning opportunities to sighted students undertaking the same course. The enabling objectives the vision impaired learners must demonstrate would be the same as those for the sighted students. These learning objectives, together with the skills, tasks and knowledge are defined

within the industry standard courses chosen as the nucleus curriculum.

- Select an instructional strategy. The base curriculum chosen already displays the necessary stages for instructional strategy, however these need to incorporate accessible delivery mechanisms and specially designed methods appropriate for the vision disability entailed. The use of haptic devices as a means of presenting skills and knowledge within the curriculum was investigated and evaluated. Instructional strategies also included a virtual classroom and a virtual network laboratory, both accessible via the Internet for access by local and remote students.
- Develop materials. The materials and tools developed in the instructional process were based upon the industry standard Cisco e-learning materials already available. The converted materials consisted of electronic lecture notes, Braille lecture notes, audio lecture files, electronic instructional materials consisting of textual readings, diagram and image descriptions, laboratory exercises, quizzes, tests and examinations in accessible formats and electronic interactive media activities. These combine to produce the accessible on-line learning portal. Delivery modes included the use of blind instructors supported by a sighted teaching aide. Technical support and ongoing management of the program was provided by a university qualified academic.

A pilot study was used to gradually transform the learning materials into accessible formats and piece together the entire accessible e-learning environment. New versions of the teaching materials were produced and tested iteratively until instructors and students were satisfied with the level of accessibility. Inefficient methods were redesigned and tested until they were deemed equivalent to those for the sighted students.

- Evaluate instruction. Assessment was carried out by the vision impaired students sitting the same assessments items as the sighted students. These assessment items included proctored practical laboratory sessions, quizzes, tests and examinations. Evaluation of the project was carried out by surveys submitted at regular intervals by the students and instructors. The final evaluation was determined by a combination of the grades achieved by the vision impaired students compared to those of the sighted students, plus the survey feedback.

Evaluation in this context will determine accessibility, effectiveness and efficiency by undertaking the following tasks:

- Measuring the extent to which the technologies used by the vision impaired students can access the transformed learning materials.
- Comparing the grades achieved by the vision impaired students with those of the able-bodied students to ensure the learning experiences have produced the same skill set and knowledge.
- Comparing the time taken to complete each course by the vision impaired and the sighted students.
- Measuring the effectiveness of teaching aids in delivering the required information for students to build their knowledge and skills.
- Measuring the vision impaired students' success via their feedback on their experiences, and any affects the students and instructors considered their disability posed on their ability to complete (or teach) the course.
- Comparing the use of resources and their associated costs in course delivery between sighted and vision impaired students.

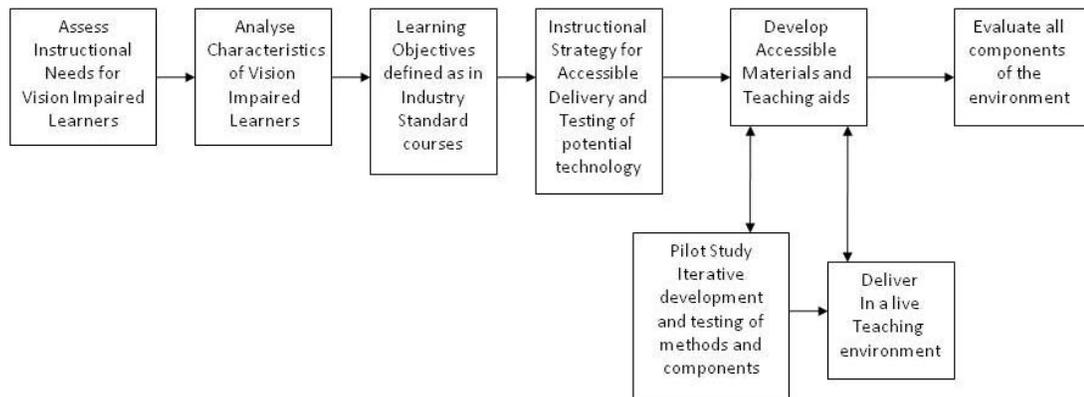


Figure 3.3: The process undertaken in this research.

3.6. The Pilot Study

A pilot study was undertaken between 2004 and 2005, in part as a feasibility study as to whether the Cisco Network Academy courses would be a possible framework for development of accessible curriculum and as an experiment in vision impaired learning. During this pilot study, tools and methodologies were trialled in an ad hoc manner so as to gain an overall impression of the requirements that will be included in a more structured developmental model. Results of this pilot study were presented at the ACE2004 (Murray & Armstrong, 2004) and WISE4 (Armstrong & Murray, 2005) conferences.

3.7. Conclusions

In order to achieve the research objectives:

1. To investigate the requirements for transforming e-learning curriculum for advanced training to ensure its suitability for acutely vision impaired persons, and

2. To build a conceptual model to guide the transformation of any e-learning course to cater for the severely vision impaired

The I.E.E.E. guidelines for instructional design were applied to an existing body of content. Requirements for additional accessibility and augmentative tools and materials extracted from the pilot study were incorporated into the Dick & Casey Model. This method was found to be the most appropriate for this type of research due to the nature of the problem and solution spaces and its flexible and integrated approach.

Action research was employed in the solution design, testing and evaluation stages due to the researcher's direct involvement in the change process. Action research also provides a sound platform for the cyclical exploration of possible solutions until resolution was achieved.

Chapter 4 discusses the problem analyses, solution design and testing phases, through the application of Design Science and action research.

4. PROBLEM ANALYSES AND SOLUTION DESIGN

4.1. The Problem-Solving Approach

Any effective problem solving model will gather data about an identified problem, analyse the problem situation, generate ideas for potential solutions, then develop and evaluate chosen solutions. Hicks (2004) proposes the generic problem solving model illustrated in Figure 4.1.

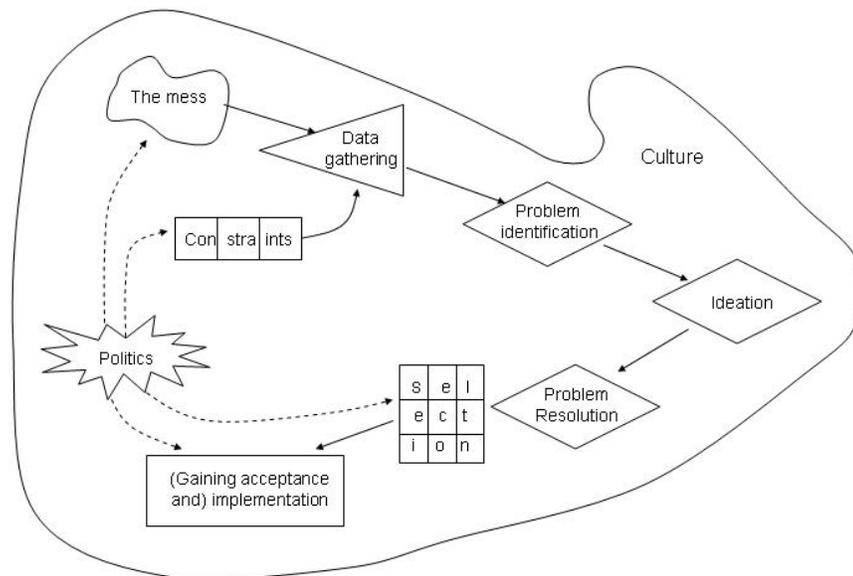


Figure 4.1: Problem-solving model (Hicks, 2004:37)

The 'mess' is the realisation that a problem exists and that the current situation is not the desired situation. In order to identify, address and prioritise requirements to move from the current state to the desired state data needs to be gathered via a fact finding mission. The problem identification stage is also termed the 'problem redefinition' and here it is important to view the problem from the perspective of all parties who hold a stake in the situation.

Ideation is the development of creative potential solutions and in this research a combination of divergent and convergent thinking drives this phase. The evaluation of these solutions against predefined criteria is carried out in the problem resolution stage and the most appropriate solutions are selected. The chosen solutions are then implemented and careful change management ensures acceptance of the changes. The entire problem-solving process needs to account for the unique culture of the setting, including any constraints and politics.

As complex systems exist in dynamic environments, the problem solving process is a cyclical one. The implementation of designed solutions will change the current problem space, and evaluation of solutions applied will provide new data about the situation under study.

4.2. The Problem Domain

The problems faced by the severely vision impaired are unique in nature. Due to their lack of sight, alternative methods of access must be incorporated into e-learning materials – a rare phenomenon occurring in today’s vision-driven IT environments. This lack of accessibility results in low levels of tertiary education for the blind. A direct outcome of this lack of education and training is high rates of unemployment for the blind, plus rising costs of supporting the blind. (Vision Australia, 2007) Also contributing to the problem is the restricted physical mobility many blind individuals face resulting in their inability to travel to, and attend educational institutions.

As discussed in chapter 2, educational institutions are not generally designed to cater for blind students, and sighted teaching staff are insufficiently trained in the needs of the blind. This has resulted in an

ineffective delivery of education to this minority group. Figure 4.2 illustrates the problem domain triggered by the lack of accessibility of education for the blind.

Although a small portion of current e-learning materials is textual in nature (and accessible by screen reading software), the majority remains visio-centric, encompassing large amounts of visual materials including diagrams, images and animation. Many file types are also not accessible by screen readers, for example, .pdf, .mov, .jpeg, .gif, .ppt, .png, .tif, .bmp etc. In general, many web sites do not comply with disability and equality laws as the content of these web sites is inaccessible, or difficult to access by those with disabilities.

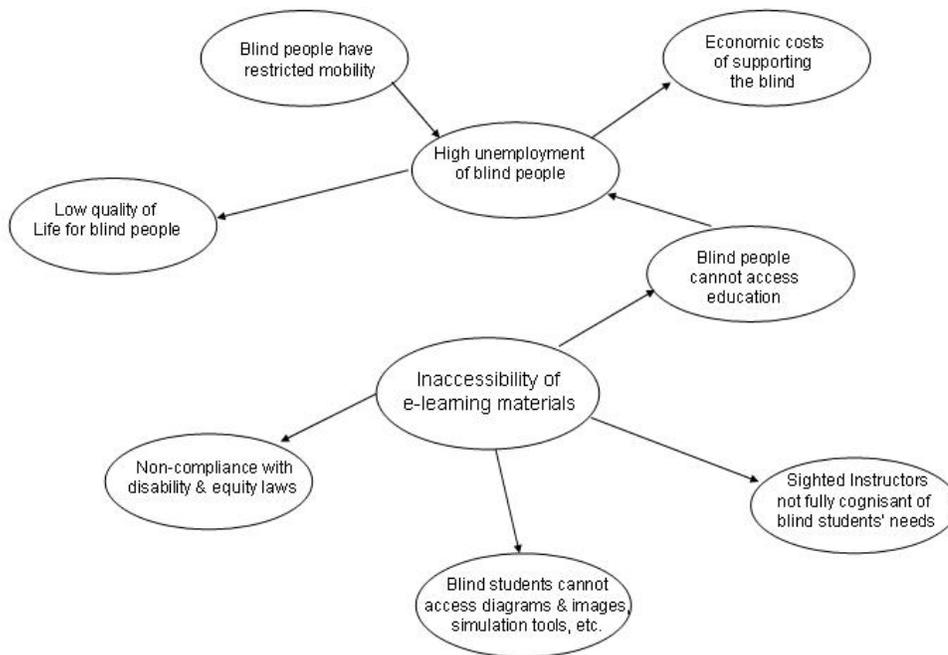


Figure 4.2: Cognitive map of problem domain relating to inaccessibility of education for the severely vision impaired

The blind are attentive and responsive to the needs of other blind students, having first-hand experience in the difficulties faced and effective methods of elucidation for confused and frustrated vision impaired students.

A detailed analysis of the problem situation to gain a holistic view and a comprehensive understanding is necessary in order to effectively improve this problem situation. Investigating the central bubble in Figure 4.2, Inaccessibility of e-learning materials, further detailed analysis produces a more detailed perspective of the specific problems contributing to the overall problem situation (see Figure 4.3).

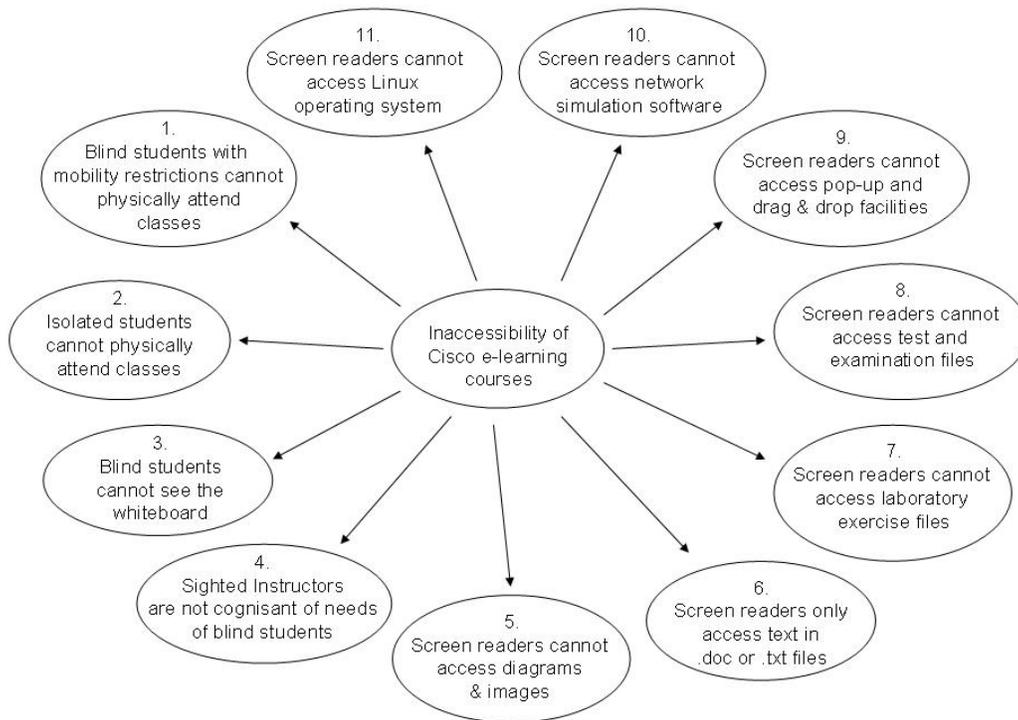


Figure 4.3: Cognitive map of problem space relating to inaccessibility of Cisco e-learning education for the severely vision impaired

A brief coverage of the detailed problems and potential solutions follows:

1. Mobility - many blind individuals have problems with mobility; some have spatial difficulties with unfamiliar environments and traveling by public transport is daunting for those with no sight. Those with limited spatial ability have difficulty finding their bearings in a room and need assistance to find any amenities they require; for example the toilet, the water fountain, their workstation, etc. One of the bolder totally blind students who participated in this research and who travels by train and bus to get to Curtin University of Technology has been accosted repeatedly and robbed on several occasions. Curtin University of Technology is not a blind-friendly

place and even walking from the bus terminal to the computer lab is fraught with obstacles – footpaths dug up, barriers and protective fences around underground maintenance work, gardening tools and vehicles obstructing walkways and the like. (K. Hoath & I. Blackburn, personal communication March 2007) The blind can become confident if they learn the journey, but this confidence is undermined when they are regularly required to re-learn each journey on a frequent basis. The issue of mobility raises the need to provide education presented in a format easily accessible to vision impaired students via remote means, and employment that does not require extensive mobility. IT network support and administration is an ideal career as the networks can be managed at the administrator's workstation.

2. Isolation – vision impaired individuals who live remotely from learning institutions cannot physically attend classes delivered on that institution's premises. A virtual classroom environment is needed that offers isolated students the opportunity to listen to lectures, participate in laboratory exercises and converse with the instructors and other students as if they were in the same room.
3. Whiteboard – blind students cannot see visual aids, and whiteboards and blackboards are commonly used by teachers to present essential learning information. Alternate methods of offering materials previously presented by the whiteboard or blackboard are required. Solutions would depend upon the type of information being delivered, and include Braille, electronic textual descriptions, audio descriptions, haptic representation and tactile representation.
4. Sighted teachers are not cognizant of needs of blind students. Students with severe vision impairment face many obstacles to their learning. As few instructors have had experience in dealing with vision impaired students in their classrooms, the teaching is geared towards sighted students. Training is rarely offered to fill this gap in

knowledge, and the instructors are left to research means of providing accessibility to their education materials. Teachers in the situation of having blind and/or vision impaired students in their classes are not fully cognizant of the difficulties, unless they are vision impaired themselves. Vision impaired teachers are able to comprehend more fully the obstacles faced by vision impaired students and can often offer more effective solutions based upon their own experiences.

5. Screen readers cannot access diagrams and images. The old saw, a picture paints a thousand words is often adopted by curriculum designers and technical writers in computing. As it is assumed the reader can see the picture, the words describing it are seldom included. Current e-learning materials in IT and computer engineering incorporate a large number of images, rarely with sufficient supporting explanation to make the image meaningful to the severely vision impaired via their screen reading software. Several research projects have been undertaken to develop accessible image descriptions, however these descriptions must form part of the design and development of the images. These products cannot be applied to materials previously developed using other methods. Tactile methods of image presentation are needed, such as tactile pallets, printing tactile output, or alternatively haptic devices such as a haptic pen have the potential to present 2-D and 3-D drawings and concepts via force-feedback mechanisms. A final option would be Braille or textual descriptions of images written by sighted individuals familiar with the complex materials being presented.
6. Screen readers are only able to access text in files, and materials presented in other formats are not accessible. For example, items presented using Flash code to illustrate sequence or associations between elements, or any animation used to highlight details are

completely inaccessible. Any method applying rotation to visual objects is also inaccessible. Icon-driven selection processes and mouse driven interaction are also inaccessible to the screen reading user due to the reliance on coordinated mouse movements. Again, research in these areas has not presented solutions to these problems. Similarly, tactile and haptic devices may provide some accessibility, but these need to be researched more deeply to ascertain if they are able to appropriately meet this need. Braille and textual descriptions are also a possible solution.

7. Screen readers cannot access laboratory exercises. Cisco laboratory exercises are presented in a format that is largely inaccessible to the vision impaired students. In the case of the laboratory presentation, much of the inaccessibility stems from the layout rather than any inherent accessibility issue. The use of diagrams to depict network topologies and embedded graphics containing tabular information on the configuration requirements, render the main instructional text incomplete and confusing to the screen reader user. Therefore laboratory exercises and worksheets must be converted into an accessible format so that the students can complete the practical activities.
8. Screen readers cannot access examination files. Cisco delivers the course examinations via the Internet (by means of Cisco's proprietary Vertuoso Web services) and are partially inaccessible by screen reader users, as they contain diagrams, images and interactive features. These must be augmented with supplementary information so as to provide the necessary diagrammatic descriptions to the student. Potential solutions include those listed for diagram representation, namely tactile and haptic devices, Braille and textual descriptions.
9. Screen readers cannot access pop-up and drag and drop facilities, again due to the reliance on mouse interaction with the media

object. Features of the Cisco e-learning materials include pop-ups and drag and drop facilities that the students must access and respond to. Many of the vision impaired students cannot see these prompts and are not able to respond appropriately. Drag and drop and the method used in the delivery of pop ups within the curriculum is not accessible to screen reader users. Each of these features must be converted into a format that is accessible so the students can respond and get the required feedback on their actions.

10. The Cisco network simulation software is inaccessible by the assistive technologies used by the vision impaired students. This means the students are not able to apply the theory they are leaning into designing effective network topologies and testing these designs. Potential solutions include modification of the Cisco software tool, development of an accessible network simulation tool, and provision of a remotely accessible network to physically test the student's network designs.
11. Limited usability of Linux based screen readers. Screen readers available for the Linux operating system fall into two main categories, command line and GUI. The command line screen readers function well and offer good accessibility to command line utilities. However, the GUI capable screen readers offer only very limited functionality and are heavily dependant on either GNOME or KDE. As much of the content of the Cisco courses focuses on the Linux operating system, in particular the GNOME graphical utilities, the vision impaired students are unable to access much of the materials written for and on the Linux platform, or undertake Linux based activities. Potential solutions are to modify the assistive technologies currently used by the students, redesign the laboratory sessions to work within the CLI rather than GUI and develop a screen reader for Linux environments.

4.3. Ideation and Potential Solutions

For each of the problems listed above, potential solutions were identified and analysed. Figure 4.4 illustrates the solutions examined, and a description of each follows.

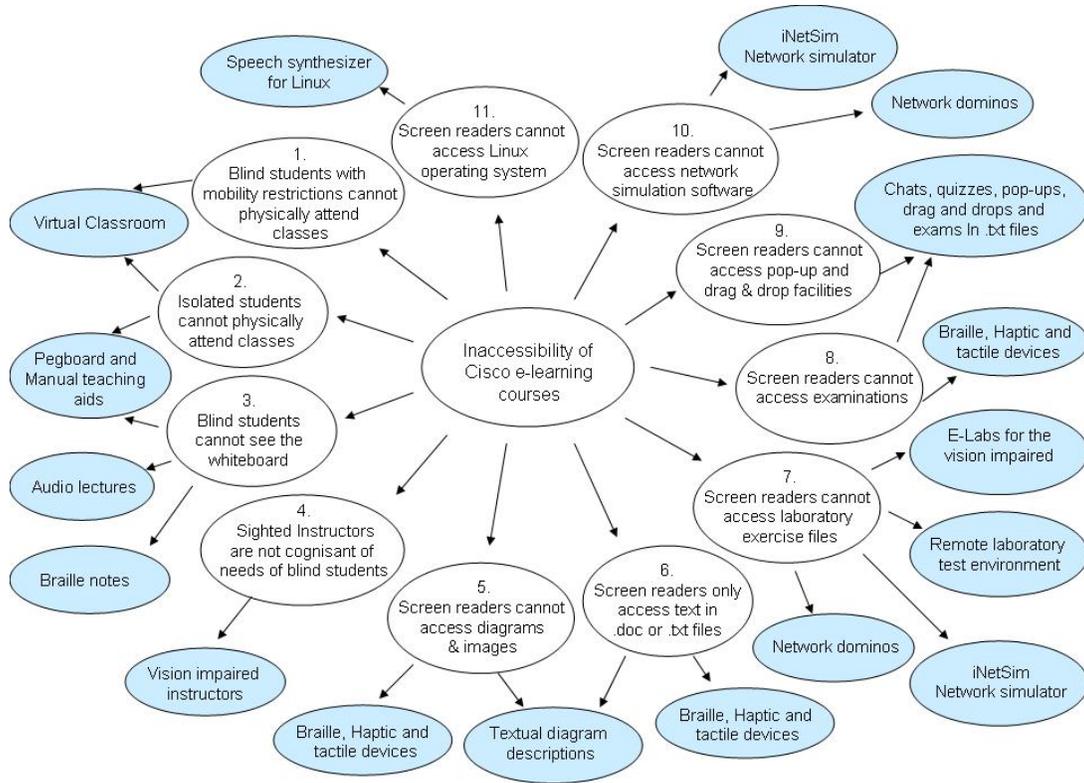


Figure 4.4: Cognitive map of potential solution space relating to inaccessibility of Cisco e-learning education for the severely vision impaired

As a result of brainstorming with instructors and students in the vision impaired classes, a number of solutions were identified and the impacts of each carefully considered. Of those indicating promise, further research was carried out to find and study any past application of the proposed solutions, and to discover the nature of the solutions in greater detail.

Many of the potential solutions addressed more than one problem, and in essence the potential list of solutions was refined to the following:

1. Undertake a pilot study to identify and test potential methods and solutions *in situ*
2. Produce Braille notes for lectures, laboratory exercises, and other learning materials
3. Produce audio lectures to enable students to hear lectures and access audio files at any time for revision
4. Develop manual teaching aids to assist learning of complex concepts, with particular emphasis on tools for IP addressing, decimal-hexadecimal-binary conversions and network topology design
5. Develop a virtual classroom environment to enable students to interact with instructors and other students as if they were physically in the same room
6. Use vision impaired instructors to deliver teaching and assist vision impaired students
7. Experiment with haptic device to determine appropriateness for presentation and assimilation of complex diagrams
8. Experiment with tactile devices to determine appropriateness for presentation and assimilation of complex diagrams
9. Experiment with textual descriptions of images
10. Develop a network simulation application for use by both vision impaired and sighted students for network topology design and testing
11. Develop a remote laboratory test environment for both local and remote vision impaired students to design and test their network architectures

12. Convert the standard Cisco laboratory exercises into accessible formats presented in electronic format using Braille, textual, haptic or tactile means
13. Redevelop examinations into accessible formats presented in electronic format using audio, Braille, textual, haptic or tactile means
14. Hold chat sessions and quizzes in real time using low cost VoIP to ensure students can work through exercises and ask questions as they progress
15. Develop accessible electronic tools to deliver drag and drop and other interactive functions to vision impaired students
16. Develop audio demonstrations and descriptions of items and exercises that are not available to remote students due to either cost or complexity of the equipment involved

The identification of potential solutions and initial testing was accomplished over a three year period. A pilot project was commenced in 2004 involving 19 legally blind students progressively testing converted versions of the Cisco e-learning materials and utilising the manual teaching aids developed.

As part of the research the following solutions were investigated and evaluated:

1. Braille and Braille Displays
2. Pegboard
3. Network Dominos
4. iNetSim network simulator

5. Remote Bundle laboratory environment
6. Remote Delivery
7. Virtual Classroom
8. Tactile displays
9. Haptic Pen
10. Textual Image Descriptions
11. e-Labs
12. Drag and drop interactive functions
13. Audio demonstrations.

These solutions are discussed in detail following a description of the Cisco e-learning curriculum that formed the content base for delivery within the scope of this research.

4.4. The Cisco Network Academy Program

4.4.1. Cisco e-learning Curriculum

The two fundamental equalisers in the global economy are the Internet and education. The Internet is creating unprecedented opportunities for businesses, individuals and governments and the winners will be those with the right skills and knowledge to compete."

John Chambers, President and CEO, Cisco Systems (Cisco, 2008)

Cisco Systems state that their Networking Academy Program empowers people, through e-learning environments, to learn anytime, anywhere, at their own pace, and with more targeted assessments and accountability than traditional classroom settings.

The Cisco Network Academy Program is global, with more than eleven thousand academies catering for more than two million students in over 160 countries. (Cisco Systems, 2008)

Cisco System's programs for training and support conform to a corporate three-tiered model. This three tiered model consists of Local Academies, Regional Academies, and Cisco Academy Training Centres known as CATCs. Curtin University is an authorised Cisco Academy Regional Academy. According to this model, CATCs train the Regional Academies and the Regional Academies in turn train the Local Academy instructors who then educate the students. CATCs and Regional Academies, if approved by Cisco, will have the opportunity to specialize in whatever curricula best aligns with their internal resources, and meets the needs of their own educational community (Cisco Systems, 2008).

The typical structure of a Cisco Course web page (see Figure 4.5) consists of four areas. At the top and bottom of the page are the normal navigation tool bars. Also at the bottom of the page there is an area that responds to mouse roll over and permits navigation to a small selection of destinations. The left of centre section in the main and middle screen area is allocated to medial objects such as pictures, diagrams and Adobe Flash type of tutorial presentations (Adobe Flash is an authoring software application for creating multimedia objects). To the right of centre in the main and middle screen area is the section allocated text.

As shown in Figure 4.5, while each of the screen areas are accessible by mainstream users, much of the viewing area is not accessible by blind or vision impaired students relying assistive technology for viewing web pages. An example of a representative page from the Cisco program is shown in Figure 4.6 clearly indicating how much screen information is not available to non sighted users.

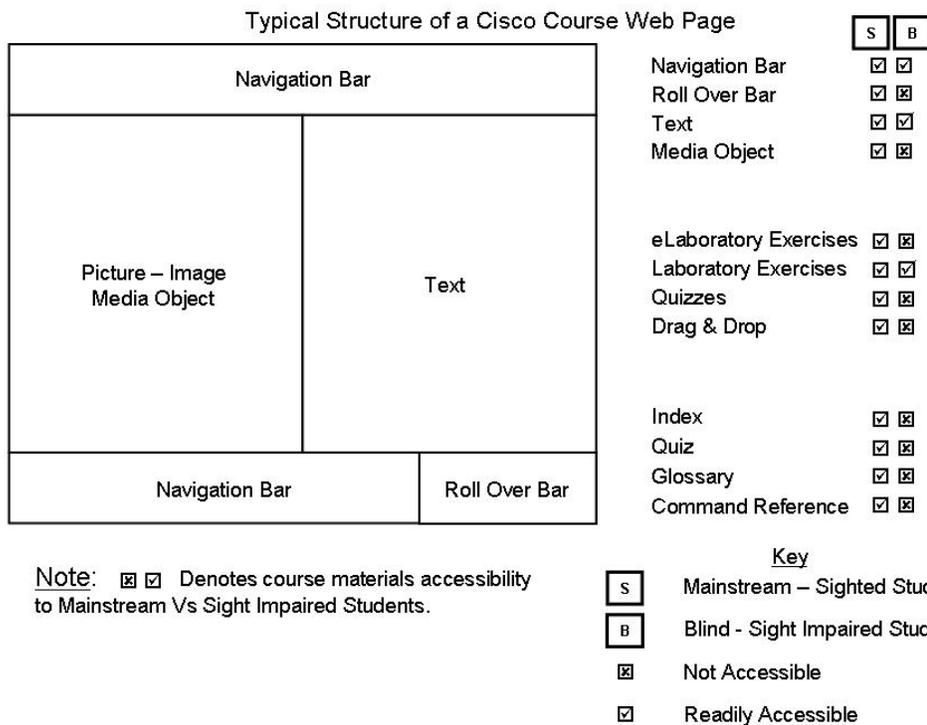


Figure 4.5: Accessibility to information on a typical web page.

S	B	
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Navigation Bar
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Roll Over Bar
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Text
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Media Object
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	eLaboratory Exercises
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Laboratory Exercises
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Quizzes
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Drag & Drop
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Index
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Quiz
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Glossary
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Command Reference

Figure 4.6: A Representative Cisco Network Program web page.

The early stages of the research examined methods of extending a variety of Cisco accredited training programs and resources to vision impaired students at Curtin University. At issue in extending the Cisco curricula to students with sight related disabilities was not the content of the course materials, it was rather how to convert the information (already fully accessible to sighted mainstream students) into formats that would permit accessibility to both sighted and vision impaired students.

4.4.2. Learning Design

The teaching resources provided for the Cisco Networking Academy Program course content consist of lectures, laboratory exercises, on-line learning course content, simulation tools, images and diagrams, and examinations and quizzes. The curriculum and delivery mechanism developers appear to have given little thought to the issues involved in delivering said resources in an accessible manner to vision impaired students. An understandable and common paradigm, as most developers concentrate on meeting the requirements of the majority of the user base, those with no disability. As there was an underlying assumption that Cisco program students are not vision impaired, the training resources were designed to impart information that requires the student to be sighted. To accomplish desired learning outcomes for vision impaired students these material resources required modification. Figure 4.7 maps the modifications implemented to meet vision impaired student requirements.

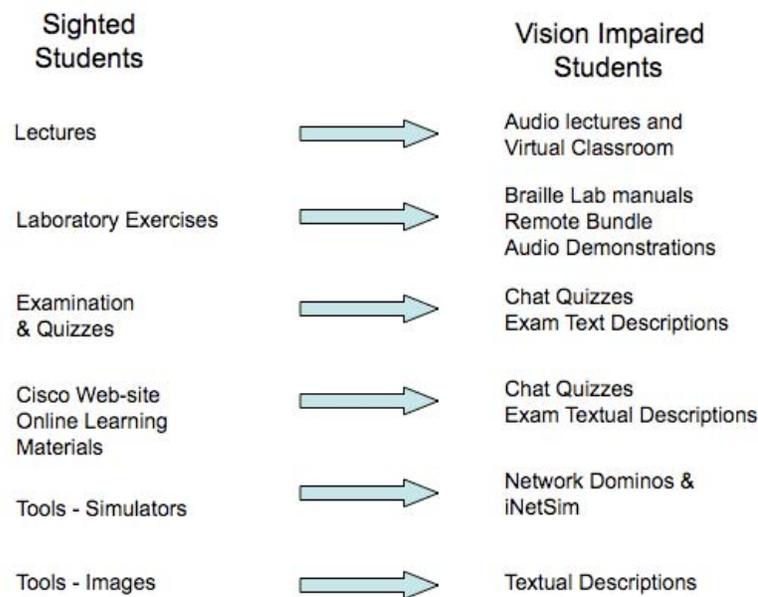


Figure 4.7: Mapping of Cisco course materials for vision impaired students

The modification of Cisco course materials necessitated consideration of basic teaching and learning methodologies as well as the nature of vision disabilities. There are consistencies and commonalities in the desired learning outcomes for both mainstream and vision impaired students. There is, however, a requirement for different approaches to achieve those desired outcomes. It is also necessary for those learning outcomes to demonstrate that students have acquired the level of learning expected. The principles as provided by Bloom's taxonomy (Bloom, 1956) and Kolb's experiential learning (Kolb, 1984) provided the foundation for undertaking course material modifications.

Bloom's taxonomy identifies; knowledge, comprehension, application, analysis, synthesis, and evaluation as the sequence for progressively

contextualising educational materials. (Bloom, 1956). Bloom's taxonomy also recognises that the cognitive domain of training for technicians may cover knowledge, comprehension and application, but not concern itself with analysis and above, whereas full professional training may be expected to include this and synthesis and evaluation as well. (Bloom, 1956)

Kolb's experiential learning model is cyclic and based on four elements: concrete experience, observation and reflection, the formation of abstract concepts and testing in new situations. This experiential approach is crucial for students with vision impairment who rely on practical application, reflection and concrete experience to fully understand underlying foundations.

4.4.3. The Cisco Courses

The Cisco Networking Academy Program provides an e-learning program for students wishing to gain an accredited industry certification in networking and computer technologies. The four Cisco courses converted for the vision impaired students were: IT Essentials 1, IT Essentials 2, Certified Cisco Network Associate 1, and Certified Cisco Network Associate 2. Appendix C: briefly describe the scope and sequence of each course. The details discussed are taken directly from the scope and sequence notes provided by Cisco Systems (see <http://cisco.netacad.net/>). They explain prerequisite knowledge and skills, the course objectives, and a listing of the topics addressed during the course. Because of the extensive nature of the topics covered in each course it is not appropriate to provide the complete list of topics in this document.

Cisco Systems Inc is the acknowledged global market leader of computer network router and switching equipment and services. The demand from business organisations seeking appropriately knowledgeable and skilled employees to operate corporate computer and communication networks is not expected to diminish in the foreseeable future. Employment opportunities exist in these information technology areas because organisations value the contribution IT makes to their business. Cisco has long recognised that the marketing of their product is inextricably linked to the ability of trained technicians to manage the equipment efficiently. Public accountability requirements placed on corporate organisations ensure that people employed to work in the IT area are suitably trained and qualified. The manner in which Cisco training courses are conducted around the world is determined by Cisco corporate policy, and organisations working in partnership with Cisco to provide courses must conform to those policies. All teaching and training materials, and resources are provided on-line from the Cisco web site (may be mirrored in the local academy to reduce bandwidth requirements) ensuring that all students work with the same materials. Instructors must attend Cisco authorised training centres and pass instructor examinations for all curricula they wish to deliver. Courses are instructor-lead with students physically attending laboratory classrooms. Curtin University⁴ is at the time of writing, the only Cisco academy in the world delivering to blind students in an on-line mode for both local (attending in person) and

⁴ Delivery of the courses to vision impaired students has been delegated to the Association for the Blind (WA) as of 2008. Curtin University involvement is now that of research and development of teaching methods and tools to support the delivery of remote training to people with vision impairment.

remote students. The following section discusses how the Cisco course adjusted to accommodate teaching blind students.

4.5. The Potential Solutions Investigated

4.5.1. Braille and Braille displays

As discussed in Halliday (2006), Braille is particularly useful in the comprehension of technical or complex subjects. It was determined that the exploration of Braille in limited areas of application would be beneficial. In particular the use of hard copy, or embossed Braille, may be an effective adjunct to the vocalised output of the curriculum reference material. Even though levels of Braille literacy have been declining in recent years (NFB, 2006) it can be shown empirically that hard copy Braille is effective in a laboratory environment. It was noted throughout the research that Braille literate students made extensive use of the hard copy embossed Braille laboratory manuals, in much the same manner as sighted students printed hard copies of the same manuals. During a typical laboratory session students (sighted or vision impaired) will have the following windows or applications open:

- Module curriculum in a web browser
- Text document for note taking of laboratory results
- Web browser for research on laboratory topic
- PDF document reader for laboratory manual
- A minimum of one, often 3, telnet sessions with the laboratory equipment command line interface
- Text document of lecture notes

- Ciscopedia – An Application that allows the search and syntax of Cisco Operating System commands

Hard copy Braille laboratory manuals have the advantage of reducing the number of open applications on the students desktop and thus lessening clutter and confusion. This is of particular importance to screen reader users due to the linear nature output by this technology. Screen reader users must cycle through each open application and window, listen to the description of that application and document until the required window has focus. Reducing the number of open item, even by one, is a significant time saver.

An additional advantage of Braille is that of the reduced ambiguity of output. Complex terms or abbreviated Cisco Internetwork Operating System (IOS) commands may not vocalise correctly or clearly. For example the command to display the running configuration on a router may be abbreviated as `sh run` and appear with the command prompt as –

```
Rname#sh run
```

As may be seen, this would be difficult to understand at a high rate of text to speech. For this reason refreshable Braille displays were utilised on router console connections wherever possible. However the high cost of these devices, typically over \$8,000Au, restricted the number and location of this form of assistive technology particularly for students in developing countries. Installation of refreshable Braille displays were of two types, attached to the standard PC for general reading and curriculum access and connected to the router bundles, acting as a console display of commands and configurations as shown in Figure 4.8.



Figure 4.8: Installation configurations utilising refreshable Braille displays

It should also be noted that whilst the ambiguity is reduced, it is not eliminated. A common point of confusion is the lossy compression of grade two Braille, caused by the availability of just 64 possible combinations in Braille. A case in point is that of the router command prompt in privileged mode.

```
Router#
```

Which in ASCII Braille contracts to

```
r\t],no4
```

When expanded back to English text becomes (as the Braille reader will interpret it)

```
Routerble
```

To overcome ambiguity in router commands, uncontracted Braille, or computer Braille, was used where commands were needed. (in much the same manner as fixed width fonts are used in print)

4.5.2. The Binary Abacus or “Pegboard”

An essential aspect of any computing course is that relating to mathematics, particularly number systems and Boolean algebra. Reading strings of binary digits is time consuming and error prone when using screen reading software and speech output, whilst numbers in hexadecimal may, under certain circumstances, be enunciated as a word. For example hexadecimal value “FEFE” would be pronounced as |fā fā|⁵.

There are numerous teaching aids available and suitable for mainstream students working towards an understanding of, and being able to, work with numbering and computer addressing systems. These teaching aids tend to be inappropriate for blind or vision impaired students for various reasons, including inaccessible software, visual nature of the instruction or method. The pegboard was developed by the author as a cheap, easy to manufacture device to address this problem. This is considered a particularly important feature for students in less developed countries.

The pegboard consists of a plastic or wood board measuring 290 mm by 140mm. The pegboard, shown in Figure 4.9, has three rows of 32 drilled holes. Each of these rows may represent an IP address, subnet mask, network range or binary number. A binary 1 is represented by a “pin”, a binary 0 is represented by an absence of a pin. A pin is a standard Rawl Plug, or short length of timber or metal rod, readily from a handyman hardware supply shop.

⁵On Apple OS X 10.4 Text to Speech.



Figure 4.9: The Pegboard

Learning, understanding and being able to work calculations with different number systems can present students with some conceptual challenges. It is particularly difficult for many vision impaired students.

An important foundation concept in the CCNA and ITE courses is that of number systems and conversions between them. It is critical that the student is fluent in binary, octal, hexadecimal and decimal conversions. The pegboard is used in these calculations by converting the number to binary by successive subtraction (decimal) or 4 bit segmentation (hexadecimal), with pins being placed into the appropriate “hole value” and the result being read off in the correct base. The example in Figure 2.4 illustrates this process.

Table 4.1: NUMBER SYSTEM CONVERSION EXAMPLE

Description	Steps/Results
-------------	---------------

Convert the Decimal number 134 to hexadecimal	
Subtract the largest power of 2 possible	$134 - 128 = 6$
Place a pin in the most significant position of the octet, bit 8 (x marks undetermined results)	Pegboard contains 1xxx xxxx
Step through the possible powers of 2	
Remainder is not divisible by 64	Pegboard contains 10xx xxxx
Remainder is not divisible by 32	Pegboard contains 100x xxxx
Remainder is not divisible by 16	Pegboard contains 1000 xxxx
Remainder is not divisible by 8	Pegboard contains 1000 0xxx
Remainder is divisible by 4, place a pin in bit 3	Pegboard contains 1000 01xx
Remainder is divisible by 2, place a pin in bit 2	Pegboard contains 1000 011x
There is no remainder	Pegboard contains 1000 0110
Read off the first 4 bits	$1000 = 816$
Read off the second 4 bits	$0110 = 616$
Concatenate the result	8616

The process of creating subnets from a given network address is a fundamental topic in the CCNA and key to student success. However, this is not an easy concept for all students to grasp. Subnetting is particularly

difficult for vision impaired students as they are unable to visually scan a string of 1's and 0's associated with the normal dotted decimal convention of IP addresses. Figure 4.8 illustrates an example subnet calculation. In this example the top row contains the network address, 10.3.44.0, a subnet mask of 255.255.255.192 and an IP address of 10.3.44.70. It may be clearly seen that the subnet mask ends at the second most significant bit of the last octet and that the IP address is on the first network, assuming the zero'th network is not usable. Full ranges of IP addresses within subnets may be calculated in this manner.



Figure 4.10: Pegboard with IP Addresses and Subnet Mask

Note in relation to subnet mask of 255.255.255.192, that for speed of subnet mask entry, a blanking piece is used. This item has 2 pegs, one at either end, joined to a plastic strip, effectively blanking out a complete octet and therefore representing the decimal number 255.

4.5.3. Network Dominoes

Network topologies and device interconnections are normally conveyed to students in a graphical form, either in print or soft copy. Figure 4.11 illustrates a selection of these standard graphical representations used in describing network diagrams to sighted students.

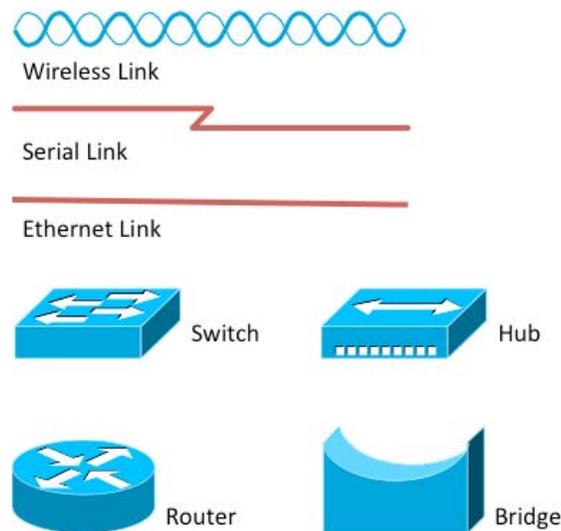


Figure 4.11: Graphical representation of network devices and connections

A method of tactile representation of network diagrams, called the “network Dominoes”, was developed and an example network is depicted in Figure 4.12. The network Dominoes are machined from 10mm thick PVC and are 80 x 50mm for the rectangular objects. Routers (circular object) are 70mm diameter. Where required symbols are engraved in relief on the upper surface of the Domino, for example the four arrows on a router. This allows for easy differentiation of devices such as the switch and hub, which are an identical rectangular shape but have a single double-headed arrow and four individual arrows on the upper surface respectively. Dominoes may be placed on a cloth “pin board” and are held

securely by a small patch of Velcro adhered to the reverse side of the network object.

Four holes are drilled into the object to allow interconnecting wires to link the devices. These wires take a similar form to the visual representation, straight wires for Ethernet, “lightning bolt” for serial and chain for wireless. (see Figure 4.11)

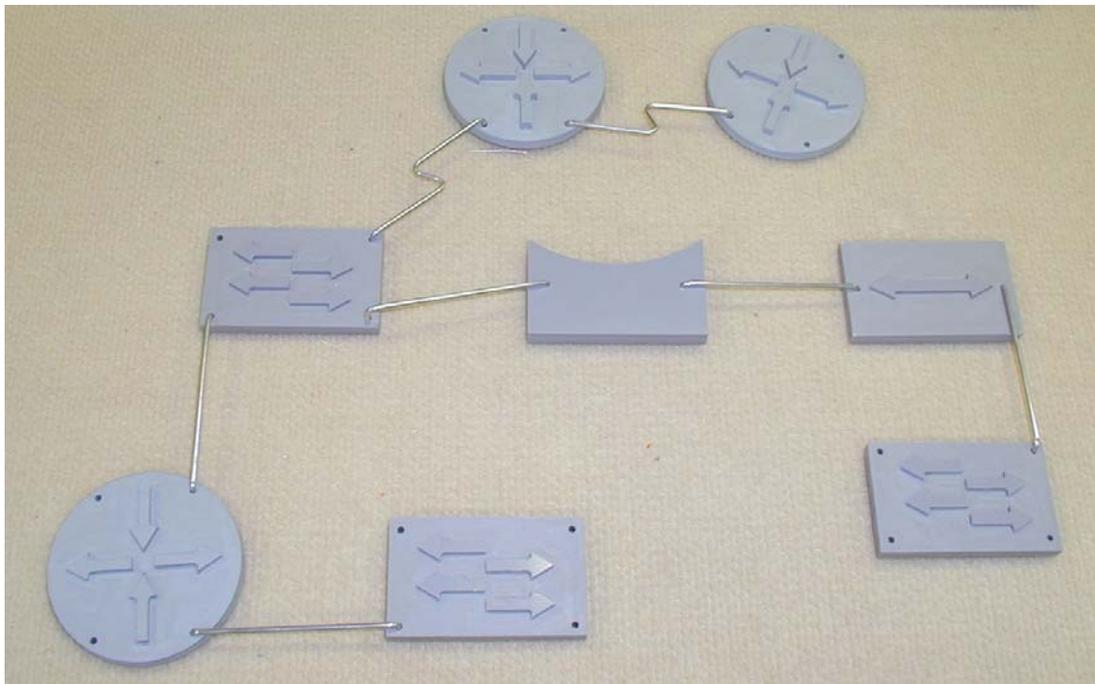


Figure 4.12: Sample network Dominoes topology

Network diagrams may then be constructed, as in Figure 4.12, that convey topological and logical connection structure of a network design.

A disadvantage of this method of representation is the cost involved in producing the Dominoes.

4.5.4. Remote bundles

Laboratory exercises form a significant portion of the curriculum. In order for students situated remotely to access and participate in the laboratory sessions, a functional, remotely accessible network has been established. Laboratories generally consist of three routers and two switches. The configuration may be described as two branch offices, say Perth and Sydney, connected together via the ISP or Internet cloud. The edge routers are configured by the students so as to allow connectivity via the middle router (cloud or ISP) Local students interact directly with the routers configuration via serial (console) interfaces. A problem exists when attempting to allow remote students access to “real” routing hardware. The routers may not be placed on production networks for obvious reasons and initial configurations must be entered via the console connection, a local RS232 port. Therefore a remote lab solution was needed that will allow students to perform:

- Initial configuration via the console cable
- Remote power cycling of network equipment and workstations
- Connectivity tests
- Advanced router and switch configuration

One such system does exist, Netlab, developed and distributed by NDG (<http://www.netdevgroup.com/>), however the cost of this system is a major factor in its adoption. Additionally, the java based applications in Netlab, including the booking system, telnet client to interact with the network hardware and server system are not accessible by screenreaders. The system developed costs significantly less than the Academy Edition of Netlab. Whilst it does not offer advanced feature such as equipment booking system it performs all the required functions for the vision impaired class applications. In its most simple form, it consists of the

standard CCNA laboratory bundle (3 routers and 2 switches, with several Linux PC servers running FTP, HTTP, Telnet and other associated services) that may all be accessed by their serial ports as shown in Figure 4.13. A standard serial port or console switch is used to access the devices in the laboratory bundle. Remote students may telnet into the console switch, accessing the routers, switches and Linux servers from any locality worldwide. Figure 4.18 illustrates an active telnet session logged into the remote bundle. As the routers are on their own network, with remote access attaching only to the serial ports, this system does not offer any security risk to the institution utilising it.

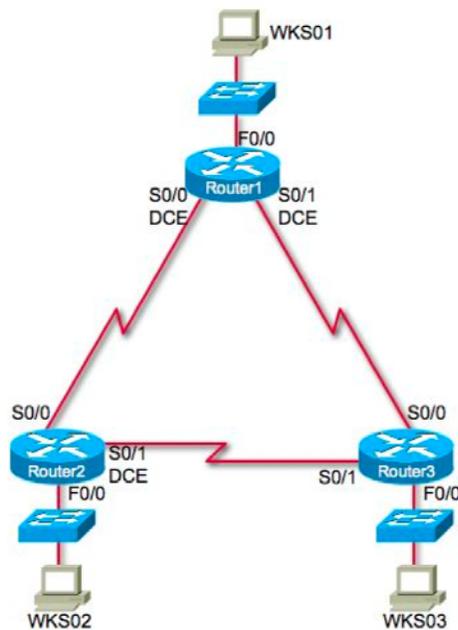


Figure 4.13: Standard router bundle

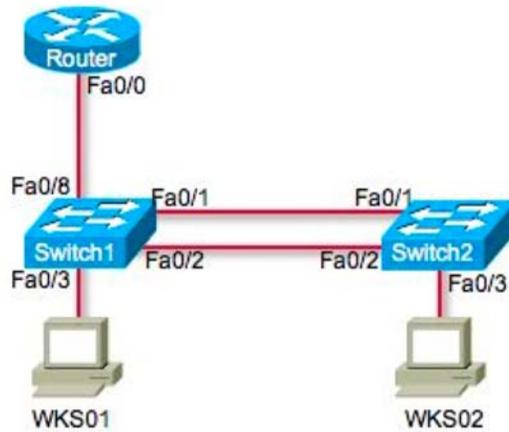


Figure 4.14: Switch bundle

Once the student has authenticated with the console switch (simple plain text password) a list of available equipment is displayed, as shown in Figure 4.15.

```

[Murray-2:~] iainmurray% telnet 134.7.43.171
Trying 134.7.43.171...
Connected to 134.7.43.171.
Escape character is '^]'.

Enter Password: *****

PORT STATUS:  Version 3.0,  Site ID: Curtin -o o- --oo o- -o oo -o

PORT | NAME | PASSWORD | STATUS | MODE | BUFFER COUNT
-----+-----+-----+-----+-----+-----
09 | Router1 | (defined) | Free | Any | 0
10 | Router2 | (defined) | Free | Any | 0
11 | Router3 | (defined) | Free | Any | 0
12 | WKS1 | (defined) | Free | Any | 0
13 | WKS2 | (defined) | Free | Any | 0
14 | WKS3 | (defined) | Free | Any | 0
  
```

Figure 4.15: Remote bundle equipment list

Several commands are available and are listed in Table 4.2. Connection to equipment is made via the /C n command, where n = required equipment port number.

Table 4.2: Console switch command menu

Display Options	
/S /SD	Port Status
/W	Port Parameters (who)
/J	Site ID
/H	Command Menu (Help)
Control	
<Enter>	Enter Command Mode
/x	Exit Command Mode
/C n	Connect to Port (n: Port# or name)

As there the booking system was incomplete at the time of writing, the virtual classroom (discussed in section 4.5.5) was utilised as a method of ensuring students knew if the equipment was in use. When undertaking a laboratory, students logged into the Ventrilo server and enter the appropriate channel, as shown in Figure 4.16. In this way students not only can tell if a particular bundle is in use but may also conduct laboratory sessions collaboratively with other students.

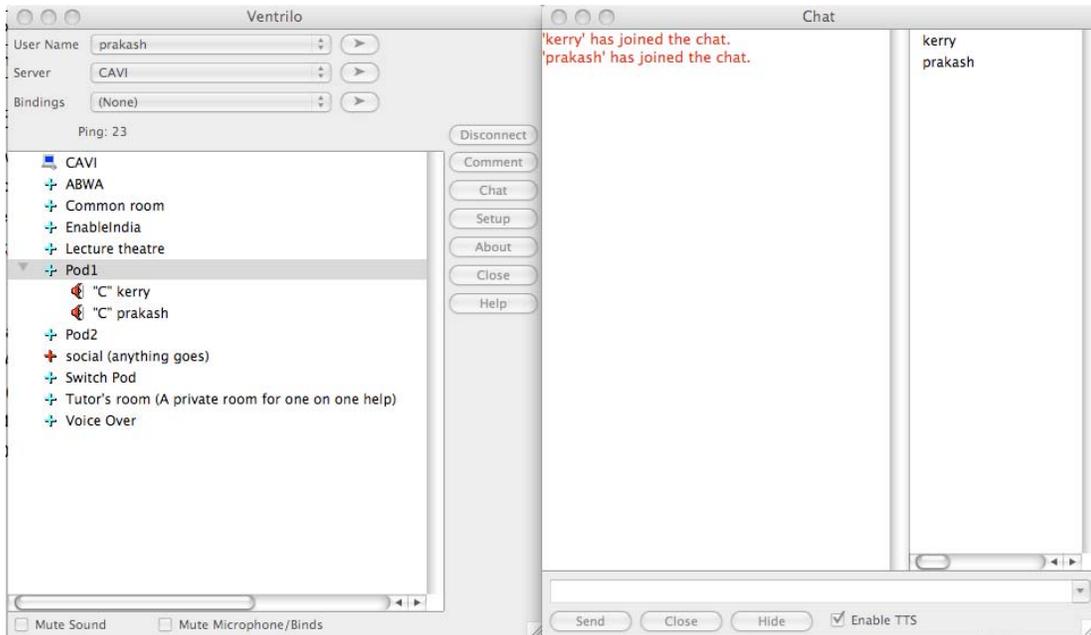


Figure 4.16: Ventrilo session in conjunction with use of the remote bundle "Pod1"

Power cycling of equipment is undertaken by authenticating first to the console switch and connecting to the remote power switch on port 16. The power switch may then be used to power down individual devices within the bundle. This is usually done with a secondary telnet session, allowing access to the router/switch to be power cycled and therefore the boot process to be interrupted (as in the case of password recovery laboratories) Each device may be powered on, off or rebooted. Figure 4.17 illustrates the process of remotely rebooting a router.


```
Terminal — telnet — 81x38
Dakar(config)#dialer-list 1 protocol ip permit
Dakar(config)#dialer-list 1 protocol ipx permit
Dakar(config)#!
Dakar(config)#line con 0
Dakar(config-line)# password cisco
Dakar(config-line)#line aux 0
Dakar(config-line)#line vty 0 4
Dakar(config-line)# password cisco
Dakar(config-line)# login
Dakar(config-line)#!
Dakar(config-line)#end
Dakar#
00:17:47: %SYS-5-CONFIG_I: Configured from console by console
Dakar#show int
FastEthernet0/0 is administratively down, line protocol is down
  Hardware is AmdFE, address is 0013.c4da.b9a0 (bia 0013.c4da.b9a0)
  MTU 1500 bytes, BW 100000 Kbit, DLY 100 usec,
    reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  Auto-duplex, Auto Speed, 100BaseTX/FX
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input never, output 00:01:35, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
    0 packets input, 0 bytes
    Received 0 broadcasts, 0 runts, 0 giants, 0 throttles
    0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
    0 watchdog
    0 input packets with dribble condition detected
  394 packets output, 204432 bytes, 0 underruns
  0 output errors, 0 collisions, 0 interface resets
  0 babbles, 0 late collision, 0 deferred
--More-- █
```

Figure 4.18: Remote bundle active session

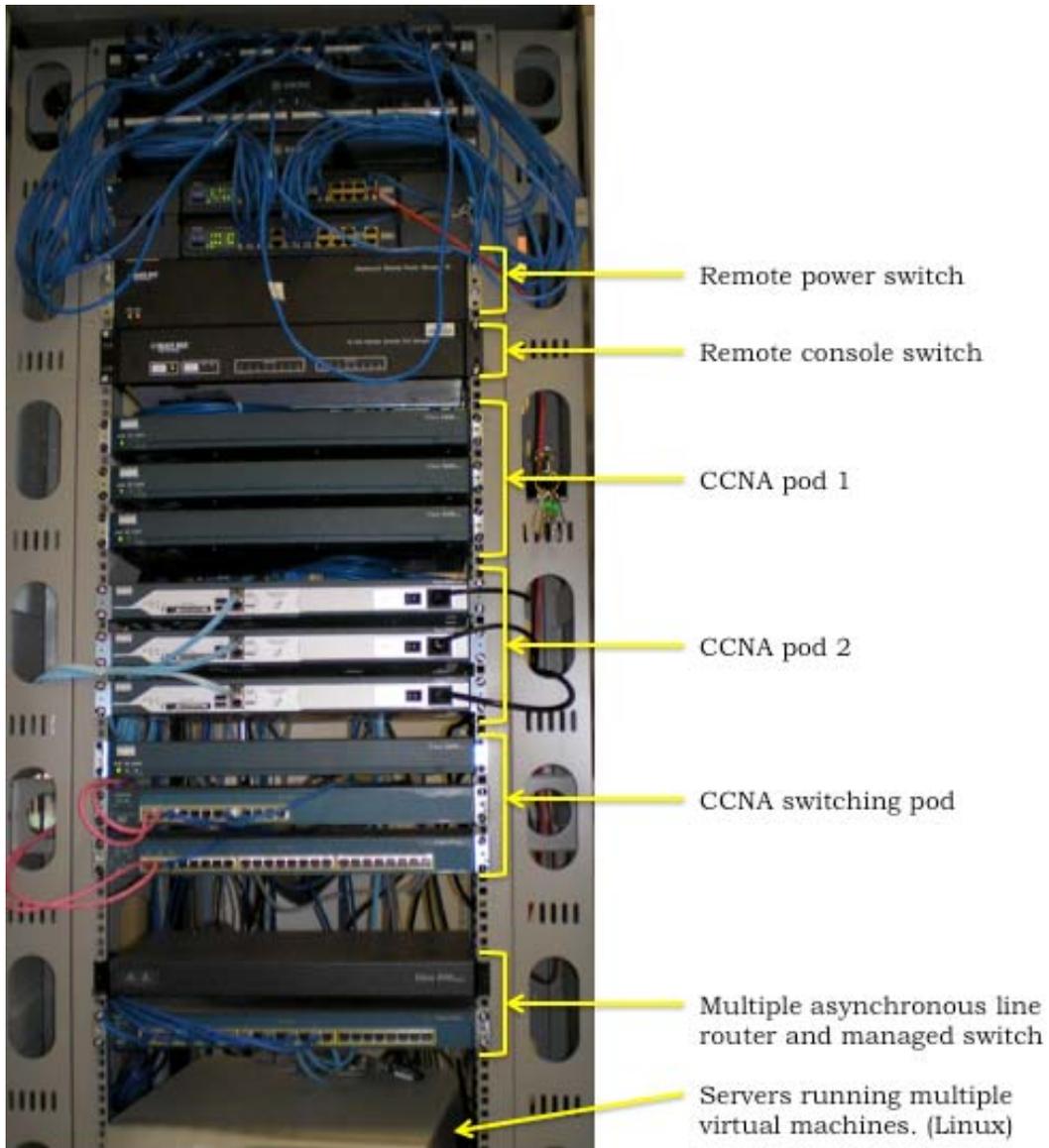


Figure 4.19: Remote laboratory equipment rack

4.5.5. Virtual classroom

Local and remote students interact with each other in a “virtual” classroom as shown in figure 3. Remote students connect to the Ventrilo server via the internet, thus avoiding high cost international calls, and the local students connect to the conference in the classroom. In this manner lectures, laboratories and discussions are shared with all participants

interacting with one another, just as if all were in the same locality. Participation and interaction in this manner may be termed a “virtual presence” as the individual may not be physically present but is able to fully participate in the same manner as physically present students. This allows the instructors to also conduct interactive quizzes with the students by utilizing the chat function. A question is asked of the entire class and replies are sent via the chat window once the instructor informs students to send the answer. The instructor may then check the replies and provides feedback to the students as required.

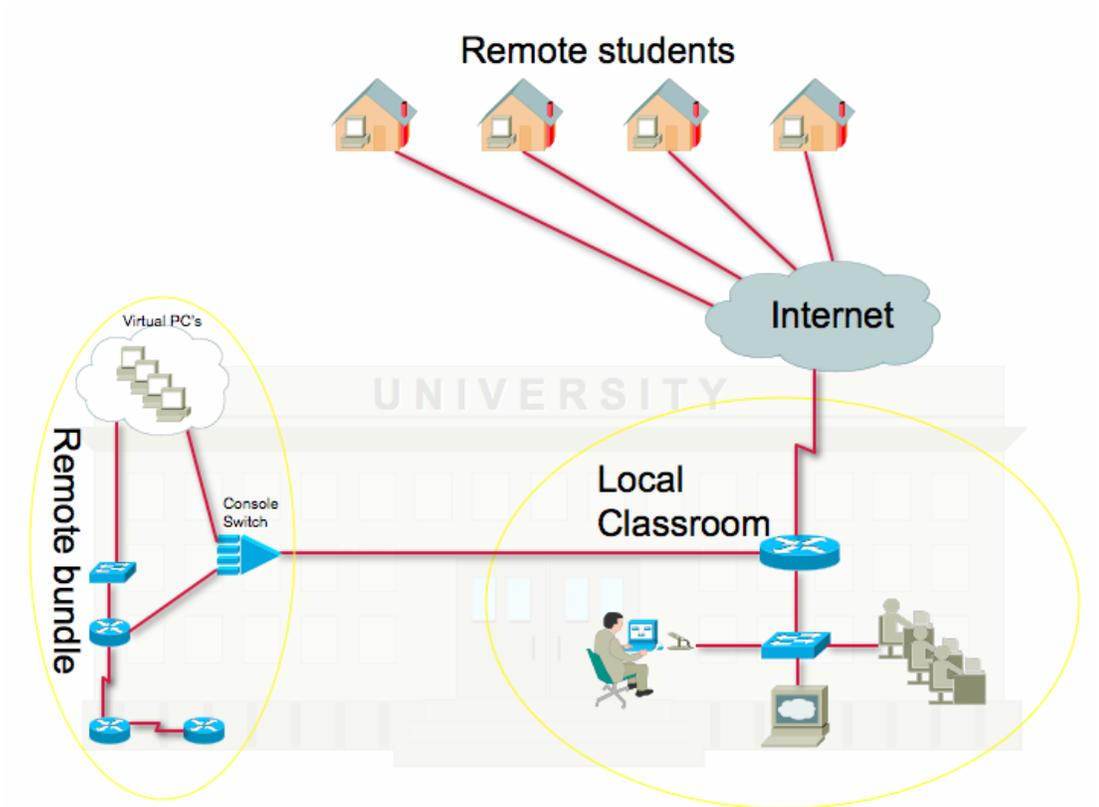


Figure 4.20: Virtual classrooms topology

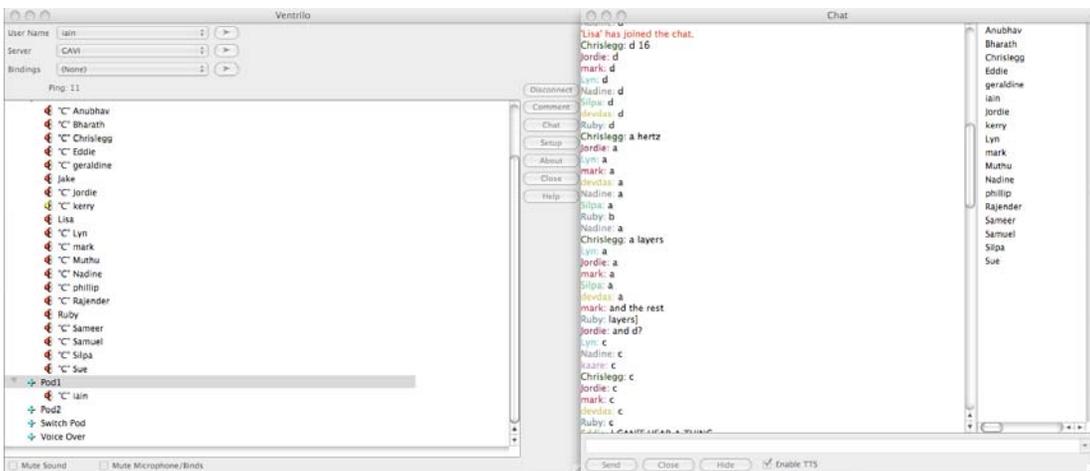


Figure 4.21: Ventrilo conference in operation

4.5.6. Tactile Graphics Devices

Students without the primary exteroceptive sense of sight must rely on touch and sound to compensate for the removal of vision-centric learning opportunities.

While many of the available assistive technologies meet requirements of the visually impaired users generally, they tend to become unsatisfactory when pressed to accommodate learning directed towards technology matters with high levels of diagrammatic complexity.

Vision impaired people tend to have multiple disabilities. A common example would be diabetes. Diabetes affects the body's blood circulatory system and as the system fails, patients lose sensation to the extremities. The fingers often suffer loss of feeling rendering the use of Braille difficult in the initial stages and in the later stages diabetic sufferers may experience disturbing levels of pain trying to use assistive technologies that rely on users to interpret sensations in the finger tips caused by device pins. For the vision impaired, losing the effective use of fingertips to interpret data dramatically reduces their efforts to compensate their loss of vision.

PIAF, Picture in a Flash, is an assistive technology device that uses a controlled heat source to imprint images or diagrams onto heat sensitive paper which then swells to reproduce a raised representation of the image. The output of PIAF is intended to allow the vision impaired to see by feeling tactile graphics. While in many situations this product provides a satisfactory solution to gaining an appreciation of an image or basic diagram it does not meet the requirements necessary to impart

understanding of detailed information taken from complex technical diagrams.

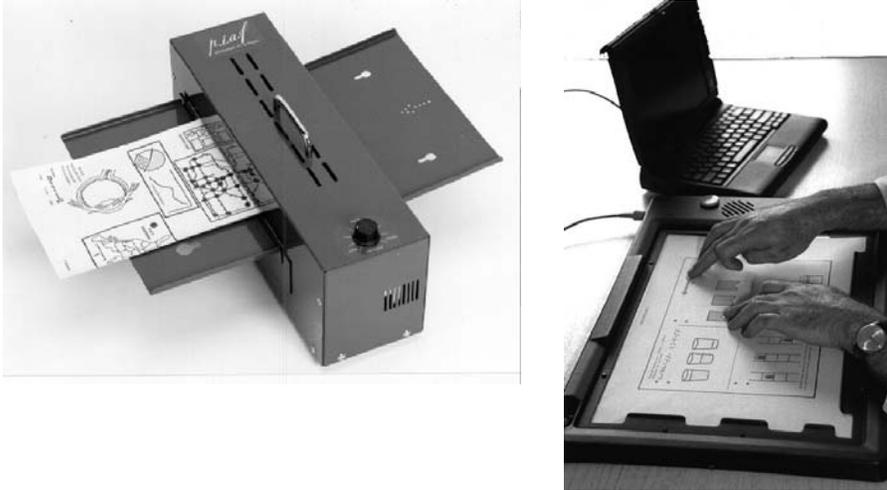


Figure 4.22: PIAF Tactile Printer and Nomad (Source: http://www.brailleworldindia.com/braille_tactile_graphics.htm#PIAF)

The Nomad mentor audio tactile processor, commonly referred to simply as “Nomad”, is a device that can be connected to a computer and using proprietary software, translate images and drawings onto a pad. The pad also has the capacity to provide audio information relating to the image.

(Source: http://www.brailleworldindia.com/braille_tactile_graphics.htm#nomad)

4.5.7. The Haptic Pen

A great deal of the literature supports the concept that haptic devices appear to be the most promising option to present technical and complex objects and images to the vision impaired students. Many haptic devices

are still in the early stages of development and only a small number are commercially available at affordable cost. Although expensive to purchase at the time of writing, the commercialisation of the haptic pen could occur to a greater extent if sufficient research reports positive outcomes in experimental trials.

To determine the suitability of this type of device in the use of describing network diagrams, an application to examine vision impaired rates of recognition and learning times for basic shape identification was developed.

The device purchased for this experiment was the Phantom Omni (see Figure 2.6). This device allows users to touch and manipulate virtual objects in a work area of 160mm width x 120mm height x 70mm depth with six degrees of freedom. Three axis are capable of force feedback (x,y,z) and yaw, pitch and roll may be read from the device. A significant disadvantage of haptic pens is that of the single point of reference. All readings of position and force feedback to the user are with respect to the end point of the pen itself. ⁶ In practical terms this is similar to attempting to determine the identity of an object by using the end of a pencil to explore its surface.

In order to determine the suitability of haptic pen devices in the context of diagrammatic and graphical identification, an experimental application

⁶ Actual reference point may be set in software but remains a single point of interaction with the object haptically rendered in 3 dimensional space.

was developed to present simple two dimensional and three dimensional shapes to participants (n=30). Shapes were presented at a consistent size within the haptic workspace, utilising the maximum possible dimensions that the Phantom Omni was capable of displaying. A variety of effects were applied to the shapes as detailed in Table 4.3.

Table 4.3: Shapes and effects used in the Haptic Showcase application.

Shape	Effect					
	Gravity	Ridge	Groove	Surface	Vertex	None
Square	√	√	√			
Circle	√	√	√			
Oval	√	√	√			
Triangle	√	√	√			
Rectangle	√	√	√			
Diamond				√	√	√
Cube				√	√	√
Cuboid				√	√	√
Sphere				√		√
Ovoid				√		√
Pyramid				√	√	√

The time taken and the accuracy of the identification attempt was recorded. Participants were divided into 3 groups based on vision level:

- Blind - Light perception or less
- Low Vision – Legally blind but with significant residual vision
- Sighted – No vision loss or correctable vision with aids

All participants were questioned as to other factors that may have an effect on results and those with additional disabilities were excluded from the study. Several wax castings of common shapes were made to ensure the congenitally blind participants were capable of identifying and naming objects correctly. This was of concern as several of the blind stated they had little experience with geometry. Cast shapes sample set consisted of a sphere, cuboid, ovoid and pyramid. Participants received verbal instructions on how to use the device and what to expect when objects were haptically displayed. A demonstration using a standard ball point pen and one of the physical shape objects was given. No time limit on object identification was set and the first response was accepted. Participants were presented with all object and effect combinations randomly in three consecutive iterations. Groups were of equal size. All tests were conducted in a controlled environment (see Figure 4.23) and supervised by the author.



Figure 4.23: Haptics shape test being undertaken by a blind student

Screenshots of the Haptic Showcase application and timing software is shown in Figure 4.25 (three dimensional) and Figure 4.25 (two dimensional).

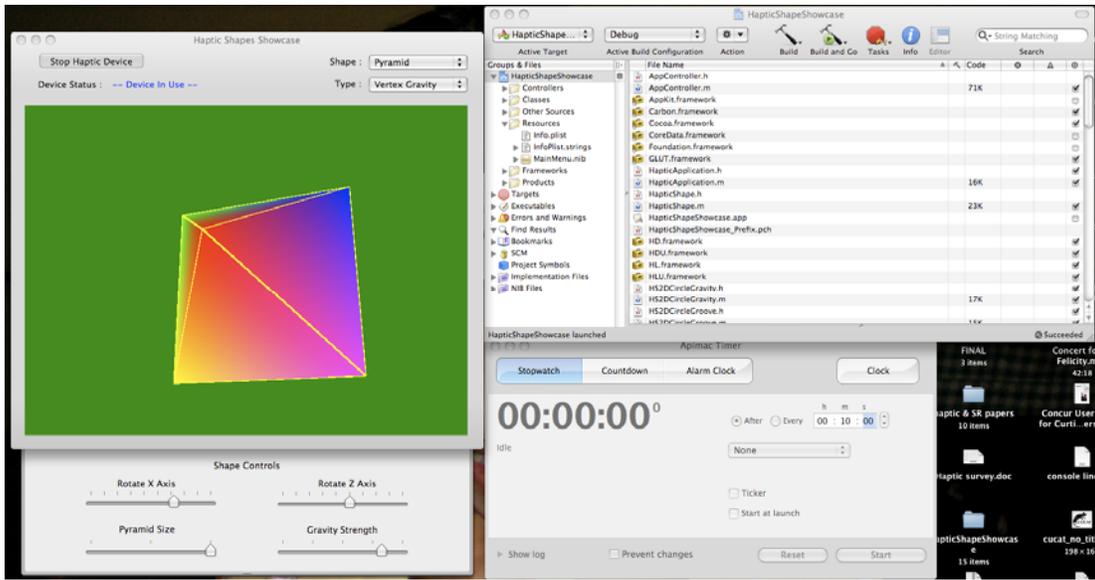


Figure 4.24: 3 Dimensional haptic shape example (Pyramid with vertex gravity)

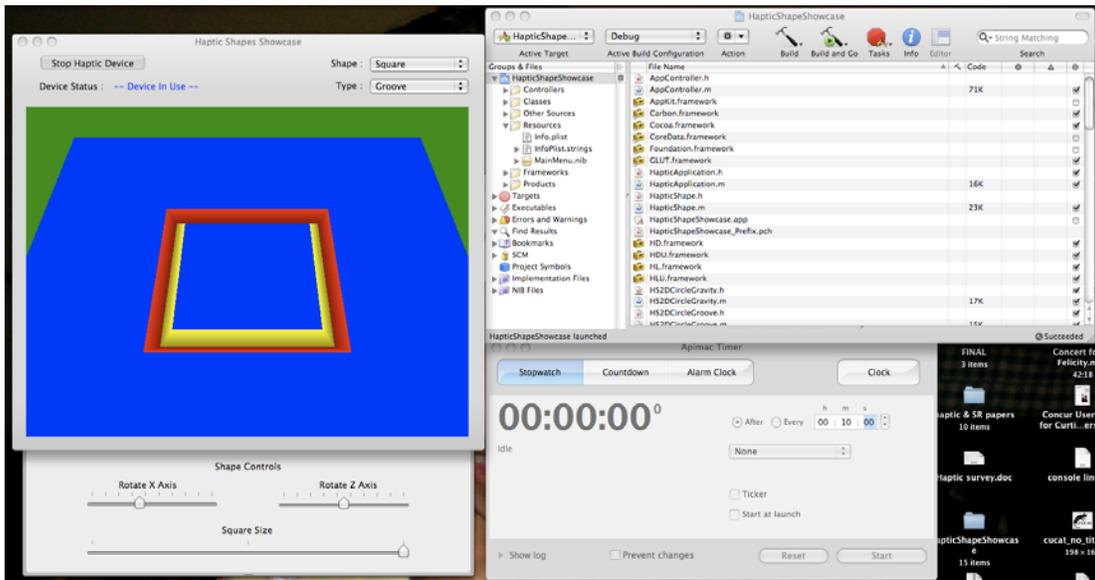


Figure 4.25: 2 Dimensional shape example (square, engraved line or groove)

As the Haptic Showcase software was designed as an experiment in haptically identifying basic shapes, objects were individually coded. In a

practical environment, for example network topology diagrams, this approach could be utilised by creating shapes for each desired networking device and plotting links between them. However this approach has the disadvantage of being static and not allowing arbitrary drawings to be displayed. The process of creating a haptically rendered object is relatively simple as shown in the code snippet of Listing 1. The object is first drawn on screen utilising OpenGL and the haptic effects applied to the rendered object.

```

- (void)drawGL
{
    glPushMatrix();
    [self rotateShape];

    glBegin(GL_TRIANGLE_FAN);
    // draw the right side
    glColor3f(1.0f,0.0f,0.0f); // red
    glVertex3f(0.0f,featureSize,0.0f);
    glColor3f(1.0f,0.0f,1.0f); // magenta
    glVertex3f(featureSize,-(featureSize/2.0),featureSize);
    glColor3f(0.0f,0.0f,1.0f); // blue
    glVertex3f(featureSize,-(featureSize/2.0),-featureSize);

    glColor3f(0.0f,1.0f,0.0f); // green
    glVertex3f(-featureSize,-(featureSize/2.0),-featureSize); //point at
bottom back left draws back side of pyramid

    glColor3f(1.0f,1.0f,0.0f); // yellow
    glVertex3f(-featureSize,-(featureSize/2.0),featureSize); // front
left point draws left side

    glColor3f(1.0f,0.0f,1.0f); // magenta
    glVertex3f(featureSize,-(featureSize/2.0),featureSize); // front
right point draws front side

    glEnd();

    // draw base
    glBegin(GL_QUADS);
    // no need to color this point as we are starting from where we
finished
    // with the triangle fan
    glVertex3f(featureSize,-(featureSize/2.0),featureSize); // front
right point
    glColor3f(0.0f,0.0f,1.0f); // blue
    glVertex3f(featureSize,-(featureSize/2.0),-featureSize); // rear
right point
    glColor3f(0.0f,1.0f,0.0f); // green
    glVertex3f(-featureSize,-(featureSize/2.0),-featureSize); // rear
left point
    glColor3f(1.0f,1.0f,0.0f); // yellow

```

```

        glVertex3f(-featureSize,-(featureSize/2.0),featureSize); // front
left point
        glEnd();

        glPopMatrix();
    }

- (void)drawHL
{
    hlPushMatrix();

    hlTouchModel(HL_CONTACT);

    hlTouchableFace(HL_FRONT);
    hlBeginShape(HL_SHAPE_FEEDBACK_BUFFER,hlShape);
    [self drawBackingPlane];
    hlEndShape();

    hlTouchModel(HL_CONSTRAINT);
    hlTouchModelf(HL_SNAP_DISTANCE, gravitySnapDistance);
    hlBeginShape(HL_SHAPE_FEEDBACK_BUFFER,hlShape+1);
    [self drawGL];
    hlEndShape();
    hlPopMatrix();
}

```

Listing 1: Sample code for rendering haptic shapes

4.5.8. Textual descriptions

It was noted in reviewing the literature that the use of text to describe a diagram has been overshadowed by attempts to convey graphical information in various tactile forms, such as raised line drawings. A study by Ault et al (2002) noted a lack of published research in methods for describing graphical information. Ault et al (2002) developed a set of guidelines to describe statistical data that improved the accessibility of pie, bar and line graphs for people with vision impairment. Blelkhorn and Evans (1998) classified diagrams as fitting into one of five categories, real world images, maps, schematic diagrams, charts, and graphical user interfaces. All five of these categories are included in the curriculum utilised in this research. The study reported that to make graphics accessible two factors must be considered:

- What the graphic looks like
- What the graphic means

It was identified early in the CAVI pilot study that the significant issue in this particular application was conveying the meaning of graphics and that the physical layout (what the graphic looks like) was largely irrelevant. Blenkhorn goes on to state that if the diagram is relatively complex, the description becomes quite large and rather confusing. Empirical experimentation, quantitative and qualitative information from surveys and examination of students enrolled in the CAVI program showed this was not necessarily the case if a structured approach to creating diagram descriptions was used. The process involves giving an overview of the diagram content. In the example shown in Figure 4.26, the description is as follows:

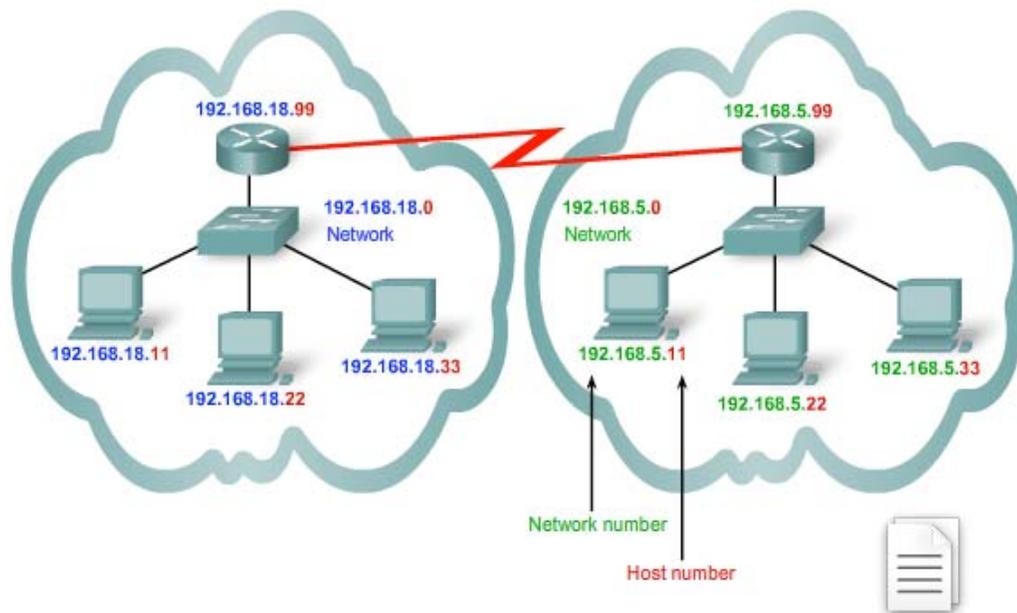


Figure 4.26: Example network diagram

Diagram depicts two network clouds. Each cloud contains a similar network with 3 hosts connected to a switch. The switch connects to a router. The routers in each cloud connect to each other. Each device has its own IP address, the key concept here is that in the first cloud all devices are on the 192.168.18.0 network and all devices in the second cloud are on network 192.168.5.0.

A “more information” ⁷link displays the following text

Multiple Logical networks on one physical network

With IP addressing, multiple logical networks can exist on one physical network, if the network portion of their host addresses is different. Example: three hosts on a single physical local network have the same network portion to their IP address (192.168.50) and three other hosts have a different network portion (192.168.70). The hosts with the same network number in their IP addresses will be able to communicate with each other but will not be able to communicate with the other hosts without the use of routing. In this case, we have one physical and two logical IP networks.

Note, that in this example, fine detail is not described, as that is largely irrelevant to the concepts being communicated by the graphic. If detailed interface connections are deemed necessary, they were presented in a table like format as shown in Table 4.4. This format is specifically designed to be easier to read with screen reader software as the headings are repeated next to each cells’ content.

⁷ The “more information” link is included in the textual description as the content is presented in an inaccessible format.

Table 4.4: Screen reader table format

Device: Router1

IP Address: 192.168.18.99

Interface: S0/0

Connects to: Router 2

Interface: S0/1

IP Address: 192.168.18.98

This may be abstracted into the following steps:

1. Functional overview description.
2. Segment the diagram into logical blocks.
3. Describe the contents of each block.
4. List block interconnections.
5. List interface details if relevant. Interface may be interpreted as object outlets and inputs in generic graphics.
6. Summarise the concept being communicated.

4.5.9. iNetsim Network Simulator for Apple OS X

iNetSim is a network simulation tool for blind and vision impaired students. This section describes iNetSim, a universally accessible network simulator, created to allow vision-impaired and sighted users to complete Cisco Certified Network Associate level two (CCNA 2) laboratory sessions without access to the networking hardware (routers and switches). Existing software used in the CCNA course for network simulation and laboratory practice (Packet Tracer 4.1™, refer to Figure 4.27, and the eLabs, see section 4.5.10) is not accessible to those with impaired vision as it utilizes images of network topology, allows only mouse selection of network devices and tools and is incompatible with screen reading

software.⁸ In contrast, iNetSim has been developed to be accessible by blind and vision impaired users in addition to those with normal vision.

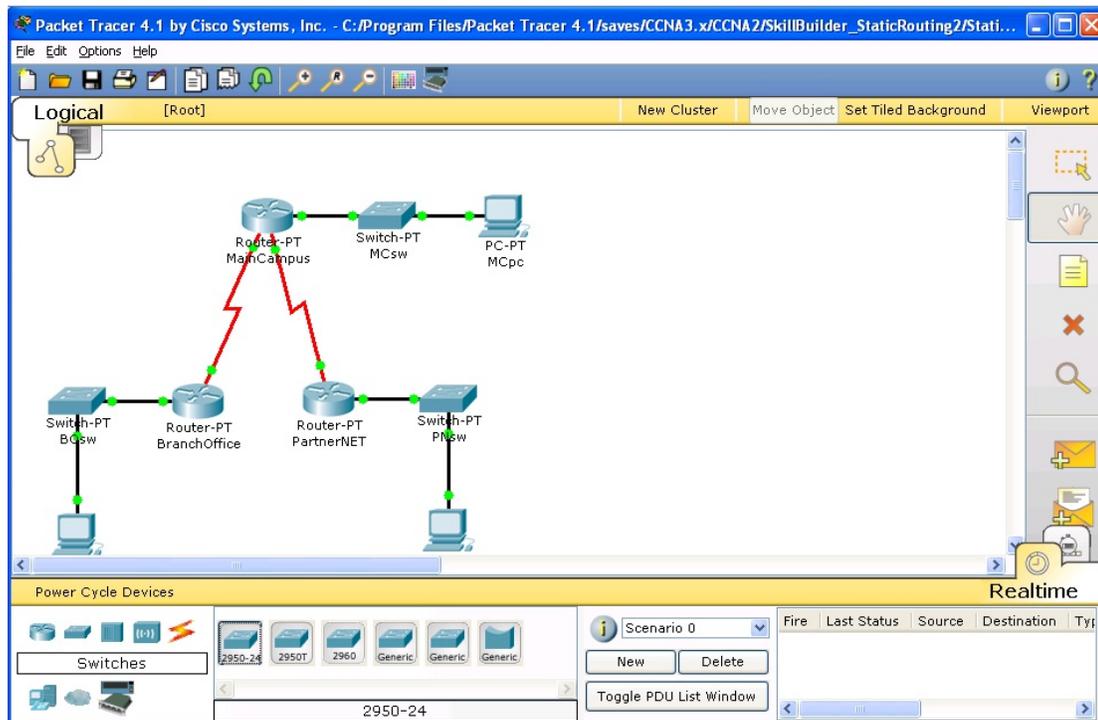


Figure 4.27: Packet Tracer 4.1™ user interface

On April 29, 2005, Apple Computer Inc. released Mac OS X Tiger version 10.4. This release included VoiceOver (Apple Computer Inc, 2005a), a system wide screen reader designed to provide full computer functionality to vision-impaired users. Mac OS X includes the Cocoa API that allows rapid development of complex applications, and Core Data (Apple Computer Inc, 2005b), which reduces the time required to implement an

⁸ Packet Tracer 4.1, when launched concurrently with JAWS 8.0, will terminate immediately with an “unexpected error” (Windows XP SP2)

application's document back-end. As a result of these features, Mac OS X Tiger was chosen as the programming and execution platform for iNetSim.

iNetSim is intended to replace Packet Tracer 4.1™, allowing vision-impaired and sighted students to complete CCNA 2 (Routers and Routing Basics) laboratory practicals when access to the network hardware is not possible. CCNA 2 objectives include; "Students will develop skills on how to configure a router, manage Cisco Internetwork Operating System (IOS) Software, configure routing protocol on routers, and set the access lists to control the access to routers" (Cisco Systems, 2004). iNetSim allows the students to perform the above mentioned tasks in a simulated environment. All user interface and network topology elements are accessible via VoiceOver keyboard shortcuts and provide a meaningful response when read by VoiceOver.

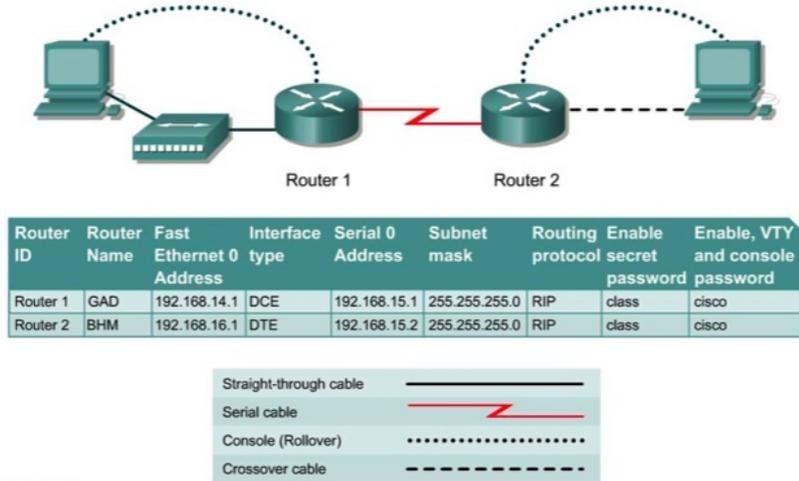
Accessibility for the vision impaired drove the design of iNetSim. Network simulators usually rely on the use of a mouse to add simulated communication links between devices, place network devices on the work area canvas, select configuration options and view simulation results. To connect two devices with a communications link, the user must generally click on icons for the simulated devices and drag the connection to its end point, another network device under normal circumstances. As this is usually not possible for vision-impaired users, iNetSim also incorporates the use of tables for connecting devices. Tables are used to alter a device's location in the topology area, and configure ports and links. Tables are used as navigation with speech prompts, can be achieved with VoiceOver shortcut keys and cursor keys. iNetSim can be used solely with the keyboard, therefore the eye and hand issues faced by vision-impaired students can be avoided. As a GUI is also available, sighted iNetSim users can alternatively use a more traditional drag-drop mouse-based interface.

The system is capable of representing several generic network devices including routers, switches, hubs and PCs. Each device must be configured via a command line for correct operation. Figure 4.29 illustrates the application running with the textual command line terminal session to Router0 open. Note that the IP address on Router0, interface S1 is set to the same value as in the port table (highlighted) under the main canvas. Selecting values from the drop down boxes or edit fields in the main application window has the same effect as entering the command line configuration. Changes made with either method will be reflected throughout the application. This allows rapid basic configuration to be undertaken by instructor so that students may concentrate on the particular task in the session.

Each device may have several ports of different types including Ethernet, serial and console. The user creates a connection by specifying two ports to connect and a cable type. Removing a connected port disables the connection the same way unplugging a cable would in a real network. The command line interface to devices also provides control and feedback over the simulation. The interface acts in a similar way to the operating system for that device type (e.g. a generic DOS-like system for PCs and Cisco IOS for routers). A subset of the commands applicable to CCNA 2 allows the user to display and modify device configuration, establish routing protocols and ping, Traceroute or telnet to other devices. iNetSim maintains a representation of routing tables to simulate these tasks correctly. As an educational tool, iNetSim aims to simulate the results of these tasks as close to the real systems as possible. Extensibility is important, as iNetSim will need to adapt to higher CCNA levels in future.

A sample laboratory session, Lab 2.3.4 is detailed below to illustrate a typical simulation configuration. The diagrammatic information (discussed in 4.5.8) and the session objectives are shown in Figure 4.28.

Lab 4.2.3 Suspending and Disconnecting Telnet Sessions



Objective

- Establish a Telnet session with a remote router.
- Suspend and reestablish a Telnet session.
- Display active Telnet sessions.
- Disconnect a Telnet session.

Figure 4.28: CCNA 2 lab 4.2.3 topology and objectives (Cisco,2003)

The completed laboratory is depicted in the screen capture illustrated in Figure 4.29. Note the configuration entered in the terminal screen matches the configuration in the tables and the successful pings from both the routers and workstations.

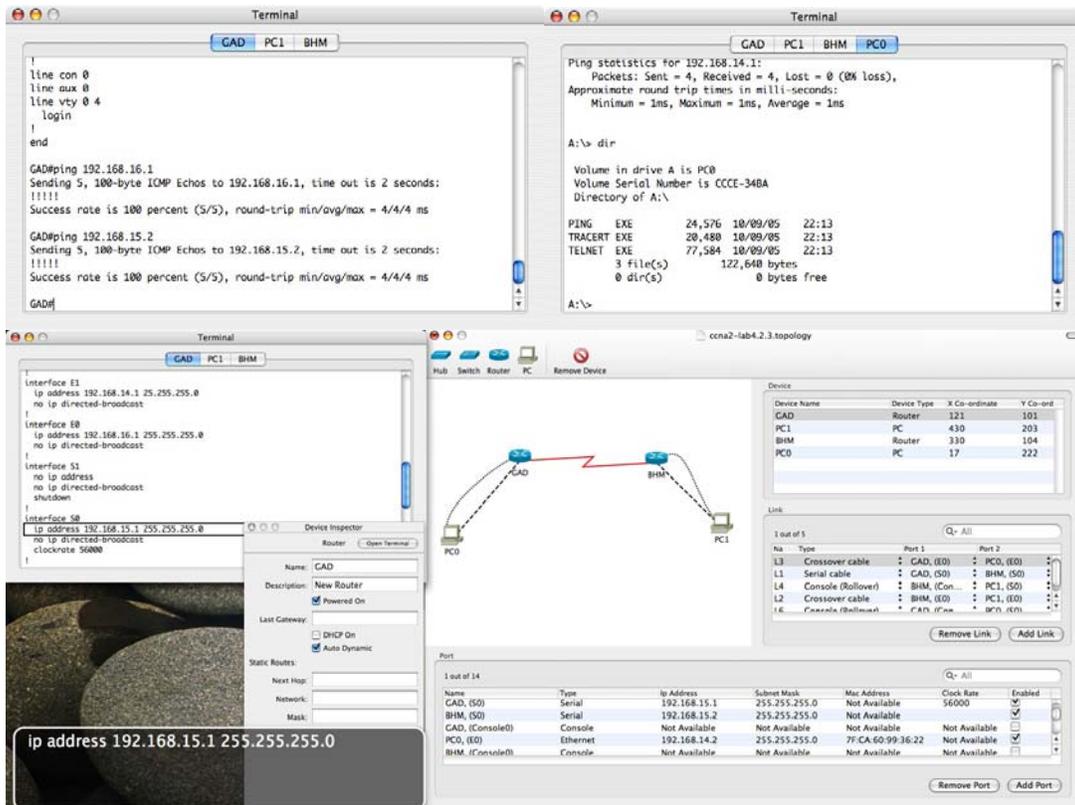


Figure 4.29: iNetSim with command line terminal session open. The text in the floating window shows the text read by VoiceOver.

4.5.10. e-Labs

The purpose of the e-Labs included in the CCNA 2 is to provide instruction in a specific learning outcome within the module being studied without the need of creating a complete configuration on either physical networking equipment or a simulator (Packet Tracer). An example of the Cisco supplied simulator is shown in Figure 4.30. e-Labs are created in Macromedia Flash and simulate the CLI of a router or switch and as such are not accessible to screenreaders and difficult for large print users to access. (Flash animations cause the large print or zoom applications to flicker and jump to areas away from the animation)

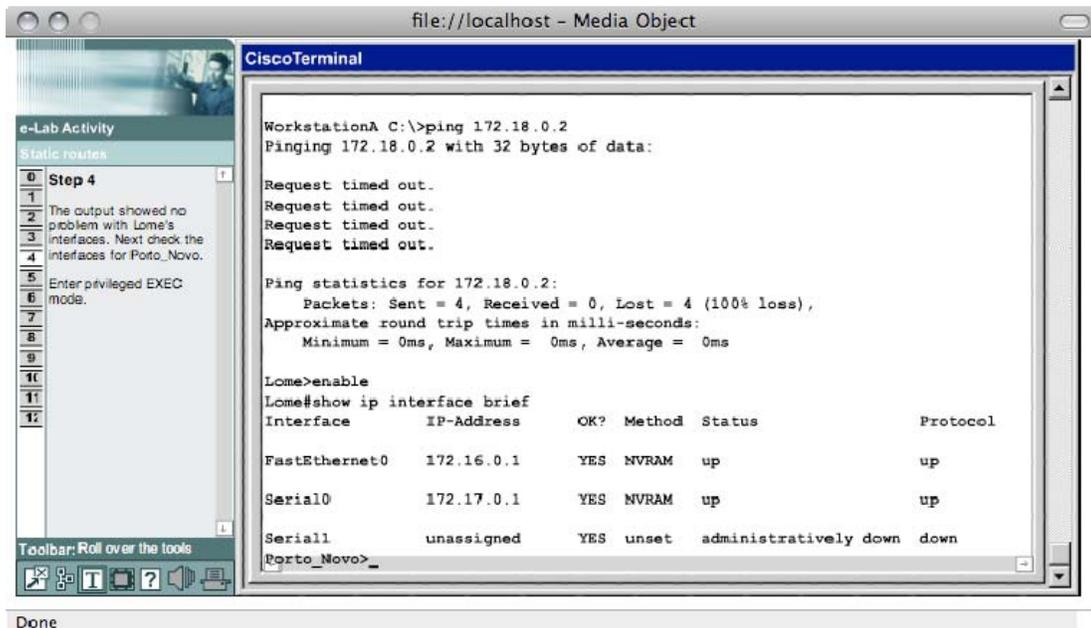


Figure 4.30: e-Lab 6.1.6 Macromedia Flash simulator (Cisco, 2004)

To overcome these issues and ensure that the vision impaired students experienced the same benefits of the focused, single learning outcome of the e-Labs, equivalent exercises were developed. These followed the same form as the flash based e-Labs and included step by step instructions and router configurations to the same level as in the simulation. The student was able to “cut and paste” the router configurations into the remote laboratory bundle and follow the same step by step instructions that the sighted students used in the flash based simulator. A total of 59 individual e-Lab sessions were created, covering all required CCNA 2 and a sample of these is detailed in Tables 4.5 to 4.7.

Table 4.5: Example e-Lab instructions (e-Lab 6.1.6)

E-Lab 6.1.6 - Static Routes
Configure static routes between routers to allow data transfer between routers without the use of dynamic routing protocols.

Step 1
Ping from Workstation_a to Workstation_b (172.18.0.2).

Step 2
Since the ping failed we want to try to find a solution. Start by checking the router Lome.
Enter privileged EXEC mode.

Step 3
Check interface status.

Step 4
Switch to the Porto_Novo Router before doing the following step.
The output showed no problem with Lome's interfaces. Next check the interfaces for Porto_Novo.
Enter privileged EXEC mode.

Step 5
Check interface status.

Step 6
Porto_Novo also has no interface related problems. Now Check the routing table entries.

Step 7
Notice that the routing table for Porto_Novo has no route to the network 172.16.0.0. Since the router has no rule that specifies an output interface for packets bound for 172.16.0.0, such packets are dropped. This explains why the ping failed.
One way to fix this is to add a static route.
Enter into global configuration mode.

Step 8
Add a static route that tells Porto_Novo that it needs to send packets destined for 172.16.0.0/16 to a next hop address of 172.17.0.1 (the neighbour router).

Step 9
Switch back to the Lome Router before doing the following step.
Configure a static route on the Lome router, except send packets destined for 172.18.0.0/16 to the next hop at 172.17.0.2.

Step 10
Use the command end to return to privileged EXEC mode.

Step 11
Now view the routing table to see the changes. The entry tagged by an S is the static route entry.

Step 12
Try a ping now that both routers have a route to each other's ethernet networks.

```
Ping Workstation_b at 172.18.0.2.
```

Table 4.6: Example e-Lab configuration (e-Lab 6.1.6 "Lome" router)

```
!  
version 12.2  
service timestamps debug uptime  
service timestamps log uptime  
no service password-encryption  
!  
hostname Lome  
!  
ip subnet-zero  
!  
interface FastEthernet0  
 ip address 172.16.0.1 255.255.255.0  
 speed auto  
 full-duplex  
 no shutdown  
!  
interface Serial0  
 ip address 172.17.0.1 255.255.255.0  
 no shutdown  
!  
interface Serial1  
 no ip address  
 shutdown  
!  
ip classless  
no ip http server  
!  
dialer-list 1 protocol ip permit  
dialer-list 1 protocol ipx permit  
!  
line con 0  
 transport input none  
line aux 0  
line vty 0 4  
!  
end
```

Table 4.7: Example e-Lab configuration (e-Lab 6.1.6 "Porto_Novo" router)

```
!  
version 12.2  
service timestamps debug uptime  
service timestamps log uptime  
no service password-encryption
```

```
!  
hostname Porto_Novo  
!  
!  
ip subnet-zero  
!  
!  
!  
interface FastEthernet0  
  ip address 172.18.0.1 255.255.255.0  
  speed auto  
  full-duplex  
  no shutdown  
!  
interface Serial0  
  ip address 172.17.0.2 255.255.255.0  
  no shutdown  
!  
interface Serial1  
  no ip address  
  shutdown  
!  
!  
!  
ip classless  
no ip http server  
!  
dialer-list 1 protocol ip permit  
dialer-list 1 protocol ipx permit  
!  
line con 0  
  transport input none  
line aux 0  
line vty 0 4  
!  
end
```

4.5.11. Interactive Media Objects

The curriculum for IT Essentials and CCNA include many embedded interactive media objects. These objects are in several forms, “Drag and Drop”, “Check Box”, “Photozoom” and “Point and Click ” (may include multiple steps). As the majority of these media objects requires the use of the mouse and sufficient visual acuity to locate the drop/check area, an alternative method of completing these tasks was required.

In the case of simple “Drag and Drop” exercises, as illustrated in the example shown in Figure 4.31, the object was converted to a question and answer format and run as a quiz within the virtual classroom environment. The instructor asks the question and students answer within the Ventrilo chat window, pressing enter when prompted to by the instructor. (See section 4.5.5 for details on the Virtual classroom and Ventrilo application) An example of the question and answer format is shown in Table 4.8. It should be noted that in review lectures, the questions may be reversed with the answer used as the question. An example from Table 4.8 would be “What function does pressing Control A perform when using the CLI?”

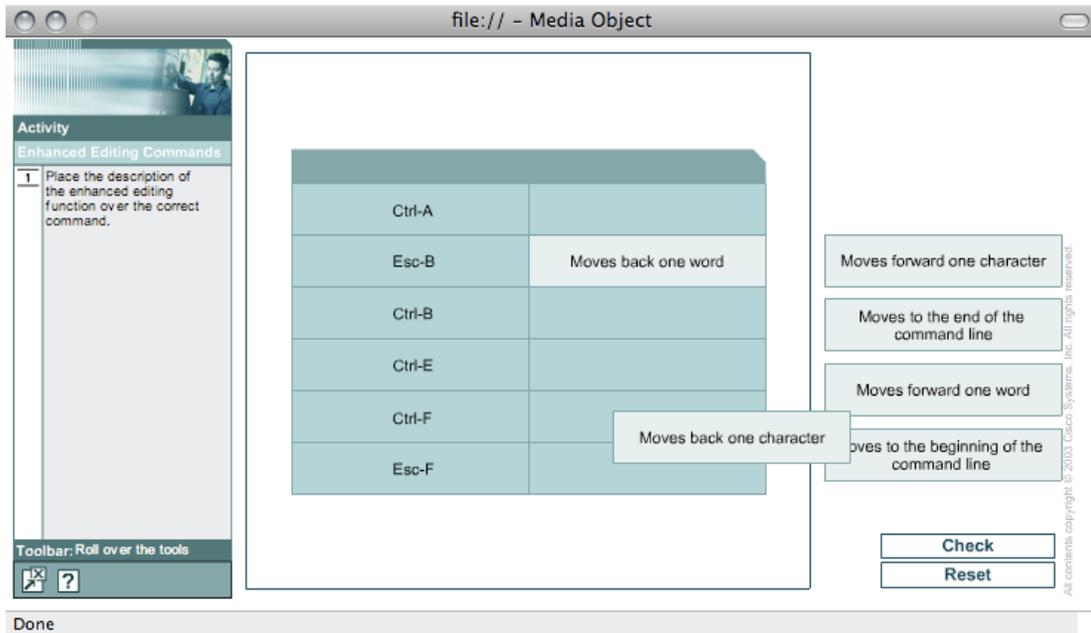


Figure 4.31: Drag and Drop exercise

Table 4.8: Question and Answer format of "Drag and Drop" media objects

Enhanced editing commands	
Question	Answer
What key combination moves the cursor to the beginning of the command line?	Control A
What key combination moves the cursor back one word?	Escape B
What key combination moves the cursor back one character?	Control B
What key combination moves the cursor to the end of the command line?	Control E
What key combination moves the cursor forward one character?	Control F
What key combination moves the cursor forward one word	Escape F

Point and Click media objects appear in two main styles. The first is a multiple choice style of question as shown in Figure 4.32, which was modified in the same manner as the Drag and Drop exercises described previously.

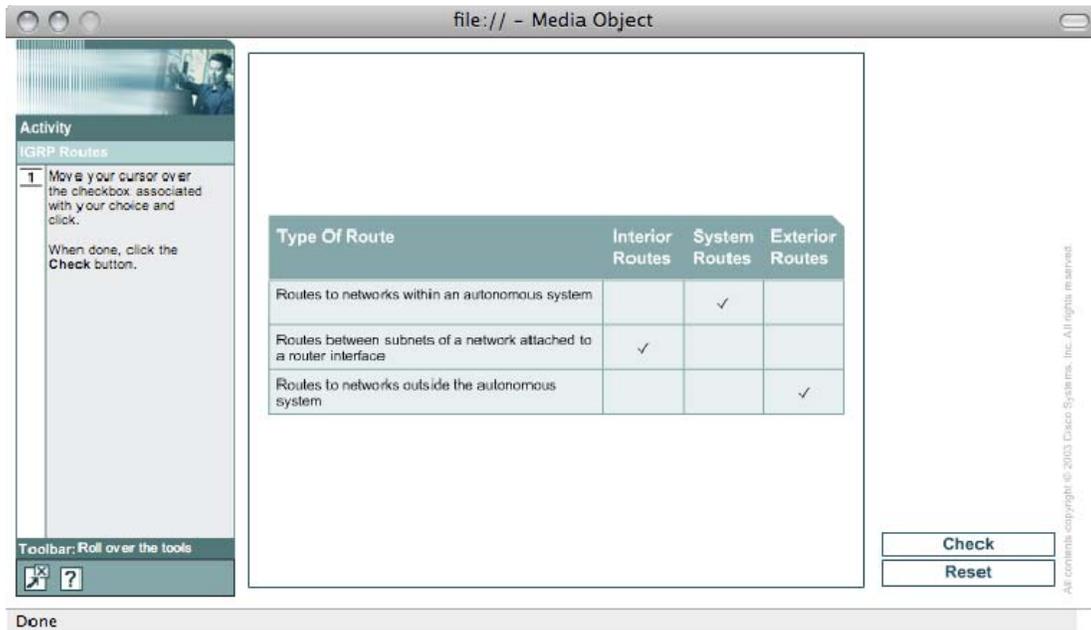


Figure 4.32: Checkbox style media object

The more complex multi step media object requires a graphical description in addition to the reformatting into a mode suitable for oral or textual delivery. An example of the process is illustrated in Figure 4.33 and Table 4.9. Note that in the topology description, router connections are separated by line breaks so as to allow rapid scanning by a screenreader to find the appropriate router interface and IP address.

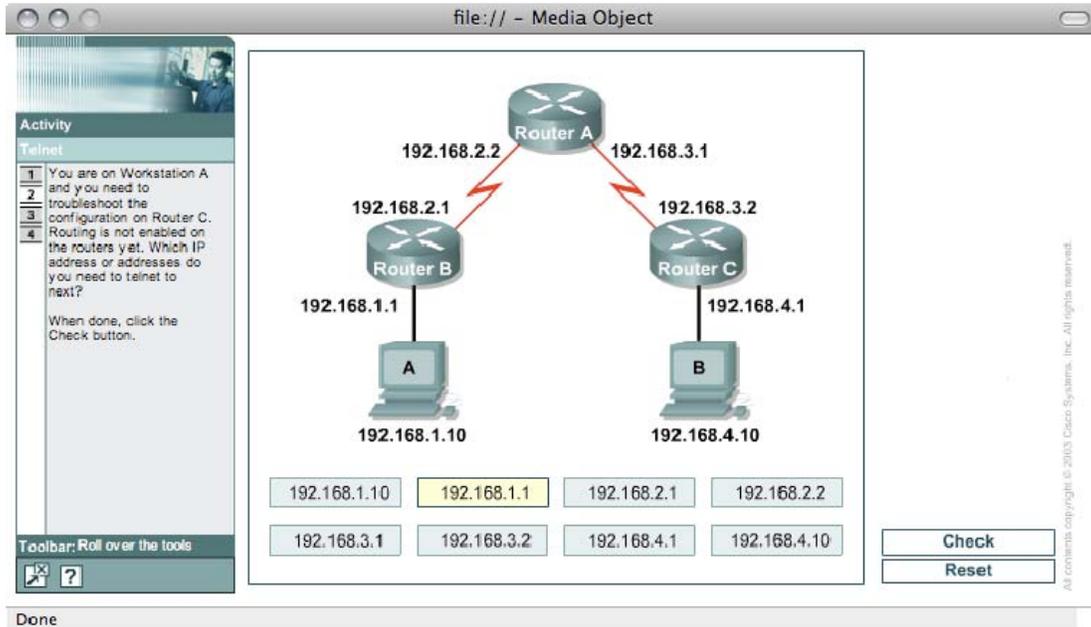


Figure 4.33: Multi step media object

Table 4.9: Textual equivalent for Media object 9.2.6

Telnet	
<p>Given the following topology;</p> <p>Network consists of 3 Routers with the end 2 routers having workstations attached. Workstation A connects to Router B's Ethernet interface on IP address 192.168.1.1.</p> <p>Router B serial connection with IP address 192.168.2.1 connects to Router A, IP address 192.168.2.2.</p> <p>Router A, serial interface with IP address 192.168.3.1 connects to router C, serial interface IP address 192.168.3.2.</p> <p>Router C connects to Workstation B on the Ethernet interface IP address 192.168.4.1</p>	
Instruction/Question	Answer
<p>Telnet can be used to connect to a router to troubleshoot a network outage. It is very important to know which address or sequence of addresses to use in order to connect to a router. You are on Workstation A and you need to troubleshoot the</p>	<p>192.168.1.1 is the first interface that may be accessed via telnet.</p>

configuration on Router C. Routing is not yet enabled on the routers yet. Which IP address do you need to telnet to first?	
Which IP address do you need to telnet to next?	192.168.2.2 is the next hop closer to the target router.
Which IP address do you need to telnet to next?	192.168.3.2 is the next hop and is located on Router C.
You are on Workstation B and you need to troubleshoot the configuration on Router B. Routing is not yet enabled on the routers yet. Which IP address do you need to telnet to first?	192.168.4.1 is the first interface that may be accessed via telnet.
Which IP address do you need to telnet to next?	192.168.3.1 is the next hop closer to the target router.
Which IP address do you need to telnet to next?	192.168.2.1 is the next hop and is located on Router B.

Photozoom media objects usually display an item of equipment that may have the view rotated, zoomed or otherwise examined on screen. An example photozoom object is shown in Figure 4.34. Items of interest, in this instance the Audio Processor, may be selected and information pertaining to that item displayed. To overcome the inaccessibility of these objects, real equipment was used. Wherever possible, remote students would also have the same or similar item and would feel the various parts as they were described by the local blind instructor. If similar equipment was unavailable, say due to high cost, a more detailed audio description was created and made available for download as a reference.

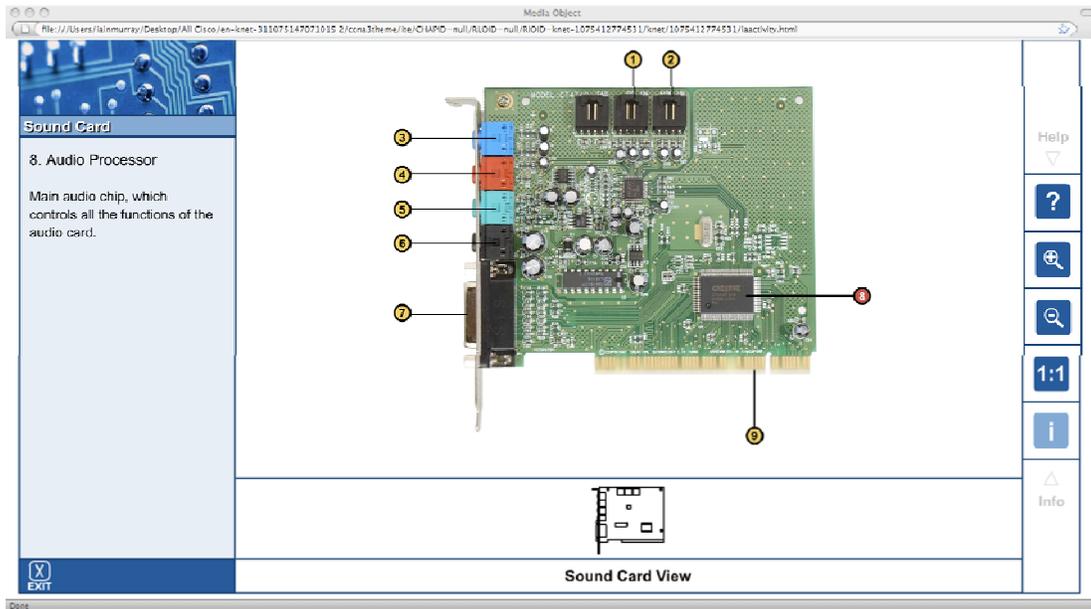


Figure 4.34: Photozoom media object - Sound Card

4.5.12. Audio Demonstrations

In situations where equipment is unavailable or too expensive for the remote students to access, audio demonstrations are conducted. Instructors lead local vision impaired students in laboratory tasks with the student describing the steps taken to complete the laboratory task. Remote students attend the virtual classroom, listen to the description and interject with questions when necessary.

4.6. The Consolidated Learning Environment

4.6.1. Lectures

During the live lectures several vision impaired students interact with the vision impaired instructor at the same time. Students can be situated physically in the classroom or connected remotely via VoIP. Local students

also connect via VoIP so they may then interact with the instructors locally or other remote students, contributing to the perception of an inclusive environment. Instructors present converted lectures. Voice communication is 2-way, instructor to students, and questions are fed to the instructor. Within the research environment utilised the Teaching Assistant (TA) is required to notify the instructor that a student wishes to ask a question as the software utilised in the virtual classroom has no audio alert (or hand up) capability. The classroom communication between instructors and students includes voice and text. Text is used when a student wishes to make a quick comment or raise attention to an issue. Text is vocalised via TTS (Text-to-speech) so all participants will hear the query.

Whilst students are listening to lectures they will interact with their notes (output only) and will occasionally check the on-line curriculum as reference. Students may also wish to review audio lectures at a later time. In review mode individual students interact with their notes (bi-directional) and check against reference material and the on-line curriculum. The TA assists in the development and writing of Braille and audio lecture notes by providing descriptions of visual content for inclusion in lecture notes delivered by the vision impaired instructors.

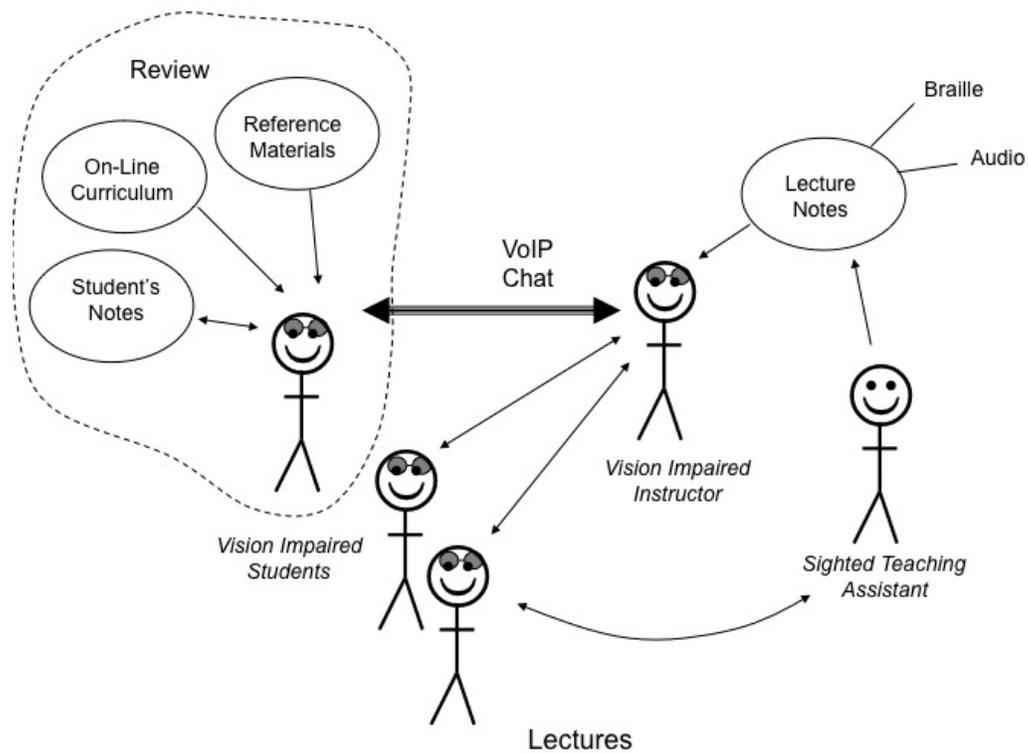


Figure 4.35: Lecture model

4.6.2. “Hands On” Laboratory Exercises

To undertake the practical of laboratory sessions, students work either alone or in small groups of 2-3. The modified laboratory procedure is accessed sequentially and at appropriate points, where further information is required, the on-line curriculum, reference materials or pegboard are utilised. Students then return to the next step within the laboratory document. When access to the remote bundle is required by the laboratory procedure, a telnet session is initiated with the remote bundle. The student will then refer back to the modified laboratory document, reference material and pegboard as required. Often a laboratory is best performed in a simulated environment before attempting a configuration on real equipment, particularly when complex router

configurations are attempted. When this is the case, students will perform the process described above, but utilise the simulator rather than the remote bundle. Completed laboratories are emailed to the instructor for marking and feedback is returned to the student in the same manner.

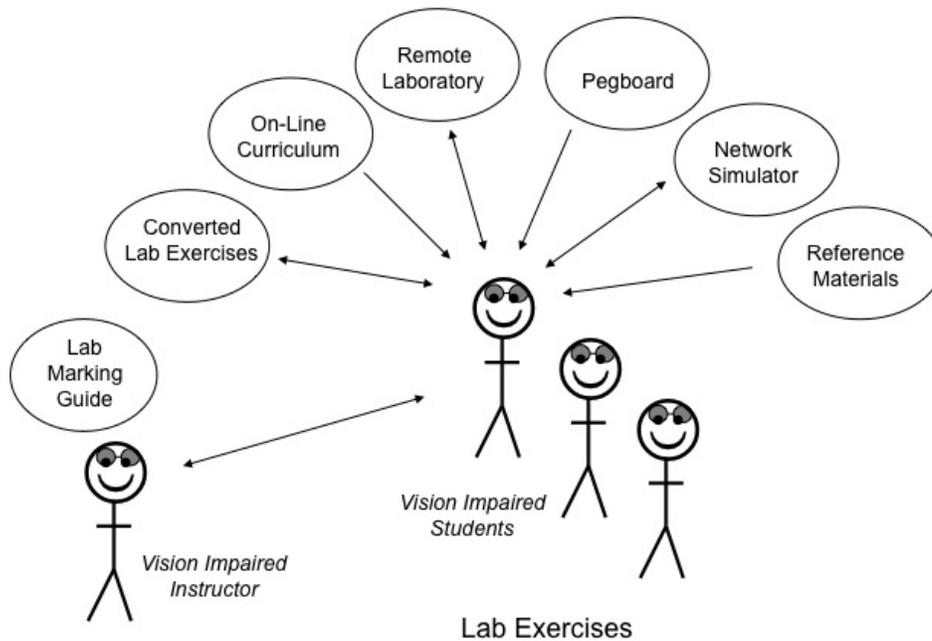


Figure 4.36: Laboratory exercise model

4.6.3. Curriculum

Curriculum study is normally undertaken individually. Students access the on line material to read the textual components and access the modified picture descriptions, associated with the page being read, in a separate document. Students keep notes of what they read and summaries of the picture descriptions. Often external reference material is accessed to provide a more detailed description or greater depth of

information on the subject being studied. On occasion, students will fail to grasp a concept, so will contact the instructor via “Skype”, an off the shelf VoIP application for individual tuition in the area of concern.

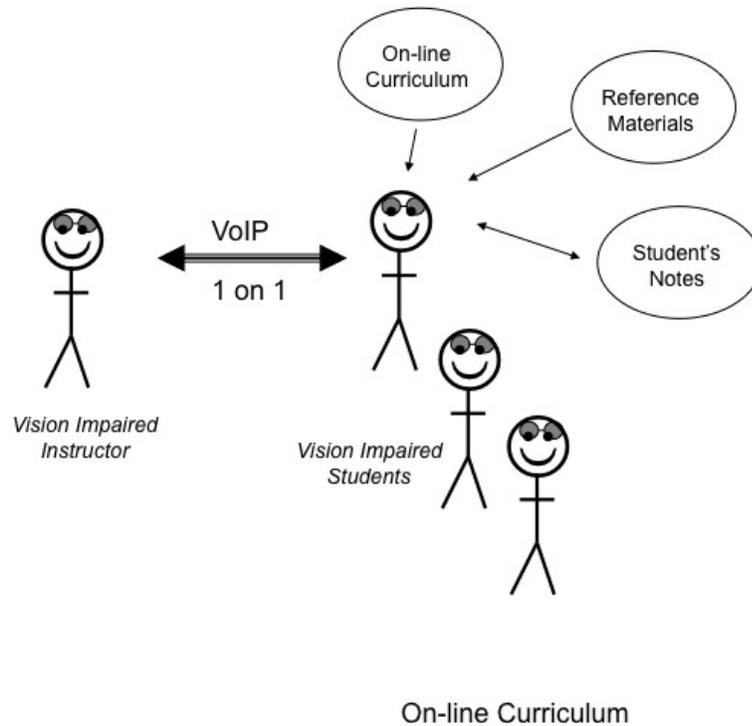
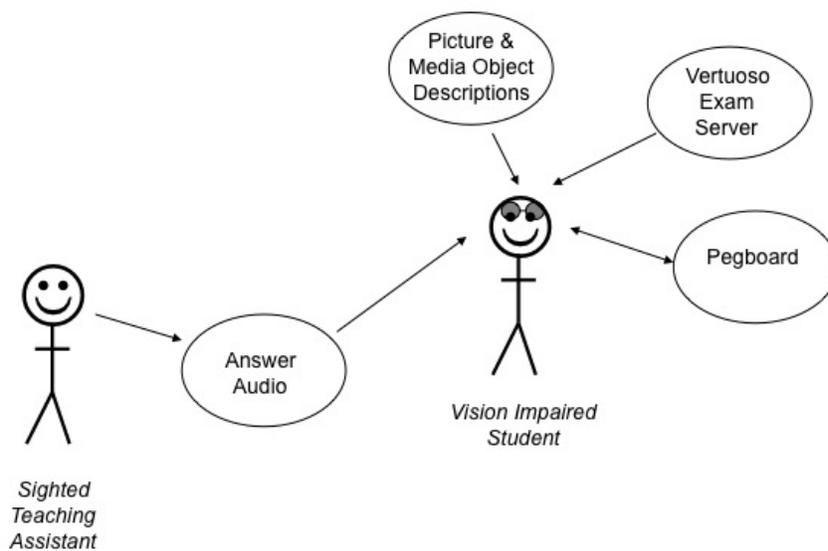


Figure 4.37: On-line curriculum model

4.6.4. On Line Assessment and Examinations

After completion of study in a particular subject area or module, an on line exams is taken. Students access the Virtuoso exam server on line and exam questions are delivered to their web browse. Students access the exam picture descriptions in a separate document and switch between applications as necessary. Where number conversions or IP addressing calculations are required the student makes use of the pegboard. Once the assessment is complete the student submits the exam to the Virtuoso

server, which automatically grades it and provides feedback to the student on subject areas that were incorrectly answered. The Teaching Assistant records answers to all questions in the module exams and provides an audio file to students who have completed a module so they may revise their answers at a later date.



Examinations

Figure 4.38: Examinations model

4.6.5. Audio Demonstrations

In cases where equipment is not available to remote students or to create reference material on practical aspects of the curriculum, audio demonstrations are created. In these demonstrations one or two students perform a laboratory task supervised by the instructor who offers suggestions and guidance in its completion. The Teaching Assistant

records all comments and the descriptions given by the students in the steps taken to complete the laboratory task.

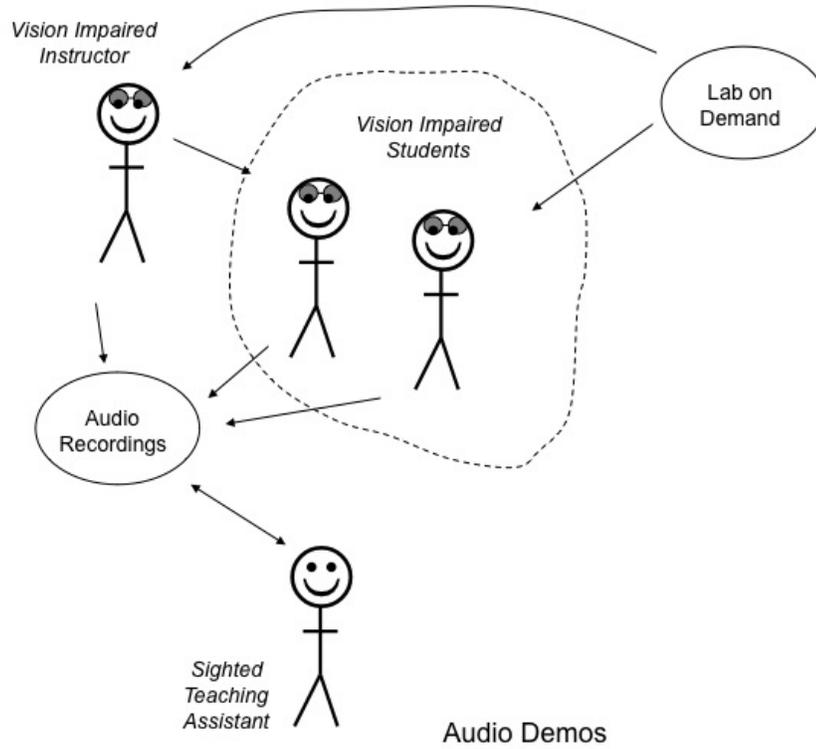


Figure 4.39: Audio demonstration model

5. ANALYSIS OF THE RESULTS

5.1. Evaluation of Modifications and Transformations Applied to the Curricula

5.1.1. Braille and Braille Displays

The use of Braille was limited due in part to low Braille literacy as discussed in section 2.3.1 with just 11 local Australian students classifying themselves as fluent Braille readers. Other factors influencing the use of hard copy Braille was the dynamic nature of technical and ICT courses. Over the duration of this research, the curricular for CCNA has received three major revisions (involving complete re-writes of manuals and support material) and six minor revisions. The cost involved in production of Braille is relatively high when compared to standard print at an estimated \$0.10Au per page (material) and embosser cost of \$3,750Au. The embossing process is slow, with the embosser used in the research, shown in Figure 5.1, capable of producing 100 pages in 17.65 minutes. (<http://www.indexbrailleaccessibility.com/products/indexbraille/overview.htm>) As the transcription process was undertaken by volunteers, no costing is available. The bulk of Braille contributed to the low level of use, particularly for students outside Australia who did not have access to Braille embossers. However, a survey of students illustrated that for those who consider themselves to be fluent Braille readers (n=5), the use of Braille rated highly in assisting students in their studies with an average rating of 4.2 and a mean of 5 (1 = no use, 5 = very useful). All Braille readers showed a preference to use the hard copy embossed Braille laboratory manuals for the reasons discussed in section 4.5.1. (see Figure 5.2)



Figure 5.1: Index Basic D Braille embosser.

Refreshable Braille displays achieved the desired results of providing console accessibility with less ambiguity than that of speech output. Limited use of the Braille displays was made in reading of the curriculum as all Braille literate students commented that the rate of Braille reading is significantly lower than that of speech. Additionally, the requirement to remove hands from the keyboard to read output, then relocate back to the home keys on the keyboard (F & J) was also found to be overly time consuming when compared to speech output.



Figure 5.2: A student utilising Braille in a laboratory session

5.1.2. Pegboard Evaluation and Survey Results

A survey of 15 blind and vision impaired students was undertaken to determine if the pegboard adequately addressed the problems of number system conversion and IP addressing schemes. All students surveyed qualify as being legally blind; nine of the students are totally blind and six students with various levels of low vision. Each of the fifteen participating students were surveyed individually in the presence of the researcher ⁹ and in situations where the student encountered difficulties with a question, assistance was given only on request.

⁹ This included “virtual presence” as described in section 4.5.5

The survey consisted of 8 questions. The students were asked to attempt five tasks, and to offer their opinions on the usefulness of the pegboard. They were also asked what they considered were the advantages and disadvantages of the pegboard. The time used by each student in answering each question was recorded. Any assistance the students may have required was noted. The eight questions are set out in Table 5.1.

Table 5.1: Pegboard Survey Questions

	Question	Marks
1	Covert the following decimal number into Hex and binary - 968	2
2	Covert the following binary number into Hex and decimal - 110110011	2
3	Covert the following Hex number into decimal and binary - AF31	2
4	Given the 2 IP addresses and subnet mask below, are these on the same subnet? 134.7.138.43 255.255.254.0 134.7.139.21 255.255.254.0	1
5	Determine the subnet mask for the following network requirements. Network IP address 148.23.0.0 Number of networks required = 14 (No subnet 0 allowed) What is the 3 rd network address, broadcast address and host IP address range?	3
6	How useful is the pegboard (1-5 1=very difficult, 5=extremely simple)	
7	Advantages of the pegboard	
8	Disadvantages of the pegboard	

Completed surveys were collected and collated for analysis. Results from the survey were considered initially in three areas: questions 1 to 5, question 6, and questions 7 and 8. One respondent did not read and understand the requirements of the survey nor did that respondent request assistance of the researcher in undertaking the survey. This one respondent only gained one (1) mark from the five questions and did not record the time taken to complete each question.

Only one respondent requested assistance. The assistance requested related to question number one and was possibly due to initial nervousness. Assistance provided was of a minimal and general nature.

Table 5.2: Pegboard Survey Results

Question	Possible Mark	High Mark	Average mark	Lowest Mark	Shortest Time	Longest Time	Average Time
1	2	2	1.3	0	0.6	32.0	4.8
2	2	2	1.3	0	0.5	8.0	2.4
3	2	2	1.1	0	2.0	11.6	5.3
4	1	1	0.5	0	0.1	11.0	3.5
5	3	3	1.4	0	1.0	45.0	11.0
Total	10						

Table 5.2 shows a breakdown of questions one to five. Respondents represented a wide spread of ability. Each question was answered correctly by some students and incorrectly by others. Table 5.3 shows how well each question was answered.

Table 5.3: Pegboard Survey Results – Questions Correctness

Question	All Correct	Partially Correct	Wrong
1	9	2	4
2	8	4	3
3	7	3	5
4	8	0	7
5	4	8	3

The range of achieved grade extends from 10% to 100%. The overall average achieved by respondents was 57%. Given the wide range of marks, it would appear from an initial analysis that there is no real value provided by using the pegboard. Examining the respondents in two groups, the totally blind and those with low vision, a significant difference becomes apparent. The results for the totally blind group reveal an average grade of 72% achieved in an average time of 24 minutes while the low vision group had an average grade of 35% achieved in an average time of 23 minutes. This result demonstrates that the totally blind group having a greater reliance on the pegboard proved its value. Further more, the disparate variations in the students results is seen as an indication that a device such as the pegboard addresses some of the teaching and learning issues previously discussed. Table 5.4 lists the results obtained by each participant.

Table 5.4: Pegboard Survey Results – Respondents

Participant	Graded Mark	Time Taken: Minutes
1	70%	20.00
2	55%	29.00
3	70%	16.10
4	80%	9.20
5	25%	72.00
6	70%	26.00
7	50%	32.00
8	40%	34.40
9	10%	Not Recorded
10	30%	53.10
11	5%	28.00
12	90%	12.60
13	90%	13.50
14	70%	19.00
15	100%	12.75
Average	57%	27.00

Respondents were requested to indicate their opinion of the usefulness of the pegboard. A Likert type scale was adopted where usefulness was to be measured on a scale of 1 to 5, where the value of 1 indicates ‘not useful’, and the value of 5 indicates ‘very useful’. Results returned an average grading as shown in Table 5.5. Three respondents did not submit a scaling grade. The grade of 3.6 is seen as a favourable acceptance by respondents of the device’s usefulness.

Table 5.5: Pegboard Survey Results – Usefulness

Participant	Grading
1	5
2	2
3	5
4	2
5	5
6	4
7	3
8	4
9	5
10	N/R
11	2
12	N/R
13	3
14	N/R
15	3
Average	3.6

The final part of the Pegboard Survey provided respondents an opportunity to express their opinions about the advantages and disadvantages of using the pegboard as a teaching aid. Respondent comments relating to advantages were consistent and favourable. Most commented on ease of use and that it provided a simple place marker during calculations. Feedback from one student summarised the general tone of respondents' comments.

The pegboard is one of the most important pieces of equipment for learning how to subnet, once you learn the values of each position it gradually gives the individual the understanding of subnetting and how logical anding works. It is also an integral tool for working out whether a host is on a particular subnet by anding the two IP address with the subnet using boolean logic. Without this pegboard I would have found it harder to understand the subnetting process. Each student should have a pegboard to learn the subnetting process so that the lecturer can refer to it when lecturing so that the students can follow the instructions given in the lecture.

Even when given a subnetting exercise to do, the pegboard is very important to be able to do the exercise. Once you get the basic knowledge of subnetting most problems can be worked out in your head but the knowledge gained in the first place with the pegboard is extremely important.

Respondent comments relating to disadvantages were less consistent and it was possible to see separate views offered by the two groups. Comments were still favourable. The most often mentioned disadvantage was speed. The totally blind respondents tended to appear more readily accepting of the pegboard and offered portability, with the large physical size of the pegboard as a disadvantage.

While none of the respondents stated outright that they could not have achieved the required learning outcomes associated without using the pegboard, the overwhelming consensus of opinion by students was that the pegboard facilitated quicker understanding of the core numbering and addressing system concepts. Students also held the view that the pegboard offered them a faster method for calculating required numbers, and an aid to their memory when conducting complex calculations. The observations of teaching and support staff confirm these opinions. The pegboard has also been used in the instruction of sighted students and

has been beneficial to a significant proportion of those having difficulties with the concepts involved in IP subnetting.

5.1.3. Network Dominoes

The concept of a tactile method of displaying network devices and interconnections was initially well received by students in the pilot study. A survey of totally blind users of the Network Dominoes showed that students rated the usefulness highly at 4.4 out of 5 (n=6). An interesting item was raised in the comments section of the survey, as detailed in the following quote.

“The network dominoes are interesting for showing students what the network shapes look like. This can be useful for if they have a sighted person without any networking knowledge trying to explain a diagram to them, they are able to tell the sighted person what the shapes are.”

The ability to identify standard graphic icons is of obvious import given that it is expected that students will be in mainstream employment and required to interact with their sighted peers. Whilst the network dominoes achieved the desired result of communicating topologies, it was decided to discontinue their use in the later iterations of the courses. The primary concern with the Network Dominoes became apparent with the inclusion of students undertaking the courses remotely. Remote students would connect the dominoes in the manner that they thought was correct, but on occasion was significantly different to the intended topology. As the instructors have no method of checking the said topology, being both blind and geographically separated from the tactile topology, errors in construction would not be identified and thus lead to possible misconceptions by students. A secondary issue was that of cost, both in production of the full range of network device objects and that of

distribution of multiple sets. If the cost of production could be reduced, use of these devices should be explored in future trials.

5.1.4. Remote Bundles

A survey of students (n=15) that made use of the remote laboratory bundles illustrated that the development of this system was a major contributing factor towards the success of students undertaking the CCNA courses. Students graded the remote bundle usefulness at an average of 4.6 and median of 5 (1 = no use, 5 = very useful) It is noteworthy to examine comments submitted.

“This was a truly awesome feature of the course. Without it, I don't think I would have had any chance of passing, since I could not afford to purchase the required equipment myself”

“It provides free access to the innards of expensive routers. Without that access, I couldn't do the labs from home.”

“The remote bundle is essential in order to complete all the lab work, as it is a completely accessible setup. It is empowering to be able to complete all the labs as instructed, control all the devices and reset them as needed, without having to rely on a sighted instructor.”

However it is a complex system that is not optimised for ease of use, requiring several steps to gain access to the device required for a particular laboratory session. Additionally as students are remote to the facility housing the equipment re-cabling the physical topology is not possible. A generic topology was created that would allow all CCNA

laboratory sessions to be undertaken but this consumed greater resources (in the addition of extra interfaces to the network equipment) and added some complexity to the configuration. The high cost of each “pod”¹⁰ was offset by the ability of students in remote locations to utilise the equipment without the need for local installations of the networking equipment. An issue of booking resources in the remote bundle arose, in that several users may connect and attempt to configure network components within the same pod without realising it was in use by other students. This situation was overcome by use of the virtual classroom. (refer to Figure 4.16) Students wishing to utilise a particular resource would enter a classroom named after that resource. If another student also connected to that resource, they would be announced as entering the room. Students could then discuss sharing or collaborating on laboratory tasks and equipment. A booking system would have been a better solution but time did not allow the development of such a system, however it is envisaged that the calendar and laboratory reservation system will be completed at the end of 2008.

The remote bundle allowed students to successfully perform all laboratory tasks within the CCNA curriculum although some modification was required to the instructions. All eLabs, described in section 5.1.10, within CCNA 2 were also completed using this equipment.

¹⁰ A Pod is the term used for one full set of equipment required to undertake CCNA laboratory tasks.

5.1.5. Virtual Classroom

The virtual classroom, although an “off the shelf” application designed for voice communication of on-line gamers, met the requirements for this study. Students interacted with instructors to a level consistent with the authors’ experience with mainstream university undergraduate lectures and tutorials. Survey results confirmed the perceived usefulness of the virtual classroom with respondents rating it at an average of 5.0, median of 5.0, n=13. (1 = no use, 5= very useful) Comments were exceptionally positive, as shown in the examples below.

“Another excellent feature of the course, this worked much better than skype.”

“Recorded lectures do not allow for students to ask questions in real time. Students asking questions can show up areas of understanding where the class are having trouble and therefore shape the direction of a lecture. Also, I have found it important to have the interaction with other students to gain a sense of having peers to work with who are in the same situation.”

“The Virtual Classroom is one of the best parts of learning with the CAVI Courses as you can participate in the lecture by answering question in real time instead of downloading a pre-recorded lecture, which dehumanizes the learning experience. The Ventrilo program is one of the best high speed conferencing software we have used, skype high speed conferencing was not very good and it interfered with how we interacted with the lecturers. The virtual classroom is very important as questions can be asked in real time so that we can get to know how much knowledge each student has gained as he or she traverses each module. Without this we would not

know how much knowledge he or she has and whether or not they understand what is being achieved by doing this course. And the virtual classroom has the ability to let others know if they are doing their labs for the CCNA courses so they don't cause problems by over writing their configurations.”

Students (n=13) were asked to rate if text and/or recorded lectures (similar to podcasting) would be better (5) or worse (1) than the virtual classroom scenario. Results yielded an average of 1.8 and a median of 1.5. It should be noted that all lectures are recorded and posted on the project website at <http://www.cucacat.org/student.php> so may be downloaded if a student misses the live lecture or wishes to review material. The Ventrilo service was hosted externally (by Darkstar Communications, www.darkstarllc.com) and suffered just a single failure in over two years. It is also highly scalable with the capability of up to 400 concurrent users on a single server. Scalability became a crucial requirement in 2008 when enrolments of vision impaired students undertaking the various courses exceeded 140. Bandwidth requirements were sufficiently low being in the range of 2.15 to 24.6 kbps for 32kbps, 16 bit sampling when utilising the Speex codec (source: <http://www.speex.org/comparison/>). This allowed dial up connections (56kbps), which was an important consideration for those in developing countries. A comparison of speech quality is shown in Figure 5.3. Latency was also acceptable at 20ms for the codec and typically less than 25ms propagation and processing delays.

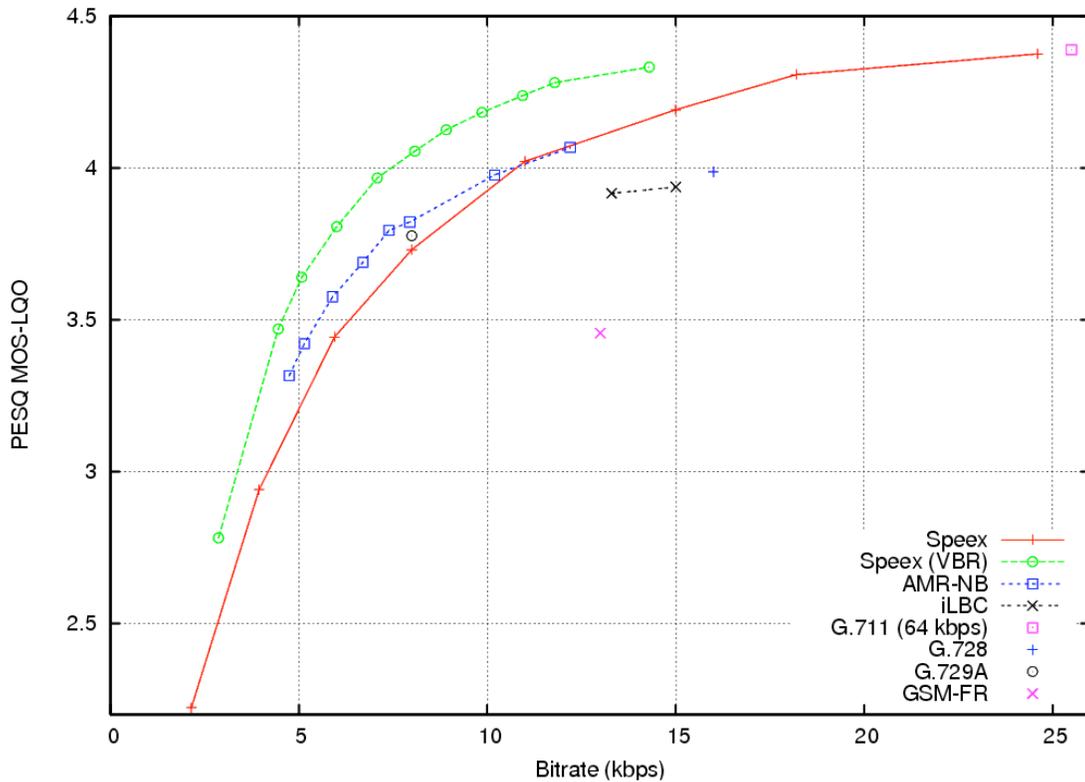


Figure 5.3: Codec quality comparison (source: <http://www.speex.org/comparison/>)

The virtual classroom was also utilised for pop quizzes, chapter quizzes and a replacement for the drag and drop/check box interactive media objects. Student participation via the text chat capability in the communications application was good, with the majority of students responding. This was a popular part of the lecture session with students requesting a greater number of questions within the quiz period (typically 10-12 questions per lecture). Statistics and feedback were not formally gathered on the effectiveness of the quiz components, as such has been done exhaustively by other researchers (Marcell, 2008).

5.1.6. Tactile Graphics Diagrams

As Dulin (2007) identified, raised line drawings may increase the blind individual's spatial cognition and communicate information from graphics that would otherwise be inaccessible, several issues were noted when utilising this media in the context of technical drawings. Many of the network diagrams, in order to fit on the A4 capsule paper, required the network device icons to be of limited dimensions (approximately 30mm by 30mm) the tactile resolution of the human senses made it difficult to identify or differentiate between similar objects, for example hubs and switches (refer to Table 2.2 for details on tactile resolution). A significant number of tactile diagrams were produced, utilising the PIAF system, in the pilot study stage of the research (in excess of 150 individual diagrams and charts). Totally blind students within the pilot study were surveyed (n=6) on the suitability and usefulness of this style of graphic representation with the disappointing results, given the cost and time taken in production. Overall on a scale of 1 to 5 (1 = of no use, 5 = very useful) an average result of 2.4 (mean of 2.0) was returned. The physical bulk and material cost of tactile pictures made it difficult and inefficient to distribute up to date material to remote students, particularly when compared to electronic text descriptions. An example set of PIAF produced tactile diagrams is included in Appendix F: Sample Tactile Graphic Diagrams.

PIAF and Nomad along with the tactile assistive technology devices suggested as being useful to vision impaired students and discussed in the literature review proved to be unsatisfactory in meeting the needs of the vision impaired student studying to the Cisco course materials. The complexity of images and diagrams in the required teaching materials and the individual health issues of students proved these devices/methods unsatisfactory. Given the logistical difficulties of shipping significant

quantities of tactile pictures and overlays to various countries the costs become prohibitive as the class size increases.

The challenges relating to teaching materials focused directly on how best the students could gain an understanding of course materials. While not all, many complex computer related technical images and diagrams rely on the use of colour, which is difficult to represent on tactile media. The main difficulty with these devices or tactile media was that the demands being placed on them were inconsistent with their ability to meet teaching requirements.

5.1.7. Haptic Showcase: An Application to determine the Suitability of Haptically Describing 2 and 3 Dimensional Shapes

5.1.7.1. General Results and Overview

Experiments using the haptic pen as an alternate means of presenting graphics produced varying and disappointing results. The initial identification of wax shapes indicated that all participants could identify the shapes, some blind individuals (n=2) could not name them accurately. Of interest is the comment made by blind subjects who are parents (n=3) that they were very familiar with shapes due to the interaction with their sighted children. The experiments carried out collected data from 3 groups of students; totally blind, low vision and sighted. The promise portrayed in past research involving the use of haptics (and the haptic pen in particular) for the blind drove the testing of student recognition of several 2-D and 3-D shapes. The 2D shapes tested were square, rectangle, circle, oval, triangle and diamond. The 3-D shapes tested were cube, cuboid, sphere, ovoid and pyramid. In addition, three different methods were used to identify the edge of the shape; gravity, groove and ridge. Three textures were also tested; surface, vertex and none.

Three attempts to identify each shape were undertaken by each participant in the three groups. Accuracy and timing were recorded for each attempt. A discussion of the results follows.

5.1.7.2. Results for the Blind Participants

In the experiments to identify 2D shapes with totally blind participants accuracy was found to increase in subsequent attempts with an average of 64.44% correct in attempt 1, 78.89% in attempt 2, increasing to 83.89% correct in attempt 3. Recognition of the 2D shapes appears to have increased with repetition and familiarization. Timing reduced from 32.98 seconds in attempt 1 to 19.53 seconds in attempt 2 and 13.33 seconds in attempt 3. The most difficult 2D shapes for the blind to correctly identify were the oval and square, however expertise in identifying these improved as the number of attempts increased. The longest single attempt was 218 seconds to identify the oval shape with ridge texture as a first attempt and the answer was not correct. With regard to timing and accuracy of 2D shape identification the poorest results for given individuals were 0 correct with an average of 27.8 seconds per shape, and 6 (out of 18) correct with an average of 102.78 seconds per shape. The strongest result for a given individual was 17 (out of 18) correct at average of 7.78 seconds per shape.

Accuracy also increased in subsequent attempts of identifying 3D shapes, but not to the same extent as 2D shape recognition. The results were 69.23% correct in attempt 1, 76.92% in attempt 2 and 77.69% in attempt 3 (see Table 5.6). Timing for 3D progressively reduced from an average of 40.75 seconds in attempt 1 to 23.19 seconds in attempt 3. The poorest 3D result for a blind individual was 225 seconds to incorrectly identify the cuboid on the second attempt 2. On average the poorest results for blind individuals on all 3D shapes were 5 correct with an average of 49.38 seconds per shape, and 6 correct with an average of 68.92 seconds per

shape. The best individual case for all 3D shapes was 13 correct in an average of 24.38 seconds per shape.

5.1.7.3. Results for the Low Vision Participants

Low vision participants attempting to identify 2D shapes showed that accuracy increased with subsequent attempts; 74.44% correct in attempt 1, 88.33% correct in attempt 2 and 87.22% correct in attempt 3. Repetition and familiarization appears to have made it easier for these participants to recognize the 2D shapes. The average time to answer reduced from 20.57 seconds in attempt 1 to 9.58 seconds in attempt 2 and 8.20 seconds in attempt 3 (see Table 5.7).

The 2D shape associated with the longest time for a participant to answer was the square with groove reported at 111 seconds for an answer on the first attempt and this was not correct. The fastest time to identify 2D shapes accurately was 4.11 seconds with 17/18 accuracy, and the poorest result was 8/17 correct in an average of 23.77 seconds.

Accuracy in identifying 3D shapes did increase between attempts 1 and 3, however attempt 2 on average gave poorer results; demonstrated by an average for vision impaired participants of 78.46% correct in attempt 1, 76.92% correct in attempt 2 increasing to 86.15% in attempt 3 (see Table 5.6).

The average time taken to identify 3D shapes by the low vision participants reduced from 40.38 seconds in attempt 1 to 23.25 seconds in attempt 2, dropping to 17.04 seconds in attempt 3. The poorest time for a low vision participant to identify a 3D shape was 182 seconds, and this

reading correctly identified a cube shape with surface texture on the first attempt.

The best overall score for a low vision participant identifying 3D shapes was 13/13 in an average of 16.15 seconds. The poorest overall score for a low vision participant identifying 3D shapes was 6/13 correct in an average of 46.77 seconds.

Table 5.6: Summary of accuracy – average % correctly identified shapes

Shapes	Attempts	Blind	Low Vision	Sighted
2D (18 Q's)	Attempt 1	64.44	74.44	78.40
	Attempt 2	78.89	88.33	82.10
	Attempt 3	83.89	87.22	85.19
3D (13 Q's)	Attempt 1	69.23	78.46	64.10
	Attempt 2	76.92	76.92	65.81
	Attempt 3	77.69	86.15	59.83

Table 5.7: Summary of average in seconds per question to identify shapes

Shapes	Attempts	Blind	Low Vision	Sighted
2D	Attempt 1	32.98	20.57	13.78
	Attempt 2	19.53	9.58	11.11
	Attempt 3	13.33	8.20	11.58
3D	Attempt 1	40.75	40.38	32.63
	Attempt 2	30.53	23.25	29.91
	Attempt 3	23.19	17.04	29.38

5.1.7.4. Results for the Sighted Participants

The accuracy in identifying 2D shapes increased slightly over the three attempts for sighted participants. As can be seen in Table 5.6 the readings were 78.4% correct in attempt 1, 82.1% in attempt 2, increasing to 85.19% correct in attempt 3.

Average timing reduced from 13.78 seconds in attempt 1 to 11.11 seconds in attempt 2 and increased to 11.58 seconds in attempt 3.

The poorest singular case for a sighted participant produced a time of 124 seconds to correctly identify a triangle with a groove on the third attempt. The poorest reading overall for 2D shapes was 11/18 correct in an average of 17.94 seconds, and the best was 17/18 in 5.94 seconds.

Accuracy in identifying 3D shapes decreased for sighted users over the three attempts, with 64.10% correct in attempt 1, 65.81% in attempt 2, decreasing to 59.83% in attempt 3.

Timing for 3D shape recognition for sighted participants reduced from an average of 32.63 seconds in attempt 1 to 29.91 seconds in attempt 2 and 29.38 seconds in attempt 3 (see Table 5.7).

The poorest reading for accuracy of 3D shapes for a sighted participant was 127 seconds to correctly identify a cube with vertex texture on the first attempt. The poorest overall result for a sighted user was 4/13 correct in an average of 65.84 seconds, and the best was 13/13 correct in 14.77 seconds.

5.1.7.5. Summary of 2D Shape Results

The easiest 2D shape for all participants to correctly identify was the triangle with an accuracy rate of 92.96%. The triangle, however, took the longest to identify in the collection of 2D shapes with an average of 17.77 seconds. The 2D shapes most difficult to correctly identify were the oval with 77.04% accuracy and the rectangle with 78.15% accuracy (see Table 5.8 and Figure 5.4). Ironically timing for the rectangle was the lowest in the 2D group of shapes, indicating that participants thought they had identified the shape reasonably quickly, but the accuracy rate was generally poor in comparison to the other 2D shapes.

Patterns in the incorrect answers indicate that two sets of 2D shapes were difficult to correctly differentiate: the square and rectangle, and the circle and oval.

Table 5.8: Summary of accuracy and time taken to identify 2D shapes

2D Shapes	Square	Rectangle	Circle	Oval	Triangle	Diamond
						
Seconds	15.70	14.46	15.11	17.14	17.77	16.80
Accuracy	82.59	78.15	89.26	77.04	92.96	86.30

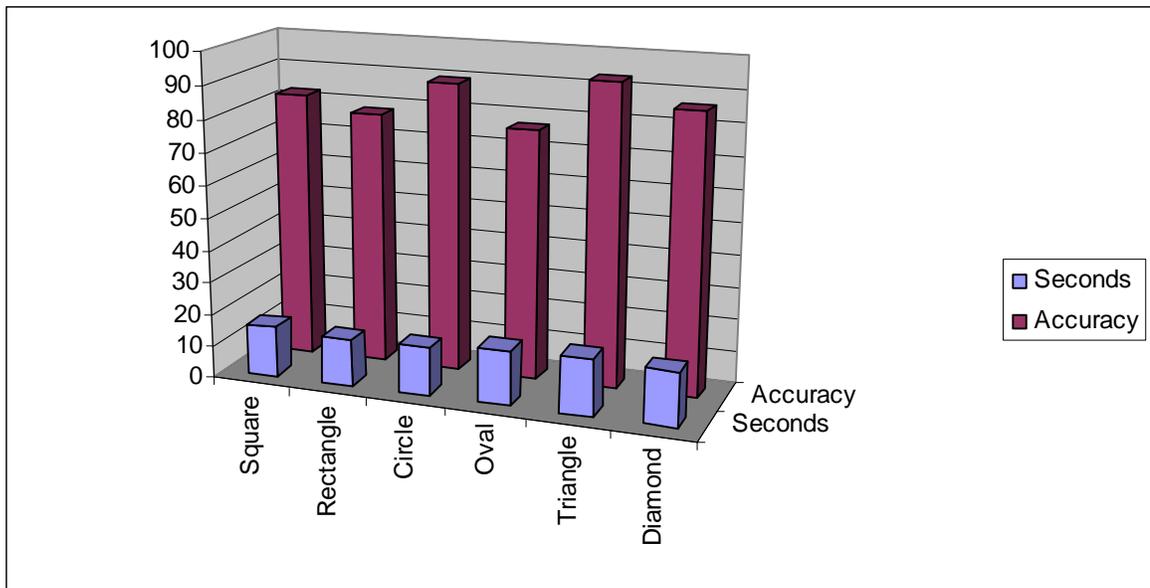


Figure 5.4: Bar chart of accuracy and time taken to identify 2D shapes

5.1.7.6. Summary of 3D Shapes Results

Of the 3D shapes tested the sphere and ovoid were the quickest shapes to be identified by the participants with average times of 22.94 seconds and 23.68 seconds respectively (see Table 5.9 and Figure 5.5).

The most accurately identified 3D shape was the cube with 81.48% correctness; however this was not the fastest shape identified with an

average of 28.03 seconds taken to answer. Although the ovoid displayed a fast identification time, the accuracy rate for this shape was only 57.77%. Table 5.9 shows the answers given by the participants indicate that two sets of 3D shapes were difficult to differentiate: the cube and cuboid, and the sphere and ovoid.

Table 5.9: Summary of accuracy and time taken to identify 3D shapes

3D Shapes	Cube 	Cuboid 	Sphere 	Ovoid 	Pyramid 
Seconds	28.03	32.36	22.94	23.68	33.82
Accuracy	81.48	76.67	75.00	57.77	73.33

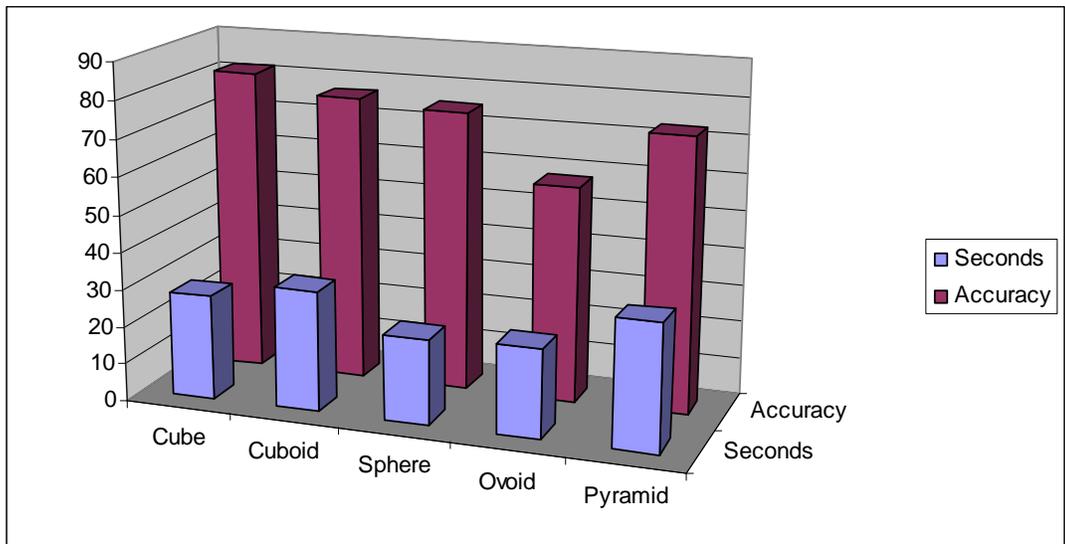


Figure 5.5: Bar chart of accuracy and time taken to identify 3D shapes

5.1.7.7. Edge Definition

Three methods were used to indicate edges of the 2D shapes – gravity, groove and ridge. Participants were not informed that there were three different methods of defining the edges of the shapes.

The most accurately identified edge definition method was gravity with 88.33% correctness, and the least was the ridge with 81.48% accuracy. The ridge and gravity produced the fastest average decision rate at 13.65 seconds and 13.88 seconds respectively (see Table 5.10 and Figure 5.6).

Table 5.10: Summary of accuracy and time taken for 2D shape edge definition methods

	Gravity	Groove	Ridge
Seconds	13.88	20.97	13.65
Accuracy	88.33	83.33	81.48

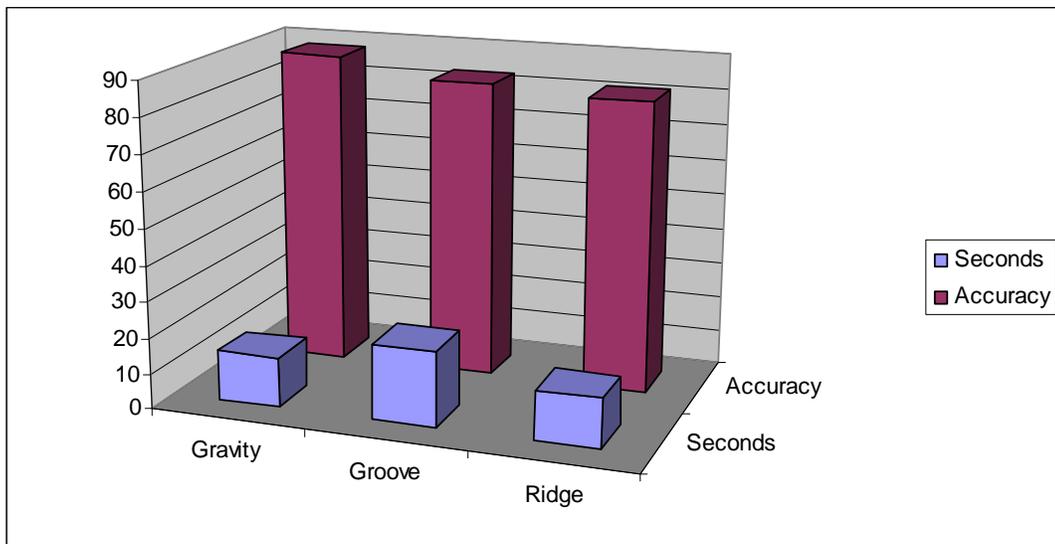


Figure 5.6: Bar chart of accuracy and time taken for 2D shape edge definition methods

A summary of the overall findings for 2D shape edge definition methods are as follows:

1. Gravity: Accuracy ranged from 75/90 (83%) to 87/90 (96%) with an average of 79.5/90 (88%) correct, and a standard deviation of 3.99. The timing for identifying gravity-edged shapes ranged from 11 to 15 seconds, with an average of 13.88 seconds and a standard deviation of 2.05. Overall gravity was found to be the more superior means of the three edge definition methods for defining 2D shapes.

2. Groove: Accuracy ranged from 64/90 (71%) to 82/90 (91%) with an average of 75/90 (83%) correct and a standard deviation of 6.16. Timing for identifying shapes with groove edges ranged between 16 and 26 seconds, with an average of 20.97 seconds, and a standard deviation of 2.77.
3. Ridge: Accuracy ranged from 59/90 (65%) to 84/90 (93%) with an average of 73/90 (81%) correct and a standard deviation of 8.6. Timing for identifying shapes with the ridge edge ranged between 12 and 16 seconds, with an average of 13.65 seconds, and a standard deviation of 1.55.

5.1.7.8. Textures

The most accurate texture from the three methods tested was using vertex with an average of 82.96% and the least accurate was no effect with 70%. The vertex and surface produced the fastest average decision rate at 26.46 and 26.58 seconds respectively (see Table 5.11).

A summary of the overall findings for 3D shape texture methods are as follows:

1. Surface: Accuracy ranged from 53/90 (58%) to 70/90 (77%) with an average of 65/90 (72%) correct, and a standard deviation of 6.16. The timing for identifying gravity-edged shapes ranged from 16 to 37 seconds, with an average of 26.58 seconds and a standard deviation of 7.31.
2. Vertex: Accuracy ranged from 67/90 (74%) to 79/90 (87%) with an average of 75/90 (83%) correct and a standard deviation of 5.44. Timing for identifying shapes with vertex texture ranged between 24.7 and 29.6 seconds, with an average of 26.46 seconds, and a standard deviation of 2.23. Overall vertex was found to be the more superior means of the three texture methods for defining 3D shapes.

3. None: Accuracy ranged from 51/90 (56%) to 73/90 (81%) with an average of 63/90 (70%) correct and a standard deviation of 7.72. Timing for identifying shapes with the ridge edge ranged between 27 and 42 seconds, with an average of 32.72 seconds, and a standard deviation of 5.54.

Table 5.11: Summary of accuracy and time taken for texture methods

	Surface	Vertex	None
Seconds	26.58	26.46	32.72
Accuracy	72.22	82.96	70.00

The most successful texture for correct identification of shapes was vertex with 82.96% accuracy. Vertex also resulted in the fastest identification time. Shapes with no texture scored the lowest average accuracy rate at 70% and longest average time to answer at 32.72 seconds (see Table 5.11 and Figure 5.7).

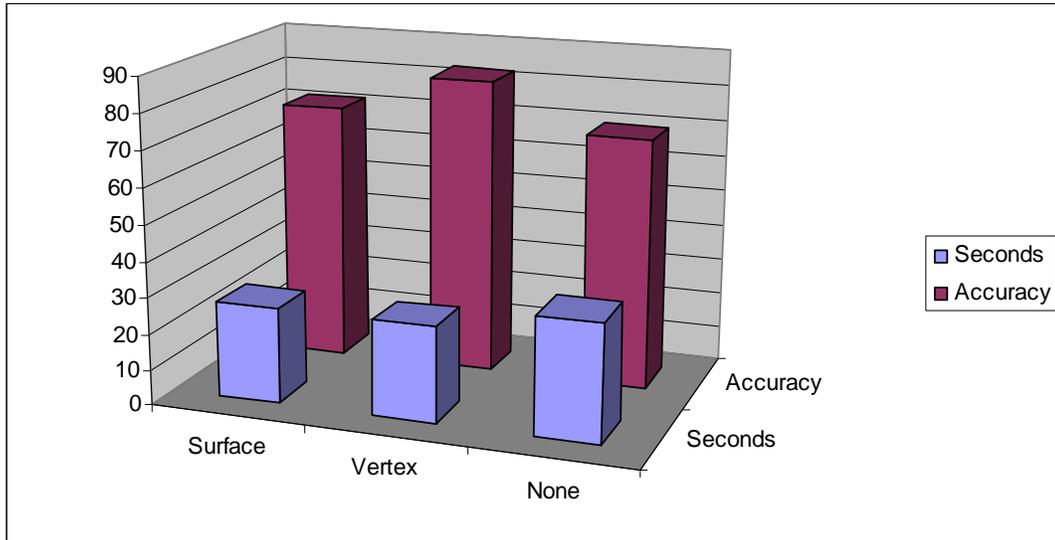


Figure 5.7: Bar chart of accuracy and time taken for texture methods

5.1.8. Textual Descriptions

Whist tactile methods have shown to be of limited use, the textual descriptions proved to be more efficient, both in cost and production time and less complex to produce. Empirical results and course feedback reinforce this viewpoint. Student survey results (n=13) when queried on how well the picture descriptions, both in exams and curriculum, assist understanding of the material, rated text descriptions at an average of 4.5 and a median of 5. Comments submitted support the observed results of students in the classroom setting.

“For exams they are essential.”

“Text descriptions help immensely”

“They make it much easier to complete the course independently”

“Without text description we can’t pass these courses. It’s more than excellent.”

“These I believe are very useful, although I’ve been able to muddle through some times with out them; there have been occasions where I’ve really appreciated these. They are on the whole well worded and you can see that careful planning and a vast amount of time and thought have been put into these.”

“Text descriptions are essential in the understanding of the curriculum material. There is information in the text descriptions that is not in the notes and they also reinforce important concepts. The text descriptions for exams are also essential, because diagrams used in the questions can be quite complex. It is necessary to be able to gain the correct understanding of the diagrams in the exams in order to complete the exams properly.”

Correctly prepared structured textual descriptions have shown to be an efficient and effective method of communicating graphical and tabular interrelationships that are, in the main, delivered by visiocentric means.

5.1.9. iNetSim Network Simulator for Apple OS X

The prototype application, iNetSim, allowed students to successfully simulate network topologies and conduct configuration exercises within the CCNA (1 and 2) curriculum. Those users involved in the testing process reported that the application was easy to use. Accessibility

testing, utilising the tools supplied by Apple Corporation, verified the applications conformance to accessibility guidelines (Apple, 2008) The application was implemented only as a proof of concept and further development ceased at the end of 2007. The justification for ceasing further work on iNetSim was that the Packet Tracer API's were made available to developers in April 2008 and it was thought that a better approach to the simulation problem was to work in conjunction with the Cisco developers to create an accessible user interface to the superior Packet Tracer engine. Appendix G outlines the features of Packet Tracer 5.0.

5.1.10. e-Labs

As discussed in section 4.5.10, eLabs are utilised to communicate a single learning outcome from the curriculum chapter being currently studied without the necessity of the student creating multiple complex router configurations. Vision impaired students took significantly longer than their sighted counterparts to complete each eLab due to the necessity of connecting to the remote bundle, pasting configurations into the required network prior to commencing the laboratory session. However, students found that completing a set of eLabs reduced this setup time considerably. Trials of eLabs with instructors, both vision impaired (n=3) and sighted (n=4) established that there was no perceived difference in the user experience once configurations were copied to laboratory equipment. Students (n=13) rated the usefulness of eLabs at an average of 4.6 (median = 4.5). The disadvantage of eLabs is primarily in the preparation involved, each piece of equipment used in a particular session required a configuration file to be created and tested. Instructions needed to be transcribed from the Flash files, tested by qualified personnel and altered to suit use on the remote bundle. In excess of 180 individual files were created.

5.1.11. Interactive Media Objects

The four different styles of interactive media objects were each modified in significantly different manners. To analyse the effectiveness of the transformations each style was evaluated under the topics shown in Table 5.12.

Table 5.12: Interactive media object discussion sections

Interactive Media Object	Discussed in
Drag and Drop	5.1.5 Virtual Classroom
Check Box	5.1.5 Virtual Classroom
Photo Zoom	5.1.12 Audio Demonstrations
Point and Click	5.1.10 e-Labs

5.1.12. Audio Demonstrations

Where equipment covered by the curriculum was unavailable to remote students, audio demonstrations were conducted utilising the virtual classroom. (including photozoom interactive media objects). Whilst not as effective (in raising student interest and inclusion in the process) as having students interact physically with the item being investigated, the core outcomes could be achieved. The preferred method of conducting said demonstrations was where remote students have similar equipment to hand, for example an old computer as shown in Figure 5.8. Students would then copy the steps taken by the local student demonstrating and describing actions undertaken. Empirical evidence showed that demonstrations conducted by severely vision impaired students delivered better learning outcomes than those given by sighted instructors. As the virtual classroom had no video component, each step and the identification of components needed to be well described, in a succinct manner that made sense to a remote blind person. As the vision impaired

are familiar with the need to describe scenarios without the aid of vision, they could offer a better verbal representation of the laboratory demonstration being undertaken. It was also beneficial if a low vision or sighted person was available to read descriptions, part numbers or identify cable colours.

Audio demonstrations of key laboratory and IOS features were also undertaken in the same manner as would be conducted in mainstream classes, for example, using the remote bundle. An instructor would describe step by step the methods and processes required to perform a task without the use of visual aids or visual cues (for example holding up a video card for the class to see). Demonstrations would also be recorded and made available on the project website (<http://www.cucacat.org>) for student reference.



Figure 5.8: Audio demonstration of computer assembly

5.2. Summary of Modifications and Transformations Applied to the Curricula

The following discussion covers an analysis of how effectively and efficiently problems were addressed. Definitions of effectiveness and efficiency as the basis for these evaluations are:

- *Effectiveness* is evaluated by determining how well the solution achieves the given objectives. In this context effectiveness is measured by determining whether the vision impaired students studying the converted e-learning courses achieved the same outcomes as able-bodied students studying the unconverted courses.

- *Efficiency* is evaluated by determining any increase or decrease in the level of the resources used to achieve the stated objectives. In this context efficiency is measured by ascertaining whether the difference in costs for teaching methods and tools between the vision impaired accessible environment and the traditional Cisco e-learning environment is minimal for the same level of output.

Each mode of presentation is evaluated via a ranking of 0 through 5, where 0 denotes “no use whatsoever”, 3 gives the same or similar outcomes or resources, and 5 shows a significant increase in outcomes or significant decrease in resources. An acceptable solution should rate at least 3 and a summary of the ratings is presented in Table 5.13.

Table 5.13: Effectiveness and Efficiency of Potential Solutions

Requirements	Potential Solution	Effectiveness (same outcomes)	Efficiency (more or less resources)	Comments
1. Lack of student mobility	Virtual classroom	4	5	Highly scalable without increasing resources
	Remote Bundle	5	4	Slightly more complex to use. Reduces cost of distributing multiple laboratory pods. Equipment available 24/7
2. Inclusion of remote students	Virtual classroom	4	5	No realistic limitations on lecture size
	Pegboard and manual teaching aids	4	3	Transport and production costs of multiple sets.
3. Unable to see whiteboard	Audio lectures	4	5	Available as a permanent resource
	Pegboard	4	4	Slow in comparison to visual methods. In use by mainstream classes to demonstrate subnetting.

4. Sighted instructors not aware of needs of the vision impaired	Vision impaired instructors	4	3	Vision impaired instructors are as capable as sighted. No discernable difference efficiency. The non reliance on visual cues increases worth of "podcast" lectures to any audience.
5. Communicate graphic and visual material	Haptic devices	1	1	Learning time is significant. Error prone, wrong shape identification. Difficulty in creating dynamic objects.
	Tactile devices	3	2	Static diagrams. Bulk and cost of materials. Useful for some aspects network component identification.
	Braille	3	3	High production cost and bulk.
	Textual descriptions	4	3	Labour intensive. Of some assistance to those with print and learning difficulties.
6. Text only access in teaching materials	Haptic devices	2	1	Time consuming to produce application that allow dynamic building of diagrams
	Tactile devices	3	2	Static diagrams
	Braille	3	3	Static text, very bulky and low levels of Braille literacy.
	Textual descriptions	4	3	Labour intensive to produce. Requires updating with curriculum revisions.
7. Cannot access laboratory exercises	e-Labs	3	3	Labour intensive conversion process.
	Remote labs	5	4	No access to physical cabling. 24/7 availability of equipment. Lower cost to small Academies (shared resource)
	iNetSim	3	2	Proof of concept only.
	Network dominos	3	2	High production cost and bulk.
8. Cannot access	Text examinations	5	3	Labour intensive conversion process. Less

examinations				ambiguity than graphics, lower bandwidth requirement for assessment
	Haptic devices	1	1	Time consuming to produce application that allows dynamic building of diagrams.
	Tactile devices	3	3	Labour intensive to produce. Requires updating with curriculum revisions.
	Braille	3	3	High production cost and bulk.
9. Cannot access drag and drops	Text drag and drops	4	4	High preparation time. Greater flexibility, may be delivered as an interactive quiz.
10. network topology/ simulation software	Network dominos	2	2	High production cost and bulk. Not interactive and do not simulate the operating system.
	iNetSim	3	2	Modification of Packet Tracer user interface to overcome the access issues.
11. Linux / UNIX	Speech synthesizer	4	3	Poor access to GUI. Allows full access to command line.

As can be seen from Table 5.13, almost all identified barriers to accessing the eLearning curriculum chosen as the instrument for this study has been overcome with one exception. At the time of writing, there was no comprehensive network simulator available that is fully accessible. This shortcoming should be overcome in the near future with the development of an accessible GUI for Packet Tracer. Of particular import were the final results in the on-line exams. The Cisco Network Academy connection site (<http://cisco.netacad.net>) allows instructors to view exam results for all students who have completed the on-line tests. A comparison of results

for the final exam in each of the four courses was performed in three demographic groups presented in Table 5.14. Results are for students who undertook the same exam form¹¹. Numbers of students sitting the exams differ for each question in the population group so an average is taken across all questions. The sighted class sample was selected for the previous reason and was also a class taught by the author that was similar in number to the group of vision impaired students.

¹¹ Several exam forms may be available over a period of time as corrections are made or questions updated. Numbers shown consist only of those utilising the same form.

Table 5.14: Final exams participant numbers

Course	Demographic	n	Comments
CCNA 1	Population	214,499	Average across all questions
	Vision Impaired	24	
	Sighted	19	
CCNA 2	Population	67,601	Average across all questions
	Vision Impaired	23	
	Sighted	19	
ITE 1	Population	61,386	Average across all questions
	Vision Impaired	23	
	Sighted	19	
ITE 2	Population	28,484	
	Vision Impaired	22	
	Sighted	32	

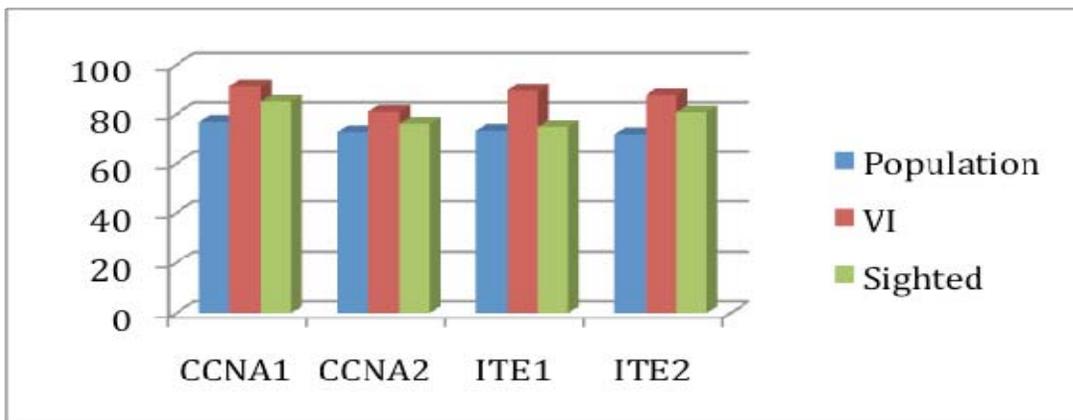


Figure 5.9: Comparison of vision impaired to sighted students final exam results

As can be noted by the graph in Figure 5.9, the vision impaired group consistently scored better across the full range of courses when compared to the sighted groups. The population group may not be representative a no level of support, availability of resources and other relevant information is available for this group. The sighted group may be directly compared as they consisted of students taught at Curtin University of Technology as part of their coursework in the Bachelor of Technology (Computer Systems and Networking) and as such had a comparable educational background and access to resources such as laboratory equipment and information.

6. Conclusions

6.1. Findings

The focus of this research was to identify means of producing an e-learning environment that was fully accessible to those with vision impairments and identify the essential components of such an environment. Using the Cisco industry standard network training courses as the carrier the sought-after accessible environment was developed with the components summarized in Table 6.1

This development encompassed the testing of numerous potential solutions in a bid to provide resolutions to problems and needs identified earlier in the research. The results are summarized in the first 3 columns of Table 6.1. The final column presents recommendations as to the usefulness of each component in any technology-related e-learning environment accessible to the vision impaired.

The findings from this research not only give guidance for those teaching technological courses to the vision impaired, but can also be generalized to other industry skills training situations for vision impaired adults. By grouping the above components and processes, the elements presented in Table 6.2 and are recommended for maximum accessibility of many e-learning environment for vision impaired adults seeking technology-related skills.

Table 6.1: Accessible e Learning components

Learning Environment Element	Needs Addressed	Results	Recommendation for VI e-learning environments in general
Braille and Braille Displays	Access to textual learning materials	Solved problems of multiple applications open and ambiguity of speech output.	Textual material in Braille format is essential for Braille readers. Refreshable Braille displays overcome the terseness and cryptic command structure of some operating systems and programming languages.
Pegboard	Numerical representation and non decimal calculations	Solved problems of binary, octal and hexadecimal representation. Increased understanding of IP addressing and ACLs	Tactile representation of abstract concepts is recommended.
Network Dominos	Communicate complex network topologies	Achieved desired results but may be approximated with textual descriptions	Textual descriptions are recommended if possible. Tactile objects are inflexible, expensive and difficult to replicate in emote locations.
iNetSim network simulator	Simulate network configurations without the need for expensive hardware	Proof of concept successful	Application specific software should be designed as accessible. Retrospectively incorporating accessibility features is inefficient, difficult and expensive

Remote Bundle laboratory environment	Mobility Remoteness Practical experience	Solved problems of mobility and isolation without dilution of content or learning experience. Reinforced learning by practical application of theory in protected environment	Essential for accessible delivery of practical technology-based learning materials.
Virtual Classroom Remote Delivery	Mobility Remoteness, Communication	Solved problems of mobility and isolation without dilution of content or learning experience. Provided classroom facilities equivalent to traditional classrooms	Essential for accessible delivery of learning materials. Necessary for scalability. Low numbers of local vision impaired students requires that to be economical, consolidation of students is necessary.
Tactile displays Tactile Diagrams	Communicate graphical representations of information	Solved problem of communicating simple diagrammatic information	Should be avoided where possible. Textual equivalents offer greater efficiency (cost and distribution) with similar outcomes.
Haptic Pen	Communicate graphical representations of information	Poor recognition results and significant learning time involved	Not Useful due to lack of precision, excessive time to comprehend, and high development effort.
Textual Image Descriptions	Communicate graphical representations of information	Solved problem of communicating graphical information	Essential to convey meaning and content of graphical information. The hierarchical-connection model should be used in developing descriptions.
e-Labs	Emphasise particular	Solved equivalence issues with sighted learning experiences	Similar to iNetSim. Accessibility in simulation software is essential to

	learning outcomes		successful delivery.
Drag and drop interactive functions	Emphasise particular learning outcomes, Reinforce and test understanding	Solved accessibility issues with graphically based media objects	Accessibility in presentation of materials essential
Audio demonstrations	Mobility Remoteness, Lack of local equipment	Solved problem of inaccessible media objects and lack of equipment in developing countries	Essential to convey practical and visual instructions to remote locations.

Table 6.2: Generalised training environments

Elements	Details
Classroom	Virtual classroom environment accessible via the Internet is the first major requirement. This provides facilities for students to communicate not only with their instructors but also other students in real time, achieving the same results as a traditional classroom environment for the sighted.
Technical Equipment	This will be dependent on the subject matter being taught. A combination of tactile, audio, textual and remotely accessible laboratory equipment will be required. Firstly, each student will need basic assistive technologies to ensure access to the computer and the presentation of information stored on the computer. Secondly equipment associated with the delivery of the course learning materials is needed for the presentation and storage of lectures, tutorials, assessments plus any equipment-based teaching aids required. Thirdly, the equipment used for administrating and

	managing the learning environment to handle enrolments, storage of learning materials, security, communications etc. is required. Finally, any equipment associated with the learning content that provides specialist skills or knowledge included in the learning objectives and expected outcomes.
Course learning materials	All learning materials need to be presented in fully accessible forms. This means all graphical material must have textual descriptions with other tactile, audio and (possibly) haptic elements augmenting the text. All learning materials used must be tested and verified for accessibility and equivalence to materials presented to sighted students. The learning materials must also be tested to ensure compliance and achievement of educational objectives and student learning outcomes.
Assessments	Digital forms of all assessments are required. Textual descriptions of any graphical material contained within assessment items is essential. Each assessment item (test, quiz, examination) must be available on line for access by remote students. Interactive modes can be incorporated into assessment items provided they are designed for accessibility and tested to ensure full accessibility and equivalence to sighted assessment items.
Teaching Aids	The teaching required will be dependent on the subject matter being taught. Tactile devices will be needed for items that require large data sets to be memorised, or include hierarchical textual descriptions for detailed explanations. The teaching aids used in the research project described in this thesis can be modified for application in any IT-based training environment. Advice can be sought from the vision impaired to identify potential teaching aids in non IT-based environments.
Instruction and skills	Delivery by skilled instructors who are experts with the assistive technology in use is essential. Training instructors who have the same disability as the learning group is advisable, and experience in the disability group receiving instruction is preferable.

This model is not well suited to self paced learning. A major component is that of building an environment that closely resembles the traditional classroom. The audio lecture component and student interaction plays a significant role in student motivation and a sense of belonging. Peer support is a crucial aspect of learning, particularly in a group that has significant disabilities. The ability to discuss and overcome accessibility issues and foibles of applications and assistive technology was highly rated in the surveys conducted. It is also worth noting that the Cisco Academy Program was not designed to be delivered as a self paced instructional program and the instructor led aspect is emphasised.

The support of local agencies to provide mentoring, local interpretation (particularly if the local language is different to the language being used in instruction) is key to the delivery of technical training to blind and vision impaired in remote locations. Even though English is the lingua franca in technology areas, localisation is necessary, particularly for those with English as a second language. The lack of non English language support has impacted the learning of several students who do not have a local support agency, such as those in Egypt. Local agencies may also produce hard copy tactile diagrams and Braille manuals locally, reducing the cost of distributing this bulky material.

The process of developing methodologies and material for the delivery of the curricula, presented in section 3, formalised the approach taken. However, as the courses were delivered to “real” students who sincerely wished to succeed in their studies, control groups were not used to any major extent. It was considered unethical to withhold techniques such as the diagram descriptions to prove that they are a necessary item in delivery to vision impaired students. As the research progressed, details of

requirements to overcome unforeseen obstacles arose. In these cases, development of ad hoc solutions was undertaken. An example of such is the basic web accessibility (not discussed in this thesis, as web accessibility is a well researched and documented field of study). In the initial pilot, the curriculum was accessed via a large button on the welcome page. This button was a javascript function and as such was inaccessible to screen readers. To overcome the issues, a more accessible content page was developed that linked directly with the curriculum content. Techniques that proved to be unsuitable or impractical were discontinued irrespective of the effort invested. A case in point is the use of haptic devices in presenting graphical information in an accessible format. In reviewing the literature, it was noted that many researchers were of the view that existing haptic interaction devices had great potential for the vision impaired community (Brewster et al, 2000, Challis et al, 2001, Cowell et al, 1998, Fitz et al, 1999, Kirkpatrick et al, 2000, O'Modhrain, 1997, Ruspini et al, 1999, Yu et al, 2000, 2002). To test this hypothesis, an application to gauge the effectiveness and efficiency of this technology was developed. Haptic Showcase tested users ability to identify haptically, simple 2 dimensional and 3 dimensional shapes. The results (presented in section 5.1.7) were disappointing and further development in haptic interaction with network topologies ceased. However a great deal was learnt from this experiment and future possibilities in haptic interaction is discussed in section 6.2.2 and an example application is presented in Appendix H: Future possibilities in Mixed Mode Haptic-Audio Interaction.

It is arguable that the most significant finding from the work undertaken is that the reliance on graphical representation of information is the main contributing factor in the inaccessibility of learning materials for the vision impaired. The descriptive methods presented in this thesis illustrate how this may be overcome for a particular subject matter. The methods outlined here may be easily transferred to other subjects that utilise diagrams with well defined components and interrelationships such as

chemistry, computing relational diagrams, physics and some mathematics.

Much of the modification and adaptation undertaken in the presentation of the Cisco curriculum presented here is low cost, both in additional preparation and monetary terms. As such may easily be utilised for other demographics including those with other disabilities and mainstream classes. A particularly good example of the technology transfer is that of the pegboard (see section 4.5.2 and Figure 4.9). This device is in current use among several Western Australian TAFEs, schools and at Curtin University of Technology, assisting students who have difficulty conceptualising IP addressing, Access Control Lists (ACLs) and number systems. The use of textual transcription may also benefit other disability groups. Those with A.D.H.D. often utilise reading programs to reinforce the subject matter. These applications (WYNN from Freedom Scientific (http://www.freedomscientific.com/LSG/products/wynn_datasheet.asp) is one such application) utilise a bi-modal approach to reading, highlighting and vocalising text that the user is reading. Graphical information is generally not accessible to learning software due to the same limitations as exist with screen readers. Other print disabilities may also benefit from textual descriptions, such as those with dyslexia. Some severe dyslexics utilise screen readers to access electronic material. In these cases, diagrams may also be inaccessible, particularly the text labels. Use of textual descriptions and screen reading technology may help alleviate this situation. Textual descriptions may also benefit those who need to access electronic material in poor working conditions where screens may not be easily read (for example a mechanic working under a vehicle requiring access to manuals) or in portable devices where screen real estate is limited. In mobile applications spoken descriptions may augment the small displays and lack of detail in diagrammatic information that this imposes.

6.2. Future Challenges and Research Required

6.2.1. Cognition and Conceptualisation of Graphical Information by Congenitally Blind

It is apparent from the literature that little is known of how the congenitally blind visualise or conceptualise graphical information. Brown et al (2008) discusses issues in non visual presentation of diagrams by examining how sighted readers read, understand and extract information from diagrams and compare this with aural presentation. It is interesting to note that in many areas Brown et al arrived at similar conclusions to those of this study. Further study in visualisation is required to assist in developing methods to transform, efficiently and fully, information and concepts currently described by graphical means.

6.2.2. Haptic Descriptions of Graphical Media

Although the use of single point of reference haptic devices performed poorly, in terms of accuracy and speed of recognition, further research into multiple point of reference such as the Immersion Cyber Grasp system, may prove beneficial. The disadvantage of these “whole of hand” devices is cost and complexity. The Cyber Grasp system costs in excess of \$65,000US. The complexity derives from the fact that each finger must be monitored and controlled in all degrees of freedom including flex, position and force feedback. This complexity and cost made it unsuitable for inclusion in this research. Future devices will no doubt be more cost effective and given time libraries of control functions will be developed. An example is the work done by Manshad and Manshad (2008) in developing a low cost haptic glove. The combination of audio and haptic interaction may also aid in the efficiency of haptic feedback in graphical descriptions. Although this was determined to be of little use in the depiction of network diagrams (positional data is of little import in network topologies) it is a necessary factor in graphs and other diagrammatic information. An

example of the possible application of mixed mode interaction is included in Appendix H: Future possibilities in Mixed Mode Haptic-Audio Interaction. This application (developed by the author and K. Eaton) was developed to test applicability of generic tests unrelated to the eLearning environment discussed here but is useful to illustrate the concept of mixed mode interaction.

6.2.3. Automated Textual descriptions

Given the resources required to create textual descriptions of network diagrams, it would be beneficial to automate this process. The development of the TeDUB application, undertaken by Petrie et al (2002), and King et al (2004) illustrate that such systems are feasible given common definable components within the diagrams structure. Similarities in the UML diagrams handled by TeDUB and network diagrams utilised in this course exist, for example UML objects are of a defined set and interconnections must be of a standardised type. In network diagrams, the components are defined by a standard set of icons and connections. It would be necessary to have the ability to recognise, optically or otherwise, existing diagrams, extract the components and relations accurately, prior to “Graphic to text” processing. This may be achieved in a manner similar to current OCR, so that the user need not learn the intricacies of a descriptive language (e.g. XML) or be required to perform intermediary steps in the conversion process. A system capable of extracting such information and re-rendering in a hierarchical textual description would have application outside the data communications field, for example, in chemistry, two dimensional molecular structures.

6.2.4. Cloud computing

A relatively new application area in computing is “Cloud Computing”. This technology utilises thick clients to handle display and entry of information, whilst processing, data aggregation and applications are

handled by servers. The Internet, or cloud, provides connectivity between the client and services. A significant benefit of this technology is the low cost and portability of the thick client as compared to current computing platforms. However current technologies do not fully support accessibility, particularly those that utilise touch screens like the iPhone from Apple Corporation and cloud operating systems such as Microsoft's Azure (<http://www.microsoft.com/azure/default.msp>). Vanderheiden (2008) makes mention of ubiquitous accessibility and pluggable user interfaces to overcome some of the issues cloud computing may create.

With respect to eLearning for the vision impaired, cloud computing may present significant issues in the future. Many thick clients have limited screen real estate and/or utilise touch screen technology. It may be argued that cloud computing is the way forward for eLearning as may be seen in the popularity of podcast lectures and course material. (Downes 2005, Gualtieri, 2009) This points toward a trend in smaller, lightweight and limited processing power (demands of TTS engines may then become an issue) devices that may access curriculum at the students' convenience. Recent research by T.V Raman (Raman, 2009) and Kane et al (Kane et al, 2008) offers some direction for the development of accessible touch screen interfaces for the vision impaired.

As teaching and learning moves to a more distributed and "virtual world" environment, the issues in making this technology accessible in the delivery of education becomes increasingly important.

6.2.5. Braille Literacy Levels

Study of Braille literacy and the effectiveness of Braille in learning requires a greater rigor as noted by Ryles (1996). As stated previously, the majority of published work on levels of Braille literacy and its impact on vision impaired learners and workers is based on case studies and

practitioner experience. The following questions (with respect to the vision impaired, although they have some relevance to the sighted community) must be asked:

- Does Braille literacy improve understanding of written material?
- Does the availability of high quality voice based texts remove the necessity of knowing the Braille formats?
- Is listening the same as reading?

6.2.6. The Effect of Prior Learning and Experience on Vision Impaired Students Success Rates

During the course of this study, it was noted that those vision impaired students with prior experience in ICT coped better with the course material than those who entered with a rudimentary knowledge. However, no formal evaluation of outcomes compared to commencement knowledge/experience was undertaken. Understanding of the vision impaired learner may be advanced by, in future classes, having students undertake rigorous testing on experience and knowledge of the subject area prior to commencement and comparing this result with the final course outcomes and student results.

6.2.7. Expanding Available Accessible Curricular

Whilst ICT and network administration employment has shown to be suitable for people with vision impairment, there is little published on what forms of employment are suitable for those with severe vision loss. There is a need to identify profession that do not overly rely on vision and to examine teaching methods related to these occupations to assess the suitability of conversion to accessible formats.

6.3. Conclusion

It may be determined from the final exam results (as illustrated in Figure 5.9) and the number of graduates in 2006 and 2007 (see Table 6.3), that students with severe vision impairment are capable of achieving industry standard qualifications, to a similar standard as their sighted counterparts, if material is presented in an accessible format.

Table 6.3: Intake and graduates by year

Year	Number of enrolled students	Graduates
2006	19	19
2007	25	24
2008	109	N/A ¹²

¹² 2008 course is continuing at the time of writing. Figures taken at end of term 3 do not include those completing or withdrawing after completion of terms 1 and 2.

Since the inception of this research project in 2003, over 160 blind and vision impaired students have enrolled in the Cisco Academy for the Vision Impaired, illustrating the demand appropriateness of providing technical training tailored for delivery to this demographic. The adoption of the textual descriptions by the Cisco Academy Program for inclusion in the on line delivery of the curriculum is a step towards accessible learning but as this research has shown, the presentation of graphical information is a major issue in accessibility but not the only one. This research has shown that although the vision impaired have specialised needs in the provision of an accessible eLearning environment, a number of the solutions developed may have application to other disability groups. The components and processes developed in this research combine to provide a holistic solution to the problems faced by vision impaired students seeking recognised skill and knowledge sets. Current curriculum designers generally do not incorporate fully accessible solutions into mainstream eLearning courses. A change in the curriculum designers' approach and the teachers' methods are required for education to be made available for all.

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8. Appendix A: A Short History of Training the Vision Impaired at Curtin University of Technology

In 2002, Curtin University commenced offering the Cisco Certified Cisco Network Administrator course to mainstream (sighted) students as part of the Bachelor of Technology (Computer Systems & Networking) degree program. The Cisco Academy operates through the Department of Electrical and Computer Engineering, and provides a number of courses from the Cisco Networking Academy Program including the CCNA course, Fundamentals of Network Security, Fundamentals of Wireless LANs, IT Essentials I and II and Fundamentals of Unix. The Cisco training programs offered provide an opportunity to pursue IT curricula that extends beyond the normal Cisco systems programs conducted through online instructor-led training and hands-on laboratory exercises by combining Cisco provided curricula with traditional university lectures and tutorials covering related theoretical aspects of technology.

In 2004 four vision impaired students expressed an interest in entering the Bachelor of Technology program. These four students faced significant problems with accessibility to the Cisco course on-line materials as much of the on-line materials were not accessible to non-sighted users.

It was in extending the Cisco courses to vision impaired students that the author encountered teaching and learning challenges. It is important to note that the Cisco Network Program is based on instructor-led training and does not permit remote delivery, but does offer a style of blended distance learning where students attend “intensive” lab sessions for several consecutive days, whilst studying the on line material remotely.

During the intervening period since 2002, a number of vision impaired students have entered the Bachelor of Technology (Computer Systems & Networking) course at Curtin University with the total number of vision impaired students (in the CAVI program) increasing to 146 in the year 2008.

9. Appendix B: Causes of vision impairment and their impact

Blindness and Low Vision

Early figures released in 1993 estimated there were approximately 150 million vision impaired people globally, and the World Health Organisation (WHO) approximated that 38 million were blind, and 110 million had severe vision impairment (Ho and Schwab, 2001). 480,000 people in Australia are blind or are vision impaired (ABS, 2004). Many within this group are older than 65, because vision impairment is commonly age related. The most common cause of blindness worldwide is due to cataracts. The majority of cataract vision impairment cases are in Third World Countries where corrective surgery is not available. In developed countries such as Australia, most vision loss tends to be due to age related conditions that cannot be corrected. For the purpose of this research, it was determined that the definition of legal blindness would be taken from the legislative guidelines to social security law as that published by the Commonwealth Department of Family and Community Services as follows:

- Visual acuity (1.1 V 5.0) on the Snellen Scale after correction by suitable lenses must be less than 6/60 in both eyes, or
- Constriction to within 10 degrees of fixation in the better eye irrespective of corrected visual acuity, or
- A combination of visual defects resulting in the same degree of visual impairment as that occurring in the above points.

(source: <http://www.facs.gov.au/guide/ssguide/11p210.htm>)

Prior research has shown that vision loss trebles with each decade of life, impacting the opportunity for independent living and quality of life (Taylor et al., 2006).

Not everyone who is blind or vision impaired has the same type or level of visual impairment. While some blind people have very little or no vision, most vision impaired people have some level of useful vision.

Demographics of Vision Impairment

Blindness and vision loss in developed countries increases threefold for each decade for individuals over the age of 40, and the number of vision impaired or blind people will double in just 20 years (Taylor and Keeffe, 2001).

In Australia the Australian Bureau of Statistics (ABS) is responsible for recording and reporting levels of vision impairment. The ABS (2004) reports in excess of 9.7 million Australians with diseases of the eye and adnexa. Adnexa is a medical expression that refers to organ appendages. In relation to the eye, adnexa refers to disease of eye appendages, the eyelids, extraocular muscles, and lacrimal glands. The extraocular muscles are the muscles that control the movements of the eye. The lacrimal glands produce and drain tears to the eye. Further explanations of common eye conditions and levels of blindness are provided in this appendix.

Eye diseases and adnexa has resulted in 480,000 Australians being visually impaired in both eyes with visual acuity of less than 50% of normal (6/12). Approximately 50,000 of these are blind with visual acuity

of less than 10% of normal (6/60) or have a visual field of less than 10 degrees diameter. A normal field of vision is 180 degrees. A person who is totally blind has no useful vision at all (ABWA, 2006).

While nearly 300,000 Australians have visual impairment because of under-corrected refractive error, approximately 180,000 Australians have visual impairment due to other causes that cannot be corrected by spectacles (ABS, 2000). Taylor et al. (2005) predict that because visual impairment is highly age correlated the 5.4% of current 40 years of age population will increase to over 6.5% by the year 2024 resulting in an increase of visually impaired Australians from 480,000 (in 2004) to 800,000.

Economic Impact of Vision Loss

Blindness and vision loss have a huge and broad ranging effect on our society (Taylor et al., 2006). With the majority of blind and vision impaired individuals being located in developing countries, research has been undertaken to link economic development with sight disabilities (see Ho and Schwab, 2001; Javitt et al., 1996; Schwarb and Taylor, 1993; Sommer, 1996; Thylefors et al., 1987, 1998; World Bank, 1993). The Ho and Schwarb study reported the per capita income (in US\$) in less developed countries was below \$635 compared with \$7911 or more in more developed nations. Their findings were that the economic development in nations and/or regions with a per capita income of less than \$2000 could dramatically reduce the impact of preventable blindness.

In Australia alone, vision disorders cost an estimated A\$9.85 billion in 2004, comprising \$4.8 billion in the loss of wellbeing, \$1.8 million in

direct health system costs and \$3.2 billion in indirect costs (Taylor et al., 2006).

In response to the global problems of blindness and vision impairment the WHO and International Agency for the Prevention of Blindness (IAPB) launched the *Vision 2020: the Right Sight* initiative in 1999 (WHO, 1997). This initiative aims to eliminate avoidable blindness in the world by 2020 and targets the leading causes of visual impairment globally (Pizzarello et al., 2004). Successful completion of the WHO Vision 2020 project is estimated to lead to the prevention of blindness of 429 million blind person-years, where a blind person-year is defined as 1 year of blindness for an individual (Frick and Foster, 2003). Using conservative assumptions Frick and Foster estimate this would result in a decrease of over \$151 billion (2003 present value) in economic loss at an average of \$7.5 billion per year.

Common Eye Conditions and Levels of Blindness

There are different forms of vision impairment and each form can significantly affect the learning opportunities of the affected person. Vision impairments range from the congenitally blind, those who are blind from birth or from a very early age, through to the adventitiously blind, those who lose their sight in varying degrees as a result of accidents, disease or the effects of medication. It is important to recognise these different forms of vision impairment in order to address the particular and different needs of each individual. Some forms of sight impairment can be treated resulting in improved vision and in some cases the impairment may be reversed and vision corrected. Congenital blindness is normally permanent. The difference between temporary and partially sighted students and permanently blind students is considerable, particularly

with relation to student expectations and staff support as the two groups exhibit different study patterns and difficulties (Shepherd, 2001). For the purpose of this study, temporary blindness will not be considered.

Visual impairment can be broadly defined as a limitation in one or more functions of the eye or visual system. Low vision refers to a vision loss that is severe enough to impede performance of vocational, recreational and/or social tasks, but still allows some useful visual discrimination. Low vision cannot be corrected to normal vision by regular eyeglasses or spectacles. The majority of people who are legally blind are included within the low vision classification.

The most commonly occurring impairments of vision relate to visual acuity, visual field and vision colour. Visual acuity is defined as the sharpness or clarity of vision. Visual field is defined by the ability to detect objects to either side, or above and/or below the direction in which the person is looking. Colour vision is defined by the ability to recognise an object's true colour.

In Australia, the standard measure for normal vision is defined as being 6/6. The previous imperial measure for normal sight was defined as 20/20. Degrees of visual impairment are measured using a scale, where the first number is the furthestmost distance at which the person can clearly see an object, and the second number is the distance at which a person with normal vision could see the same object and detail. For example, 3/6 vision means that the person can clearly see at 3 metres or less an object that a person with unimpaired vision could see at 6 metres or less. Using this standard measure, legal blindness in Australia is defined as distance vision acuity of $<6/60$ in the better eye with correction, or a visual field of less than 10 degrees. Those with legal blindness may have either one of these limitations to vision or they may

have both. Correction is the terminology indicating the use of spectacles or contact lenses. These definitions were created primarily for purposes of determining welfare benefits and access to special services (A guide to Australian eye health data 2007) Total blindness refers to people who are unable to see light. Visual field is measured in terms of degrees from the point of fixation. A visual field of less than 10 degrees ($<10^\circ$) means that the person can only see in a visual field of less than 10 degrees radius from the point of fixation. Colour blindness, which is a genetic inability, or, more commonly, reduced ability to distinguish differences in hue, is a visual defect resulting in the inability to distinguish colours.

For the purpose of this thesis, vision impairment is defined as an acuity of less than 3/6 in the better eye with, if applicable, correction. Blindness refers to the person being capable of light perception or the total inability to perceive light. Colour blindness is of some interest to this study but is not treated in depth and where applicable will be clearly stated that the area under discussion relates specifically to colour blindness. In those instances, the colour hue deficiency, if relative to the subject matter, is specified and explained.



Figure 9.1: simulated vision with "Normal" eyesight (Source <http://www.nei.nih.gov/>)

Colour blindness affects predominantly the male population with approximately 8% of men and 0.5% of women experiencing some difficulty in colour perception. Colour blindness is usually an inherited sex-linked characteristic, transmitted through, but recessive in, females. Acquired colour blindness results from certain degenerative diseases of the eyes. Most of those with defective colour vision are only partially colour blind to red and green having a limited ability to distinguish reddish and greenish shades. Those who are completely colour blind to red and green see both colours as a shade of yellow. Completely colour blind individuals can recognize only black, white, and shades of grey. Colour blindness is usually not related to visual acuity.

There are many congenital (existing at birth) eye conditions that are inherited, caused during pregnancy, or occur during birth. Some of these conditions may cause total and irreversible blindness while others may be treatable or may leave some vision.

Refractive Errors

Refractive errors occur when the cornea is irregularly shaped (astigmatism), or the eye is too long (hyperopia) or too short (myopia). Myopia causes distant images to appear blurred whilst hyperopia causes near objects to appear blurred.

Astigmatism is a condition in which the uneven curvature of the cornea may blur and distort both distant and near objects. This causes light rays to have more than one focal point and focus on two separate areas of the retina, distorting the visual image.

Refractive errors may often be corrected by eyeglasses or contact lenses. Even though these are safe and effective methods for treating refractive errors, refractive surgeries are becoming an increasingly popular option, even though there is a slight risk associated with surgery. (source: <http://www.fda.gov/cdrh/lasik/risks.htm>)



Figure 9.2: Simulated vision with Myopia (Source <http://www.nei.nih.gov/>)

Age Related Macular Degeneration

Macular degeneration is the leading cause of vision loss amongst older people. Also known as Age Related Macular Degeneration, or ARM, macular degeneration results from degenerative changes to the macula. The macula is that part of the retina responsible for clear, sharp vision. The macula is used for seeing detail when reading, writing, watching television and recognising faces. Therefore someone with macular degeneration experiences a loss of central vision whilst peripheral vision remains normal. There are several forms of macular degeneration. The most common type of macular degeneration is dry macular degeneration

where the tissue of the macula stops working effectively because the tiny blood vessels fail to nourish it properly. Dry macular degeneration is, for some people, a part of the ageing process. Another type of macular degeneration is wet macular degeneration where fluids from newly formed blood vessels leak into the retinal tissue and cause vision loss.

If wet macular degeneration is detected early, it can be treated with laser therapy that can prevent further vision loss but this procedure does not restore sight. There is no treatment for the dry form of Age Related Macular Degeneration.

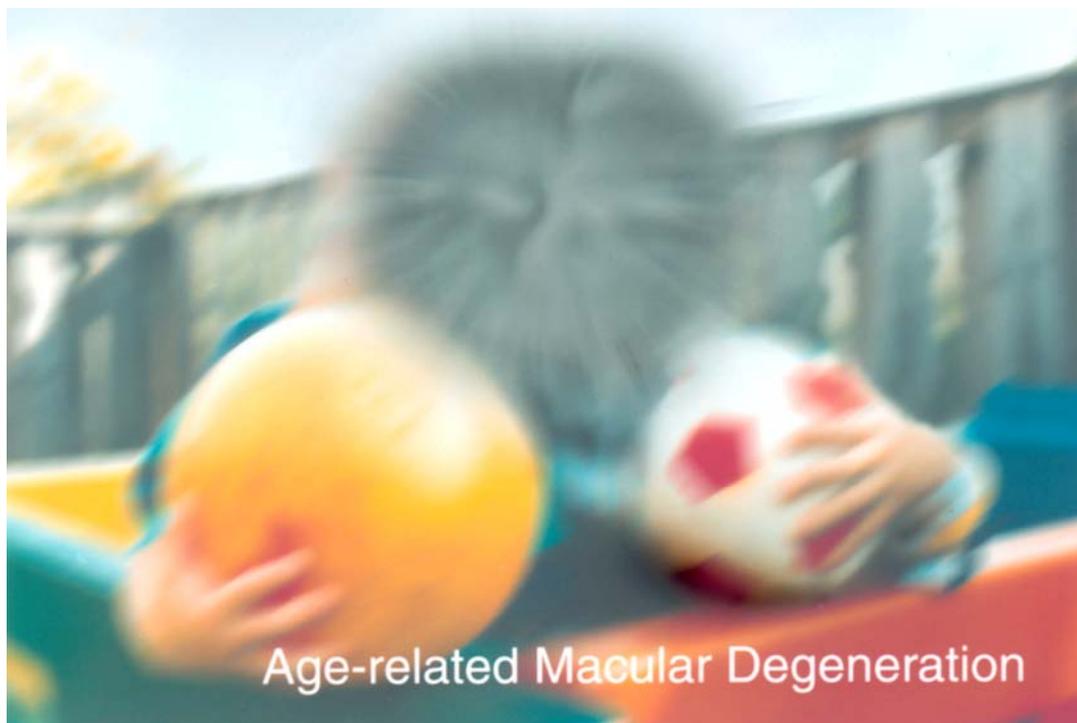


Figure 9.3: Simulated vision with Macular Degeneration (source <http://www.nei.nih.gov/>)

Cataracts

Cataracts are a cloudiness or opacity of the lens of the eye. Infection, drugs, chemical or physical injury to the eye and exposure to intense heat or radiation can cause cataracts. Cataracts typically occur with advancing age, but can be present at birth. The specific causes of cataracts are uncertain. Blurred vision is an early symptom of cataracts, a brighter light may be required for reading and glare can cause hazy vision particularly on bright sunny days. A person with cataracts may have to hold reading material closer than usual and may experience double vision, especially when looking at light sources. Frequent changing of eyeglasses may indicate that a cataract is developing.

Surgery is the only treatment for cataracts. During surgery an ophthalmologist removes the clouded lens that is replaced with a plastic lens implant. While the majority of cataract surgery procedures are successful, normally patients will still need to wear glasses for distance and/or reading.



Figure 9.4: Simulated vision with Cataracts (source <http://www.nei.nih.gov>)

Diabetic Retinopathy

Diabetes is a condition that interferes with the body's ability to use and store sugar. Over time, diabetes causes change in the small blood vessels that nourish the retina. Diabetic caused changes may include leaking of blood, development of new brush like branches of the vessels, and enlargement of certain parts of the blood vessels.

Diabetic retinopathy is damage caused to the retina of the eye due to complications bought about by irregular metabolism and harmfully high blood sugar levels. Medically, the term for high blood sugar levels is hyperglycaemia. Hyperglycaemia results from either low levels of the hormone insulin or from abnormal resistance to the effects of insulin or inappropriate compensation of the body's insulin secretion levels.

Diabetic retinopathy can seriously affect vision and may cause blindness. In the early stages of diabetic retinopathy, there may be blurring of both central and peripheral vision. As diabetic retinopathy progresses, there may be cloudiness and blind spots or floaters in the vision. In advanced stages of diabetic retinopathy, scar tissue forms causing additional distortion and blurred vision. Retinal detachment may then follow. Laser and other surgical procedures may reduce the progression of the disease and decrease the risk of vision loss. Not every person with diabetes develops retinopathy, but the likelihood of retinopathy increases after having diabetes for several years.



Figure 9.5: Simulated vision with Diabetic Retinopathy (source <http://www.nei.nih.gov/>)

Glaucoma

Glaucoma is an eye condition in which the optic nerve is damaged by increased or raised pressure within the eye. Intra-ocular pressure is not directly related to blood pressure. "Normal" pressure within the eye occurs when the amount of fluid produced by the eye balances the amount draining away. If the fluid cannot escape because the channels become narrowed or blocked, then intra-ocular pressure rises. This increased pressure damages the optic nerve that sends visual information to the brain. Damage may progress very slowly and destroy vision gradually, usually commencing by affecting peripheral vision. There is no pain and the eyesight will seem to be unchanged. Often one eye compensates for the deficiency in the other eye and the person may remain unaware of any problem until a majority of nerve fibres have been destroyed causing a large amount of vision impairment. If treatment is delayed, these defects can become permanent and severely affect vision (ABWA, 2006).



Figure 9.6: Simulated vision with Glaucoma (Source <http://www.nei.nih.gov/>)

Nystagmus

Nystagmus is an involuntary rhythmic shaking or wobbling of the eyes. The term nystagmus is derived from the Greek word, "nmstagmos", which was used to describe the wobbly head movements of a sleepy or inebriated individual. (Windsor, 2004) Nystagmus causes blurred vision, difficulty in scanning and tracking, and problems with depth perception. Nystagmus is caused by an abnormal function in that area of the brain that controls eye movement and may be congenial or develop at some later time. Sufferers may gain improved vision with the use of low vision aids, magnifiers, or null point training. Null point training, conducted by eye care professionals, teaches how to train one's eyes towards that direction with the clearest vision (Vision Australia, 2008).

Retinitis Pigmentosa

Retinitis Pigmentosa (RP) refers to a group of inherited diseases that cause degeneration of the retina. People with RP often have tunnel vision and poor night vision. As the disease progresses central vision is lost.

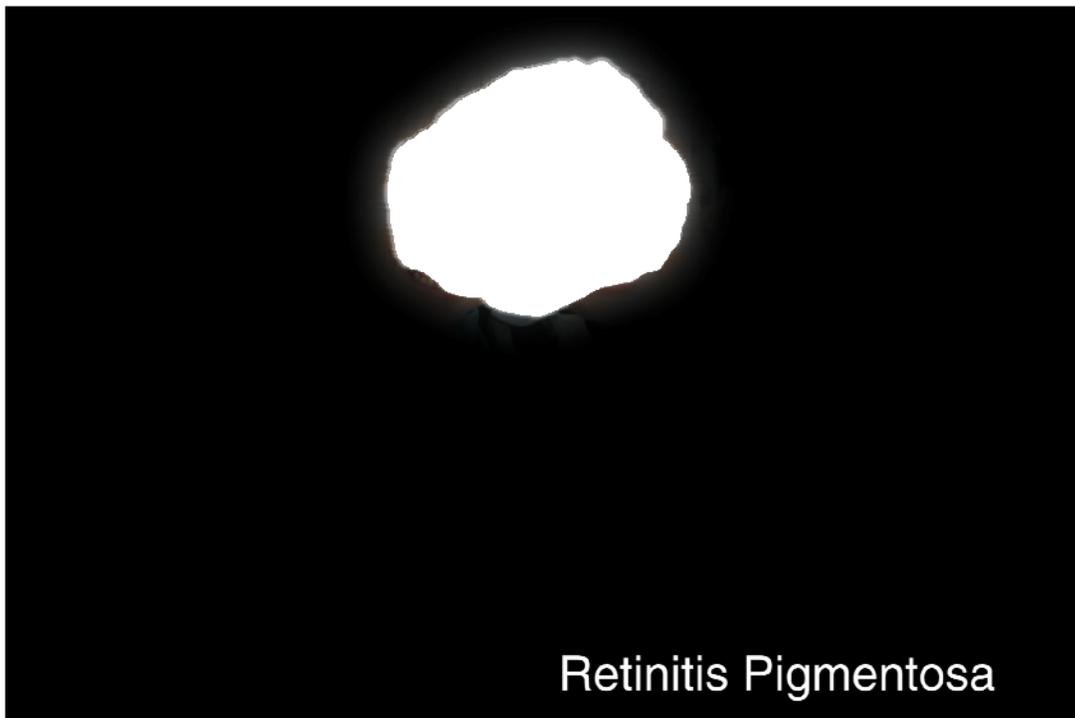


Figure 9.7: Simulated vision with Retinitus Pimgmentosa (Source <http://www.nei.nih.gov/>)

Retinopathy of Pre-maturity

Retinopathy of Pre-maturity is a condition that appears soon after birth, and more generally in premature infants exposed to high oxygen levels. It involves the abnormal development of blood vessels in the retina and can lead to retinal detachment and blindness.

10. Appendix C: Curricula Utilised – The Cisco Academy Program

IT Essentials 1

The first entry level course is IT Essentials 1: PC Hardware and Software. There are no prerequisite expectations placed on students enrolling into this course. The curriculum covers the fundamentals of computer hardware and software as well as advanced concepts. The curriculum objective of this course is to prepare students for entry-level positions of employment in the Information Technology field. Table 10.1 lists the topics covered in IT Essentials I.

Table 10.1: CISCO COURSE – IT ESSENTIALS I TOPICS

Course Outline	
Module 1.	Information Technology Basics
Module 2.	How Computers Work
Module 3.	Assembling a Computer
Module 4.	Operating System Fundamentals
Module 5.	Windows 9x Operating Systems
Module 6.	Windows NT/2000 Operating Systems
Module 7.	Windows XP Operating Systems
Module 8.	Multimedia Capabilities
Module 9.	Advanced Hardware Fundamentals and Servers
Module 10.	Networking Fundamentals
Module 11.	Printers and Printing

Module 12.	Preventative Maintenance and Upgrading
Module 13.	Troubleshooting PC Hardware
Module 14.	Troubleshooting Software

Students successfully completing the IT Essentials 1 course may enroll into the IT Essentials 2 course.

IT Essentials 2

Before students commence IT Essentials 2, they should have completed the previous course, IT Essentials 1. Although this is not a requirement it is strongly recommended by the program developers. The curriculum provides an intensive introduction to networking fundamentals and multi-user network operating systems. The curriculum objectives address a range of topic areas including: Network Operating System basics, Network Operating System components, Network design and topology, Internet connection, Network services including remote access and directory services, NIC and IP address configuration, NOS installation planning, Windows 2000 installation, Linux installation and troubleshooting, and Network security plan development.

Table 10.2 shows the structure of the IT Essentials 2 course. The full details relating to the scope and sequence notes for this course are available on-line at the Cisco web site (<http://cisco.netacad.net/>).

Table 10.2: CISCO COURSE – IT ESSENTIALS 2 MODULES

Course Outline	
Module 1.	Operating System Fundamentals
Module 2.	Introduction to Networking
Module 3.	Physical Components of a Network
Module 4.	TCP/IP Networking
Module 5.	Overview view of Network Services
Module 6.	Introduction to Network Operating Systems
Module 7.	Installations and Boot Process Overview
Module 8.	Windows 2000 Professional
Module 9.	Linux Installation Procedures
Module 10.	Linux Administration
Module 11.	Advanced NOS Administration
Module 12.	Installing and Maintaining Hardware in Linux
Module 13.	Troubleshooting the Operating System
Module 14.	Network Security

Due to the synergy of content, it is beneficial for students to undertake the Certified Cisco Network Associate course in conjunction with IT Essentials 2. This may be done sequentially (preferably with IT Essentials 2 the precursor) or concurrently.

Certified Cisco Network Associate 1

The Certified Cisco Network Associate (CCNA) Courses 1 through 4 of the Academy program consist of the equivalent to 280 hours of instruction and provide students with a basic foundation in networking. Students who successfully complete this portion of the program are eligible to earn Cisco Certified Network Associate (CCNA™) certification (Source:

http://www.cisco.com/web/learning/netacad/course_catalog/CCNA.html).

Before students commence the Certified Cisco Network Associate 1 course, they should have a Reading Age Level (RAL) of 13, possess basic computer literacy and awareness of the Internet. Cisco also advises that it is beneficial, but does not require students have prior experience with computer hardware, binary maths, and basic electronics as well as some background knowledge in cabling.

The CCNA 1 focuses on networking basics and is the first of four courses. The curriculum provides network engineering essentials. The curriculum objectives address a range of topic areas including: Network terminology, Network protocols, Local Local-area networks (LANs), Wide-area networks (WANs), Open System Interconnection (OSI) model, TCP/IP protocol, Cabling, Cabling tools, Routers, Router configuration, Ethernet, Internet Protocol (IP) addressing, and Network standards.

Table 10.3 shows the structure of the CCNA1 course. The full details relating to the scope and sequence notes for this course are available online at the Cisco web site (<http://cisco.netacad.net/>).

Table 10.3: CISCO COURSE – CCNA1 MODULES

Course Outline	
Module 1.	Introduction to Networking
Module 2.	Networking
Module 3.	Networking Media
Module 4.	Cable Testing
Module 5.	Cabling LANs and WANs
Module 6.	Ethernet Fundamentals
Module 7.	Ethernet Technologies
Module 8.	Ethernet Switching
Module 9.	TCP/IP Protocol Suite and IP Addressing
Module 10.	Routing Fundamentals and Subnets
Module 11.	TCP/IP Transport and Application Layer

The natural progression from CCNA1 is for students to enrol into the Certified Cisco Network Associate 2 course.

Certified Cisco Network Associate 2

The Certified Cisco Network Associate 2 course focuses on routers and routing basics. The curriculum provides routers and routing configuration essentials. The curriculum objectives address a range of topic areas including: initial router configuration, Cisco IOS Software management, routing protocol configuration, TCP/IP, and access control lists (ACLs).

Students having successfully completed CCNA2 should be able to demonstrate their competencies in the following areas: Install and

configure Cisco switches and routers in multiprotocol internetworks using LAN and WAN interfaces, provide level 1 troubleshooting services, improve network performance and security, perform entry level tasks in the planning, design, installation, operation, and, troubleshooting of Ethernet and TCP/IP Networks.

Table 10.4 details the structure of the CCNA2 course. The full details relating to the scope and sequence notes for this course are available online at the Cisco web site (<http://cisco.netacad.net/>).

Table 10.4: CISCO COURSE – CCNA2 MODULES

Course Outline	
Module 1.	WANs and Routers
Module 2.	Introduction to Routers
Module 3.	Configuring a Router
Module 4.	Learning about Other Devices
Module 5.	Managing Cisco IOS Software
Module 6.	Routing and Routing Protocols
Module 7.	Distance Vector Routing Protocols
Module 8.	TCP/IP Suite Error and Control Messages
Module 9.	Basic Router Troubleshooting
Module 10.	Intermediate TCP/IP
Module 11.	Access Control Lists

The natural progression from CCNA2 is for students to enrol into the Certified Cisco Network Associate 3 course.

11. Appendix D: User Guide: Pegboard

A basic guide to pegboard users is provided for all students as a text document (see Table 11.1).

Table 11.1: PEGBOARD USER GUIDE

PEGBOARD USER'S GUIDE V0.1

Before continuing ensure that you have the following items:

1 Pegboard.

A box of pegs.

A number of long pieces of plastic with pegs on each end.

Orientation:

The pegboard is wider than it is high.

Place the pegboard on the desk in front of you ensuring that the cut slots run vertically.

You will notice that the board consists of 3 lots of 32 holes. Every 8 holes there is a line that divides the pegboard.

There are 3 rows of holes into which pegs can be placed.

The pegboard is designed to assist you with binary and hexadecimal calculations as well as base conversion.

Concentrate on the top row of holes; i.e. those that are furthest away from you.

Each hole represents a binary digit. The right-most hole represents 2^0 and the left-hand most hole represents 2^{31} .

The lines that are etched into the pegboard every 8 holes are designed to show you where byte boundaries occur.

If you place a peg into a hole; that represents a binary 1. A hole without a peg is worth zero.

For example: If the right hand 3 holes have peg, peg and blank; this represents the binary number 110 or decimal 6.

There are 3 rows of pegs. This allows you to do binary calculations on the pegboard. Place your 2 operands in the first 2 rows, apply your operator and place the result in the bottom row.

This will allow you to do binary addition, subtraction, and also logical operations such as and or or.

Also included with the pegboard are a set of long strips with pegs at the end. This is to allow you to fill up a whole byte boundary (i.e. 255) without having to put 8 pegs into the board.

The pegboard is especially useful when calculating network and broadcast addresses. Place your address in the top row; (converting it to binary first) and place your netmask in the second row. And the mask with the ip address and you will obtain the network address of the ip address and mask given in the top two rows.

With this basic introduction to the pegboard, respondent students engaged in a survey to determine the usefulness of the pegboard.

12. Appendix E: Cisco “Discovery” Curriculum

The Cisco Network Academy Program released updated curricula for the CCNA in 2007. Two versions were made available, Discovery; for technical colleges, and Exploration; for University level courses. Work conducted during this study in the area of textual descriptions of graphical information was embedded in the second maintenance release of the Discovery version. The new curricular are available in “standard” or “accessible” version. Of note is that there is not two versions of the content but separate mechanisms for delivery to the client side. Examples of the accessible delivery are depicted in Figure 12.1.

5.1.3 Parts of an IP Address

Page 1:
The logical 32-bit IP address is hierarchical and is made up of two parts. The first part identifies the network and the second part identifies a host on that network. Both parts are required in an IP address.

As an example, if a host has IP address 192.168.18.57 the first three octets, (192.168.18), identify the network portion of the address, and the last octet, (57) identifies the host. This is known as hierarchical addressing because the network portion indicates the network on which each unique host address is located. Routers only need to know how to reach each network, rather than needing to know the location of each individual host.

Another example of a hierarchical network is the telephone system. With a telephone number, the country code, area code and exchange represent the network address and the remaining digits represent a local phone number.
[Display Media Text Transcript](#) | [Display Visual Media](#)

5.1.3 Parts of an IP Address
Two Diagrams

Diagram 1, Image

The diagram depicts two network clouds. Each cloud contains a similar network with three hosts connected to a switch. Each switch connects to a router. The routers in each cloud connect to each other. Each device has its own IP address.

The key concept is that in the first cloud all devices are on the 192.168.18.0 network, and all devices in the second cloud are on network 192.168.5.0.

More Information Pop-up
Multiple logical networks on one physical network: With IP addressing, multiple logical networks can exist on one physical network, if the network portion of their host addresses is different. Example: three hosts on a single physical local network have the same network portion to their IP address (192.168.50), and three other hosts have a different network portion (192.168.70). The hosts with the same network number in their IP addresses will be able to communicate with each other, but will not be able to communicate with the other hosts without the use of routing. In this case, we have one physical network and two logical IP networks.

Page 2:
[Display Media Text Transcript](#) | [Display Visual Media](#)

Figure 12.1: Accessible Discovery curriculum with "Display visual media" left and "Display media text transcript" right

13. Appendix F: Sample Tactile Graphic Diagrams

Figure 13.1: (overleaf) Tactile waveforms representing various encoding methods

Figure 13.2: (overleaf) Tactile representation of addition of waveforms

Figure 13.3: (overleaf) Tactile representation of binary streams and frame structure

Figure 13.4: (overleaf) Tactile representation of a network diagram.

Note the lack of tactile detail in Figure 13.4. This example has too greater detail and illustrates the difficulty in producing tactile diagrams for the subject matter in this research.

14. Appendix G: Packet Tracer Feature List

- **Packet Tracer Workspaces:** Packet Tracer has two workspaces: logical and physical. The logical workspace allows users to build logical network topologies by placing, connecting and clustering virtual network devices. The physical workspace provides a physical dimension of the logical network, giving a sense of scale and placement in how network devices such as routers, switches, and hosts would look in a real environment. It provides geographic representations of networks, including multiple cities, buildings, and wiring closets.
- **Packet Tracer Modes:** Packet Tracer uses two operating modes to visualize the behaviour of a network: real time mode and simulation mode. In real time mode the network behaves as real devices do, with immediate real time response for all network activities. In simulation mode the user can see and control time intervals, the inner workings of data transfer, and the propagation of data across a network. This helps students understand the fundamental concepts behind network operations.
- **Tutorials:** Familiarize users with the product features and teach users step-by-step how to engage in simulations.
- **Help:** Familiarizes users with the Packet Tracer interface, functions, and features. Annotated screenshots are used to aid understanding. Also includes important notes and tips.
- **Modular Devices:** Visually simulate hardware and offer the ability to insert interface cards into modular routers and switches, which then become part of the simulation.
- **Protocols:** Packet Tracer supports HTTP, Telnet, SSH, TFTP, DHCP, and DNS; TCP and UDP; IPv4, IPv6, ICMPv4, and ICMPv6; RIP, EIGRP, multi-area OSPF, static routing, and route redistribution;

- Ethernet/802.3, 802.11, HDLC, Frame Relay, and PPP; ARP, CDP, STP, RSTP, 802.1q, VTP, DTP, and PAgP.
- Multiuser functionality: Packet Tracer 5.0 is a network-capable application, with a multiuser peer-to-peer mode that allows collaborative construction of virtual networks over a real network. The multiuser feature affords exciting collaborative and competitive interactions, providing the option to progress from individual to social learning and features opportunities for collaboration, competition, remote instructor-student interaction, social networking, and gaming.
- Activity Wizard: Allows users to become authors, setting up scenarios, adding instructional text, creating initial and final network topologies, grading, and feedback.
- Additional Features
 - Lab grading function
 - International language support
 - Supports the majority of protocols and technologies taught in the following curricula: CCNA v3.1, CCNA Discovery, and CCNA Exploration. May also be used to teach concepts from IT Essentials and CCNP Building Scalable Internetworks.

(Cisco Systems, 2008a)

15. Appendix H: Future possibilities in Mixed Mode Haptic-Audio Interaction

An application was developed by the author and K. Eaton to assess usability issues in haptic interaction and possible benefits of combining haptic and audio feedback into testing environments for the blind and vision impaired. In each of the questions presented to the user in a format where the text may be read by a screen reader, including the answer selection and question selector. The graphical area is explored with the haptic device, an Omni Phantom. When a point of interest is touched, an audio description is spoken.

A brief explanation of the relevant audio follows.

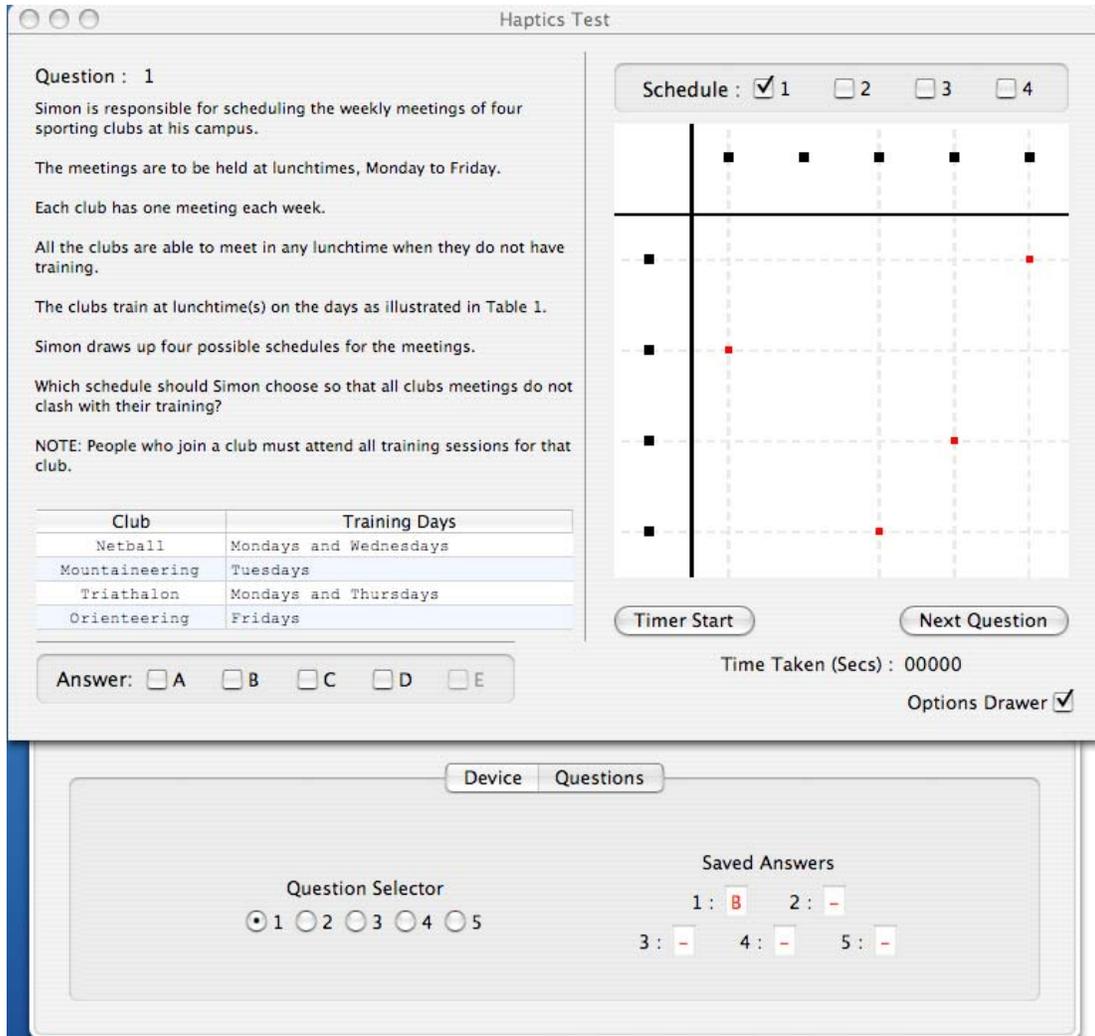


Figure 15.1: HapticTest sample question 1

Referring to Figure 15.1, when a black square is intercepted by the haptic pen, the user feels the point as a gravity well and the corresponding day or sport is spoken. The grid lines haptically guide the pen to the corresponding red point, which appears as a gravity well.

Haptics Test

Question : 2

Figure 1 shows the results of a study carried out in the USA. Approximately 250,000 men were followed over 12 years, and for those who died, the cause of death was established. The graph shows the variation with average alcohol intake of the mortality rate for three such causes, together with the variation in mortality rate from all causes. Coronary Heart Disease (CHD) is a particular and common cardiovascular disease. Mortality rates are shown as a proportion of the deaths that occur with zero alcohol intake. Also shown are the average alcohol intakes for USA and France.

According to Figure 1 (right), compared with men who consume little or no alcohol, men who regularly consume 18 g of alcohol (about one standard drink) per day are most likely to show mortality rates that are:

A - decreased for CHD and accidents, and increased for cancer.
 B - decreased for CHD and cancer and increased for accidents.
 C - decreased for CHD and unchanged for accidents and cancer.
 D - increased for CHD and accidents, and increased for cancer.
 E - increased for CHD and unchanged for accidents and cancer.

Answer: A B C D E

Time Taken (Secs) : 00000

Options Drawer

Device Questions

Question Selector

1 2 3 4 5

Saved Answers

1: B 2: -
 3: C 4: - 5: -

Figure 15.2: HapticTest sample question 2

Question 2, shown in Figure 15.2, has the graph lines rendered as grooves. As the haptic device traverses a particular curve, the curve label is vocalised. Axis graduations may also be felt and titles spoken.

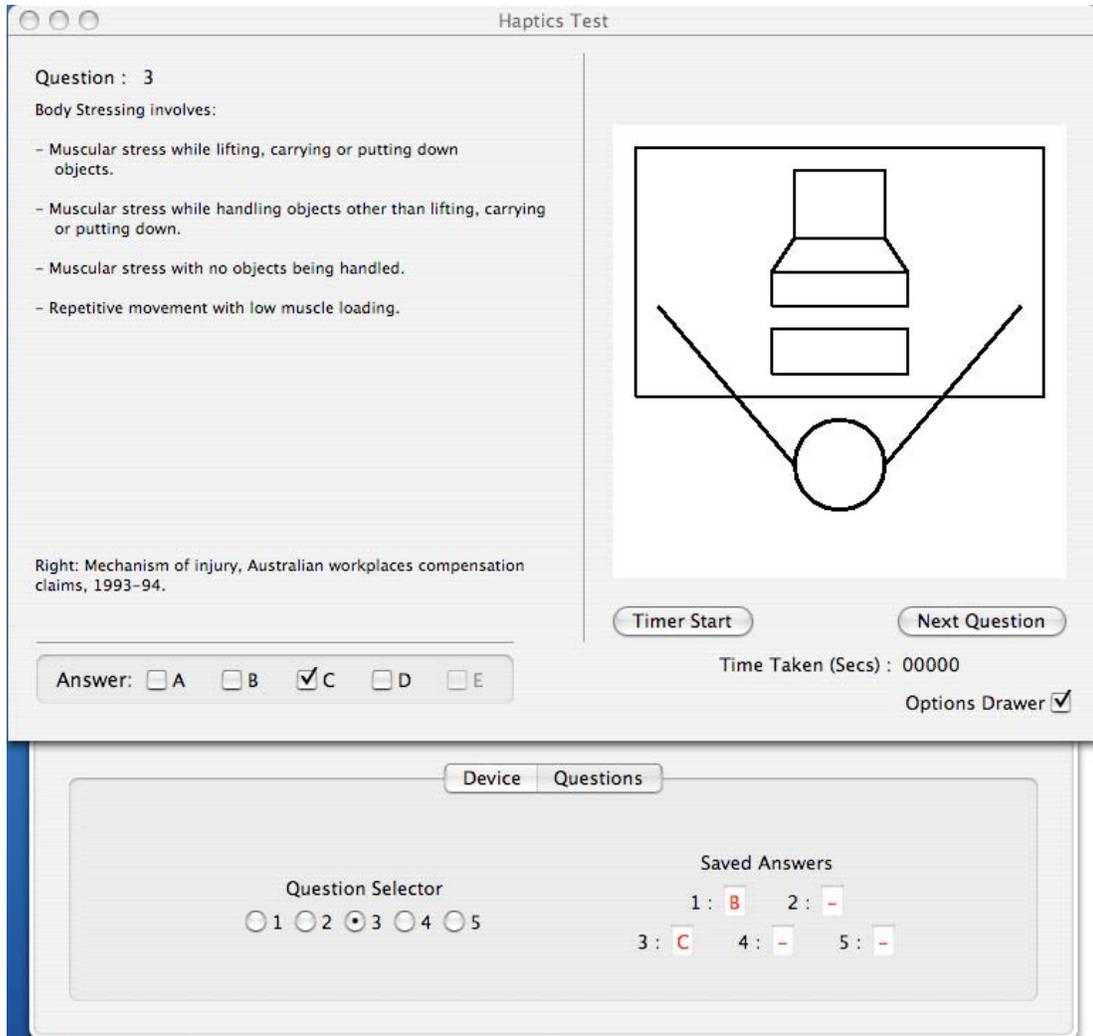


Figure 15.3: HapticTest sample question 3

Question 3, as shown in Figure 15.3, allows users to explore a person seated at a workspace. Participants exploring this workspace feel the lines drawn as grooves with gravity applied to assist in tracking. As the pen moves from object to object, the label is vocalised, for example, Arm span, Desktop, workspace and person.

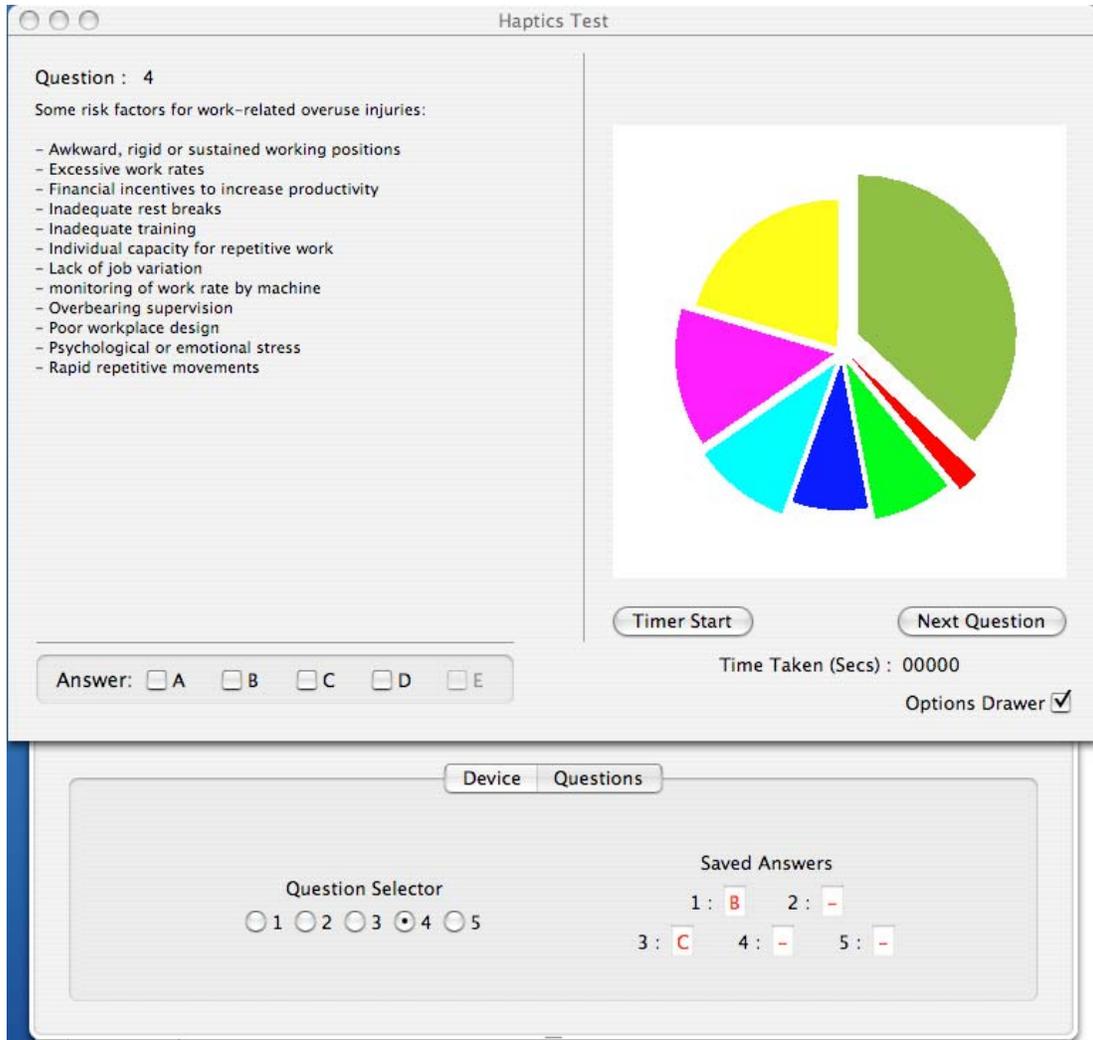


Figure 15.4: HapticTest sample question 4

Question 4 as shown in Figure 15.4, displays a simple pie chart. Segments are rendered as grooves and each has a name label and size audio label that is vocalised when the haptic device intercepts that segment.

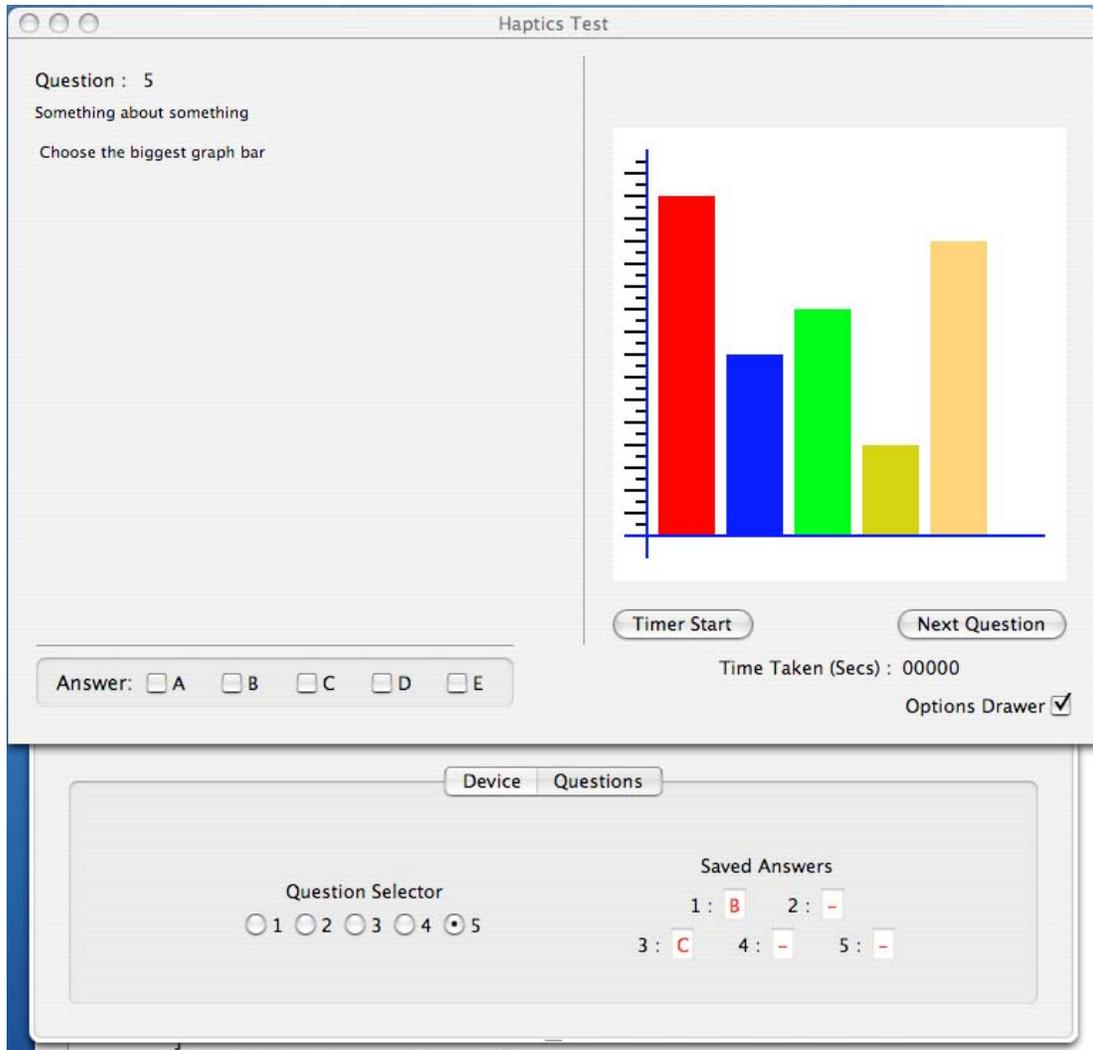


Figure 15.5: HapticTest sample question 5

Question 5, (incomplete at the time of writing) as depicted in Figure 15.5, renders the bars as grooves. Magnitude and label are vocalised when the haptic pen intercepts the object. Axis are labelled and may be haptically explored.

It should be noted that this application has not been tested on users at the time of writing. Haptic Test was implemented as a proof of concept in the possible benefits of mixed mode interaction and development will be completed at a future date.