Workshop on Advanced Learning Technologies for Disabled and Non-Disabled People (WALTD)
at
The 7th IEEE International Conference on Advanced Learning Technologies (ICALT 2007) July 18-20, 2007, Niigata, Japan

http://www.icaltd.doc.gold.ac.uk/

A User-Centred Approach for Developing and Evaluating Advanced Learning Technologies Based on the Comprehensive Assistive Technology Model

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Abstract: Learning technologies are becoming increasingly important in education. Many disabled people experience barriers in accessing education and therefore these learning technologies need to facilitate access to education for disabled people rather than generate additional barriers. There is therefore a need for development and evaluation methodologies for advanced learning technologies which take account of the needs of disabled people.

The main aims of this paper are the presentation of a user-centred design approach for (advanced) learning technologies and its link to the Comprehensive Assistive Technology (CAT) model developed by the authors and a user-centred evaluation methodology for learning technologies based on the CAT model. The application of this methodology is then illustrated by its application to a calculator for dyslexic children.

Keywords, learning technologies, dyslexia, dyscalculia, accessibility and usability, design and evaluation, assistive technology modelling.

1. Introduction

Education should be considered a basic right, but many disabled people experience numerous barriers in accessing it. A wide range of learning technologies, including computer-based ones, are becoming increasingly important in educational practice. It is therefore important that these technologies are fully accessible to disabled people.

Although disabled people often experience serious barriers in accessing and getting the greatest benefits from education, there have been advances and there are examples of good practice. In some cases there may be benefits, such as avoiding unnecessary complexity or including features only required by a specific group or groups of learners in designing learning technologies for a particular group of disabled people. However, there are clearly advantages in extending the intended group of users by taking the needs of several different groups of learners into account in the design process or, where possible, using a design for all approach.

There is also a need for tools that can support both the design process for new learning technologies and evaluate existing technologies. The paper has the following two aims:

- The presentation of a user-centred design approach for (advanced) learning technologies and its links to the Comprehensive Assistive Technology (CAT) model derived by the authors (Hersh and Johnson, 2006, 2007).
- A user-centred evaluation methodology for learning technologies based on the CAT model.

The application of the evaluation methodology is illustrated by the example of a multi-media calculator for primary school students with dyslexia.

The paper is organised as follows: Section 2 contains a brief introduction to the CAT model. Section 3 briefly discusses the specific learning disabilities of dyscalculia and dyslexia and presents the idea of a pedagogy of diversity. Sections 4 and 5 contain the main contributions of the paper in terms of an iterative approach based on the CAT model for developing learning technologies, a methodology based on the CAT model for evaluating learning technologies and an example of its application to the development of a calculator for children with specific learning disabilities. Conclusions are presented in section 6.

2 The CAT Model

The CAT model (Hersh and Johnson, 2006, 2007) gives a comprehensive description of an assistive or other technology system in terms of the characteristics of the person using it, the activities they are carrying out, the technical, end-user and other specifications of the technology and the context in which the technology is being used. The model has a number of different applications, including the analysis of existing (assistive) technologies and drawing up specifications for new technologies. The model has a hierarchical structure from the top level components of person, context, technology and activity, which can be described as follows:

The main components of the person section of the model are:
- Social aspects: community support; education and employment.
- Attitudes: attitude towards technology; general attitudes.
- Characteristics: personal information; impairments; skills; preferences.

The main components of the context component of the model are:
- Social and cultural context: wider social and cultural context; user's social and cultural context.
- National context: infrastructure; legislation; assistive or other technology context
- Local settings: location and environment; physical variables.

The assistive technology system component of the model is as follows:
- Activity specification: task specifications; user requirements.
- Design issues: design approach; technology selection.
- System technology issues: system interface; technical performance.
- End user issues: ease and attractiveness of use; mode of use; training requirements; documentation.

The activities component of the model is as follows:
- Mobility: reaching and lifting; sitting and standing; short distance locomotion inside and outside; movement on ramps, slopes, stairs and hills; obstacle avoidance; navigation and orientation; access to environment.
- Communications and access to information: interpersonal communication; access to print media; telecommunications; computers and internet; communications using other technologies.
- Cognitive activities: analysing information; logical creative and imaginative thinking; planning and organising; decision making; categorising; calculating; experiencing and expressing emotions.
- Daily living: personal care; timekeeping, alarms and alerting; food preparation and consumption; environmental control and household appliances; money, finance and shopping; sexual and reproductive activities.
- Education and employment: learning and teaching; professional and person-centres; scientific and technical; administrative and secretarial; skilled and non-skilled trades; outdoor working.
- Recreational activities: access to the visual, audio and performing arts; games, puzzles, toys and collecting; holidays and visits – museums and galleries; sports and outdoor activities; DIY, art and craft activities; friendships and relationships.

3. Learning Disabilities in Mathematics

Learning disabilities can be divided into the two main classes of specific and general learning disabilities. The two main types of specific learning disabilities are dyscalculia or mathematics learning disabilities and dyslexia or literacy learning disabilities. A sizeable group of people with dyscalculia also have dyslexia.

An estimated 5-8% of school-age children have specific learning disabilities in one or more areas of mathematics (Geary, 2004). Empirical studies have found that children with specific learning difficulties in mathematics often use strategies which do not require mental retrieval of number facts (Gersten et al., 2005). This supports the theory that they have poor short term memory retrieval skills (Dowker, 2005). There is also empirical evidence that one of the main distinguishing features of children with dyscalculia is difficulties with multistep arithmetic (Bryant et al., 2000). Since the term mathematics encompasses diverse topics which make different cognitive demands, specific learning disabilities may impact on some areas of mathematics, but not others (Geary, 2004). However most research in the area has concentrated on arithmetic and number skills.

A relatively small number of both computer-based and other tools have been developed to support people with (specific) learning difficulties. However most of the commercially or freely available tools focus on children, rather than adults or the full age range. A study of the literature indicates that coverage of mathematics topics is also relatively limited and generally related to basic numeracy skills rather than more advanced topics and concepts. There is therefore a need for further research on tools, methodologies and learning approaches to support mathematical and numeracy learning by people with dyscalculia of all ages and stages of education. There are also questions as to the role of (computer) technology in this process, whether and in what circumstances it can be an enabler rather than a further hurdle to be overcome and the appropriate balance between computer based resources and other types of support.

3.1 Pedagogy of Diversity

There is evidence that people with specific learning disabilities have particular cognitive approaches which are different from those of the non-learning disabled population. They therefore need learning approaches and technologies which are compatible with their cognitive styles. This gives rise to a need for a pedagogy of diversity, based on appropriate learning methodologies and approaches for the full diversity of students and which enables all students to draw on their strengths. This pedagogy would need to include consideration of the following factors (Hersh and Stapleton, 2006):

- The essential learning goals of the particular educational programme. Often an educational programme may have a number of goals which are not really essential and which have developed for historical or other reasons. Removing these goals may make the programme accessible to disabled people.
- The involvement of students in course design and flexible, creative approaches, which take account of the needs, circumstances and context of all students, rather than rigidly applied principles.
- Learning approaches which encourage students to meet the learning objectives while taking into account different learning styles, and a range of resources, with support to help students choose the most appropriate approaches and resources. This should enable all students to draw on their strengths and to use these strengths to support the areas in which they have weaknesses (Price, 2006). All these different resources and approaches should be available to all students. This is particularly important for students with specific learning disabilities.
- Access to the same types of experience, such as field trips and laboratory work, and the social aspects of education, including the need for peer acceptance. In some cases this will mean modifying the basic approach to make it accessible to all students. Alternatively different groups of students could undertake one of a number of options, such as different field trips, and share their experiences afterwards.
- Challenging and stretching all students to the optimal extent for the particular student, without making any student feel overwhelmed or stressed.
- Provision of assignment measures and methodologies which are fair to all students.

- Provision of sufficient resources by the institution, including teaching materials and staff time (academic, technician, secretarial, administrative and other) to prepare the different approaches and resources. This is unfortunately counter to current trends in countries such as the UK, where the staff: student ratio has increased from 1:9 in the mid-1970s to nearly 1:21 in 2003-4 and is expected to increase to 1:23 by 2010 (AUT, undated, 2002).

3.2 Accessibility and Usability

In the context of technology for disabled people there has been a tendency to focus on accessibility, for instance, of computer system or web pages. Accessibility is about the environmental characteristics of the system input and output which either enable or prevent particular groups of users from using the system. It can be defined in terms of the absence of barriers to carrying out a particular activity and the presence of factors, which may be structural or psychological, which facilitate carrying out this activity.

However, usability or the extent to which a particular group of users can use a particular system in their particular context to achieve specified goals effectively, efficiently and with satisfaction (Federici et al., 2005; ISO, 1998) is equally important. It has been characterised in terms of the following six components (McLaughlin and Skinner, 2000): allowing checks that the correct information is entering and leaving the system; user confidence in both the system and their ability to use it; user control over system operations, including input and output information; ease of use; fast response; user understanding of the system and its outputs. Therefore usability depends on design features and user characteristics, as well as the context in which it is intended to use the system.

In the context of learning technologies, there are two types of accessibility and usability issues:

- Accessibility and usability of the learning technology itself.
- The use of the learning technology to overcome accessibility barriers that would otherwise affect the learning process, for instance due to a mismatch between the cognitive approaches used by the learner and assumed by the teacher or the presentation of material in a visual format to blind learners.

4. A Framework for Developing and Evaluating Advanced Learning Technologies Based on the CAT Model

This section presents a user-centred design approach for (advanced) learning technologies and its links to the CAT model and a user-centred evaluation methodology for learning technologies based on the CAT model.

4.1 Methodology for Developing Advanced Learning Technologies

The CAT modelling approach can be used to derive a structured and user-centred approach to developing advanced learning technologies. It should be noted that some of the factors discussed in the steps may not always be relevant. The approach presented below is iterative and some steps or sequences of steps may be repeated many times.

1. Determination of the learning activity or activities to be supported by the technology. The activity section of the CAT model can be used to define some of the activities involved. This leads to detailing the task specifications in the activity specification section of the assistive technology system component of the model.
2. Determination of the user requirements in the activity specification section of the assistive technology system component of the model. These requirements can be obtained by referring to the person section of the model and in particular the user characteristics and attitudes. Advanced learning technologies are occasionally designed for a specific end-user, but more likely to be designed for a particular group of end-users. Therefore the personal information will be generic, for instance the age group and whether male or female or mixed gender. In some cases a design for all approach is most appropriate. In others it is useful to have a design which takes account of the specific needs of particular groups of disabled people. This will affect factors such as the system interface, so that disabled users can interact with the technology, the

underlying cognitive approaches and the language or symbols used, including in documentation, so that they are comprehensible. The group may be homogenous with regards to skills or there may be significant variation with regards to possession of the relevant skills across the group of learners. There is generally a relationship between skills and education and employment. Preferences of relevance include factors such as appearance and degree of customisability. It is often useful or even essential to evaluate the skills and preferences of the intended user group by carrying out a survey of a representative sample. The education and employment and skill profile of the user group will determine the types of functionality the learners require, for instance basic or more advanced principles and techniques.

3. Determination of the context in which the advanced learning technology will be used. This will influence many of the design specifications. The wider and user's social and cultural contexts will determine the appropriate language for text or speech output, menus and documentation. It will also determine the way particular words or symbols are likely to be understood and any words or symbols that should be avoided in order not to cause offence. The infrastructure component of the national context and the location, environment and physical variables can put constraints on what is appropriate in terms of the design. In particular, it may be necessary to design any hardware to be robust to humidity or extreme temperatures. The infrastructure for maintaining, repairing and updating the technology locally also has to be considered to avoid it being abandoned the first time a problem occurs. Computer based learning technologies will generally be inappropriate for areas with an intermittent electricity supply, unless a locally appropriate solution to the computer power requirements can be obtained. The existence of legislation on the rights of disabled people could contribute to overcoming any barriers to the technology getting to disabled learners.
4. Design specification: this includes the design and system technology issues sections of the assistive technology system component of the model, leading to selection of the design approach, the technical performance requirements, the technology and the system interface. Selection of the system interface will be largely determined by the end-user characteristics already considered.
5. Evaluation of the design in terms of end-user issues, including ease and attractiveness of use and mode of use. This will require consideration of both the end-user characteristics and the context of use.
6. Documentation and training: This will include consideration of the end user characteristics, as these will determine a number of important features of the documentation, including format(s) e.g. as text on paper, as an audio CD, in Braille or as a video or DVD; the type of language and symbols used; and the level at which the information is pitched e.g. for experienced or novice users of the technology. Both the local and wider social and cultural contexts need to be taken into account in determining the appropriate language and symbols for documentation. Information about the education and employment profile and likely skills of the end-user group can often be used to determine whether they should be classified as novice or experienced users and their requirements for documentation. The support component of the social aspects feature of the person section of the model should be taken into account in determining the requirements for documentation and training. This includes consideration of the support available to the user from the community and/or family and friends. This should include whether training should also be developed for others in addition to the direct end-user.
7. Construction of the device.
8. Cycle of end-user testing and repeated modifications. This will include evaluation in terms of the assistive technology system components of the model, including:
   - End-user satisfaction with the ease and attractiveness of use, mode of operation, system interface, training provision and documentation.
   - Functionality, including carrying out the required tasks, technical performance and performance of the interface.
   - Overall design.

4.2 Methodology for Evaluating Advanced Learning Technologies

The CAT model can be applied to the evaluation of advanced learning technologies by matching or comparing the different features of the particular technology with the associated requirements of the person, context and assistive technology modules of the model. The accessibility and usability with which the technology achieves the required learning outcomes can also be assessed using the requirements for accessibility and usability discussed in section 3.2 above and evaluating them for the particular user group, context and technology. As in the case of the methodology for developing advanced learning technologies, not all features of the evaluation process will be relevant. In particular some of the factors, such as robustness to local environmental conditions, including temperature extremes, will be only relevant to hardware, whereas many learning technologies are in the form of software. The evaluation procedure will now be set out in the form of a series of questions relating to each component of the model.

Person: Is the learning technology appropriate for the intended group(s) of users?

Characteristics: Is the technology age-appropriate? What basic, intermediate and advanced skills are learners required to have? Is this realistic for the intended group of learners? Has the technology taken into account learners' impairments, for instance in the choice of appropriate means of inputting and outputting information and the use of symbols and language. Have learner preferences been considered, for instance with regards to the appearance of any hardware and the mode and format of provision of information?

Attitudes: Is the technology appropriate in terms of what is known about the intended learners attitudes' to learning and the use of learning technologies?

Social aspects: What is the likely education and employment profile of the group of learners? Is this appropriate to the technology in terms of the knowledge, understanding and experience required? What support or encouragement to learning in general and using the specific advanced learning technology, in particular, is likely to be available to the particular group of learners from family and friends, teachers/tutors or the wider community? Is this support sufficient for learners to have a positive experience of using the technology?

Context: Is the learning technology appropriate to the context in which it will be used?

Social and cultural: Are any examples, symbols, metaphors, graphics and stories culturally appropriate and comprehensible? Have any sources of ambiguity or possible offensiveness been avoided? Is the language used one the users are fluent in?

National infrastructure: Is the available infrastructure able to support the technology? Have any unrealistic assumptions been made e.g. availability of technicians, continuous electricity supply? Is it possible to maintain, repair and update the technology locally?

Local settings: Can the technology function under the local conditions? Is it robust enough to cope with any extremes of temperature or humidity? Is it robust enough to cope with being dropped, getting wet and less than careful handling, particularly if the intended learners are children? Is the format of the system outputs and inputs appropriate to the local physical variables as well as the learners? For instance, will the environment be quiet enough for the learners to hear any speech or other audio output? Have headphones been provided so that audio output will not disturb other learners? Is there sufficient illumination to see a screen or keyboard clearly, particularly if some of the learners have low vision? What type of learning setting is the technology intended to be used in? A class-room? The learner's own home? A computer laboratory? Does this setting put any constraints on the design? Have these constraints been taken into account? What type of technology is likely to be familiar to learners in the local context? Is the learning technology of a type that will fit easily into this context?

Legislation: Does the learning technology comply with all relevant local, national and international regulations? Has any use been made of legislation that promotes learning technology in general or specifically for disabled people in particular?

Assistive technology system, accessibility and usability: Does the learning technology support learners to carry out the intended learning activities and is it fully accessible and usable by them?

Activity specification: What are the user requirements? How have they been taken into account? How has the target learner community been involved in the design process? Does the advanced learning technology meet learner needs? Have the tasks to be carried out been sufficiently precisely specified? Are there any accessibility barriers? Do the learners have control over the system operations, including input and output information?

Design issues: Has the design approach taken account of learner requirements and task specifications? What were the different technology options? What criteria were used in selecting the technologies chosen? How have these choices affected the performance of the learning technology and end-user satisfaction?

System technology issues: What is the system interface? Does it allow all learners to access input and output information? Does it present any accessibility or other barriers to the intended learner community? Does the system interface allow user control over system operations, including input and output information? What criteria are being used to judge technical performance? Is performance satisfactory in terms of these criteria? Does the interface allow checks that correct information is entering and leaving the system? Are these checks provided in an appropriate format? Is the system customisable e.g. the length of time users are given to respond to prompts and whether and in what format checks are provided?

End user issues: Have end-user tests been carried out? Has both qualitative and quantitative information on system performance been obtained? How easy is the system to use? How enjoyable is it to use? Are there any features that the desired group of learners may find off-putting or which may act as barriers? Is the mode of use appropriate for this group? What training is required by the particular group of learners? What, if any, training is available? Is it sufficient and appropriate? Are there any accessibility or other barriers which would prevent learners accessing this training? Is any training required by teachers, tutors, family members, friends, professionals or other people? Is this training being provided in appropriate forms? Are there any accessibility barriers to this training? What documentation is required? What documentation is provided? Is documentation provided in appropriate formats for the group of learners e.g. audio on tape or CD, electronic form to be used with screenreaders and Braille for blind learners. Is the language used in the documentation fluently understood by the group of learners? Is the level of language appropriate to them? Are any symbols, graphics and examples culturally appropriate and easily understood by the group of learners?

5. Example of the Application of the Approach to Designing a Calculator for Children with Specific Learning Disabilities

The evaluation methodology presented in section 4 will be illustrated by the example of an on-screen calculator developed by Orton-Flynn and Richards (2000) using multimedia tools for children with specific learning difficulties, in this case dyslexia. This section presents the results of applying this methodology under the three main headings of Person; Context; and Assistive technology system, accessibility and usability.

Person

Characteristics: The calculator has been designed for primary school students, both girls and boys, particularly those with dyslexia. However, there are advantages in it being useable by all primary school students, including those with other impairments and those who are good at mathematics. The design is age appropriate. The skills required are the ability to select a key from the on-screen keypad using a mouse or assistive device, such as a switch, the ability to choose the correct key and to read a simple display with clear fonts, supported by audio feedback, to use interactive base ten blocks, to recognise and use the four arithmetic symbols and the 10 digits and to work out by hand and to estimate the answers to simple calculations. Some of these skills, such as working out and estimating the answers to simple calculations and recognising the four arithmetic symbols, are skills the users are learning and where learning is being supported or reinforced by the use of the calculator. Some modifications, such as the ability to access the on-screen keypad from the keyboard in addition to the mouse would be required to make the calculator useable by blind children. The use of colour is likely to be helpful to most users. However, some users find on-screen colour difficult to look at and therefore an option to customise it out would be useful. The fact that the main user group has dyslexia has been taken into account in a number of ways. This includes the presentation of answers in spoken as well as visual form, the use of a very clear font and the organisation of the keypad with ‘1’, ‘2’, ‘3’ rather than ‘7’, ‘8’, ‘9’ on the top row, as this is a more natural organisation.

The appearance of the hardware and display are likely to be attractive to most users in this age group.

Attitudes: Many school children are nervous about numbers and calculation and many of them have already had bad experiences. The calculator is designed to increase their confidence. School children generally have a positive attitude to the use of learning technologies, particularly when they are multi-media or computer based.

Social Aspects: The group of learners are all primary school students. There are no requirements for knowledge, understanding and experience and the only requirements are the skills listed above. The support available, particularly from family and friends, will depend on a number of different factors, including the individual child's circumstances. Therefore, support from teachers and class room assistants is particularly important. The practical support that they can provide will depend on a number of factors, including their attitudes to dyslexia and class sizes. It is generally easier to provide support in smaller classes. There is increasing recognition that dyslexia is a 'real' disability, but this is still by no means universal and the degree of recognition varies considerably between countries. In the UK a high proportion of teachers consider that calculators are an essential tool in the primary school classroom, but that it is important that pupils understand the principles of arithmetic and are able to independently validate the answers given by the calculator (Orton-Flynn and Richards, 2000). Since the multi-media calculator supports learning the principles of arithmetic and acquiring the ability to validate answers, teachers are likely to be supportive of its use. However, they may require information on what it is able to do. There is very little information available about dyslexia in the countries with low literacy, but there is likely to be very little if any support available.

Context

Social and cultural: The calculator has been developed specifically for children with dyslexia and therefore the use of complex language has been avoided. The symbols used are the standard mathematical ones. The calculator has been developed in UK English and is therefore useful for children in the UK. Since the expressions used are simple, the calculator can probably be used in other English speaking countries. Since dyslexia is not restricted to the UK, the development of the calculator in other languages would be useful. There is increasing official recognition of the importance of educating disabled children in mainstream schools, as demanded by organisations of disabled people, such as Inclusion Scotland. This will require adequate resources and the provision of appropriate learning technologies such as the multi-media calculator.

National Infrastructure: The infrastructure in the UK is suitable to support the calculator and to maintain and update both the calculator software and the associated computer soft and hardware. No unrealistic assumptions have been made. The same is true of other English speaking countries, such as the USA and Australia. However, there are likely to be infrastructure issues, such as the lack of availability of computers and intermittent electricity supplies, in some of the poorer countries.

Local settings: Robustness to local conditions relates to the computer hardware, not the calculator software. This is not an issue in most countries, but may become an issue if a handheld version is developed. Since the calculator has speech output, it should be used with headphones in a classroom, computer laboratory or library setting to avoid disturbance to other school students or library users and enable several students to use the calculator at the same time. Headphone use will also make it easier for the students to receive the speech output if the classroom is noisy. This issue is not discussed by the developers. There should be sufficient illumination in a class room, library or computer laboratory for the use of the calculator, but there may not be if the calculator is used at home. The calculator seems largely intended to be used in a classroom or other school based learning space. However students may want to use it at home as well. The calculator software uses a computer to provide access to an on-screen calculator. The underlying computer technology will be reasonably familiar to primary school students in the UK and most of the industrialised countries, but unfamiliar to students outside these countries.

Legislation: There is a range of legislation and regulations which should be met by the computer on which the calculator software is used. However, this is not specifically relevant to the calculator. A number of countries have legislation on the rights of disabled people, including access to education, for instance Section IV of the Disability Discrimination Act 1995 in the UK, introduced as the Special Educational Needs and Disability Act 2001 (http://www.legislation.hmso.gov.uk/acts/acts2001). The

5-14 National Curriculum in England and Wales (http://www.qca.org.uk/232.html) made the use of calculators in the classroom mandatory. The Scottish 5-14 Mathematics Curriculum (http://www.ltscotland.org.uk/5to14/) recognises the need to teach specific calculator skills, such as reading and interpreting displays, as well as the ability to approximate and estimate. These are all skills that are supported by the multi-media calculator.

Assistive technology system, accessibility and usability

Activity specification: The activities comprise calculations involving the four operations of addition, subtraction, multiplication and division, accessing the multiplication tables, using interactive base ten blocks to work out calculations, estimating the answer to a problem and checking the result. User requirements include a system which is easy and intuitive to operate and which motivates primary school students to learn. Specific requirements include customisable audio and visual feedback of all steps in the computation, an easy to use on-screen keypad layout with easily recognisable keys and numerical digits and colour coding or other means of distinguishing digits and operation keys from each other, as well as the ability to save and print out calculations. Although the calculator is targeted specifically at students with dyslexia, it should be useable by all primary school students, including those who are gifted at mathematics. This may require additional functionality for children who find mathematics easy.

Design issues: The design approach was based on a top-down-structure for the calculator with investigations for some of the interface components. Classroom observations of performance with a sample of targeted endusers led to a cycle of iterative refinements to the overall design. The criteria used in retaining or removing features were ease of use and usefulness to users. Multimedia authoring tools were a key feature of the development process. The use of these tools allowed constant updating of the working prototype in response to classroom observations and new user requirements. A need for colourful graphics and audio facilities was recognised.

System technology issues: The multi-media calculator is currently available via CD to be used on a PC or macintosh computer. The developers recognise that there would be value in developing a handheld version, but that the costs of small colour LCD displays are currently too high. One approach to a handheld version would be through a personal data assistant (PDA) or palmtop computer, but the size of the display may be too small. The CD and on-screen buttons are accessed via a mouse, but an assistive device, such as a switch could be used. Consultation with usability research (Deininger, 1960; Conrad and Hull, 1968) was used to choose a keypad layout with '1', '2', '3' rather than '7', '8', '9' on the top row. The font was specially designed (Orton-Flynn and Richards, 2000) to be easy to read and avoid confusion between symbols or between digits. Both audio and visual feedback are given for each action and there is the option of saving and/or printing out calculations. There is only limited ability to customise the calculator, by the teacher. Further customisation, for instance, to change or remove colours would be useful, as well as a very simple customisation that could be carried out by students themselves.

System technology issues

End user issues: End-user testing, involving quantitative and qualitative evaluation and evaluation of use of the calculator in the class room, has been carried out. Feedback from the evaluation has been used to modify the calculator design: features that were easy to use or useful were retained and other features were discarded. Further evaluation with primary school students may be required, but evaluation to date has shown the calculator to be easy and attractive to use. Simple documentation of the calculators' features could easily be provided on the interactive CD on which the calculator software is made available. This should provide sufficient information to allow teachers to use the calculator themselves and to instruct school children in its use. The documentation would need to be set up appropriately to enable it to be accessed by screen readers, if required. The CD can be accessed using a mouse or tracker ball, as well as switches or other assistive devices.

This evaluation of the multi-media calculator has demonstrated that it is appropriate to the intended user group and in the context of the UK and some other English-speaking countries, such as the USA and Australia. It has also identified features not considered by the original developers, such as the requirement for headphones and the need for a greater degree of customisability and access to the on-screen keypad via the computer keyboard for the calculator to be accessible to students with additional impairments. The evaluation methodology has also been able to identify issues to be considered if the calculator is to be used outside the UK.

The example has also illustrated the value of the evaluation methodology based on the CAT model. The methodology is able to identify and evaluate the main features of an advanced learning technology. In particular, it is able to identify issues that have not been considered by the technology authors.

6. Conclusions

The paper has illustrated the application of the Comprehensive Assistive Technology (CAT) model developed by the authors (Hersh and Johnson, 2007) in the development and evaluation of (advanced) learning technologies. An approach for developing learning technologies linked to the CAT model and an evaluation methodology directly based on the CAT model were presented. The evaluation methodology was illustrated by application to a multi-media calculator for primary school students with dyslexia. The development of the methodologies was set in the context of the need for a pedagogy of diversity and the importance of taking account of accessibility and usability factors in all technology development.

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