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TOWARDS AN ACCESSIBLE SCIENCE: FACILITATING ACCESS TO SCIENTIFIC DIGITAL RESOURCES FOR VISUALLY IMPAIRED STUDENTS

D2.1 Assistive tools in scientific studies

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1 OJ L 79, 24.3.2005, p. 1.

EXECUTIVE SUMMARY

This deliverable is aimed at describing the state-of-the-art about assistive tools used or potentially usable by blind and partially sighted students at university. It is part of the activities being carried out in the work package 2 (WP2: State of the art) by the @Science network. The knowledge of state-of-the-art tools, emerging opportunities and tools actually used by sight impaired students at university is of paramount importance to come to the guidelines which will be part of the work package four (WP4: Scientific resources usable by visually impaired: textbooks, lessons, examinations).

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1 INTRODUCTION

1.1 Scope of the document

This document covers the state-of-the-art about assistive tools for visually impaired students in university scientific courses. It is divided into the following parts:

- introduction of the barriers which prevent visually impaired students from choosing or going on studying in scientific university courses;
- description of tools concerning mathematical expressions reading, writing and processing, making and exploration of technical drawings, access to symbolic and numerical computation programs and use of programming work environments;
- preparation and distribution of questionnaires about the actual state-of-the-art on tools in the countries involved in the @Science network;
- analysis of the questionnaires.

1.2 Overview

Blind and visually impaired students meet several difficulties to go through advanced scientific and technological studies at university. They are due to many factors which affect the educational curriculum of many visually impaired students. First of all, few visually impaired students choose scientific university studies. Indeed, most people regard advanced scientific studies as not accessible by visually impaired and blind students. This widely believed assumption often leads the persons who contribute to the student's choices (parents, schoolmates, teachers, etc.) not to suggest curricula based on science and technology. Furthermore, in many European countries (e.g. Italy and Spain), the teacher can choose for a certain subject the topics to be taught to a student with special needs. That is extremely useful in many situations, nevertheless that sometimes leads to not teaching some topics based on processing of structurally complex expressions or diagrams (e.g. trigonometric inequalities, proof of Euclidean geometry theorems, etc.), which need to be mastered high technicality and high expertise with assistive tools. Therefore, some visually impaired students do not get acquainted early with methods and techniques which allow appreciating advanced subjects. Moreover, if those students who studied subjects reduced to their special needs undertake scientific university courses, they often meet several difficulties due to the lack of background knowledge. In addition to difficulties related to secondary school studies, many problems come from the lack of optimal assistive tools for science learning. Up to now many projects have been carried on worldwide. Many of them led to very promising results both as for basic knowledge about how visually impaired students can access mathematical notation and technical drawings and as for the assistive tools implemented. The following sections will illustrate at first the main barriers met by visually impaired students in attending university courses, subsequently the state-of-the-art about assistive tools which can be used at university.

2 METHODOLOGY

In order to collect state-of-the-art documentation and experiences about assistive tools for science learning by visually impaired students, the following work plan was set:

- Analysis of the main barriers met by visually impaired students in scientific university studies. This was done basing on the long experience of @Science members with visually impaired students;
- Scientific and technological literature review. The proceedings of the main international conferences about technology for special needs and digital content accessibility were considered. In particular: Lecture Notes in Computer Science, ACM proceedings and IEEE proceedings;
- Participation to conferences to collect information about the state-of-the-art and emerging opportunities. In particular, the following conferences were attended by @Science members: Handimatica 2006, UMI-CIIM 2006, CSUN 2007, ICTA 2007, Web for All 2007, German e-Science 2007, SightCity 2007 and ElPub 2007;
- Preparation of a questionnaire to be filled by each @Science network member. The questionnaire aimed at getting detailed information about the national situation. Due to the extremely low number of visually impaired students enrolled at university in scientific courses (less than ten in some countries), each network member chose the number of students or university support services to contact;
- Experimentation of the main assistive tools by network members

3 MAIN BARRIERS FOR VISUALLY IMPAIRED STUDENTS IN SCIENTIFIC STUDIES

The main barriers met by visually impaired students in university scientific studies mainly concern: reading, writing and processing mathematical expressions, exploring and creating technical drawings as well as using specific programs necessary in a certain educational context, in particular symbolic and numerical computation software and programming environments.

3.1 Reading, writing and processing mathematical expressions

Reading, writing and processing mathematical expressions effectively, efficiently and satisfactorily are activities indispensable to get proficient in scientific subjects. In order to understand the reason why these activities may pose problems to the visually impaired student, a brief analysis of visual and non-visual understanding of mathematical expressions is provided [1].

A model for visual understanding of mathematical expressions was proposed in 1987 [2]. This model works as follows. A mathematical expression is visually scanned by the reader, whose gaze may rest upon the expression for a while. A mental representation of the surface structure of the expression is formed. This representation is checked for understanding, which involves checking that all symbols are known and checking that the complexity or length of the expression is manageable. If either of these two tests fails the procedure is aborted and a smaller portion of the expression is gazed. Otherwise a syntactic analysis is undertaken. In the syntactic analysis procedure the main operator of the expression is searched in order to form a parse tree. The tree representation can be properly carried out according to the rules of precedence of the domain involved. This representation of the mathematical expression guides the transformations a person will execute.

It is the initial part of this process that poses difficulties for a blind reader [1] as it implies the existence of an external memory (e.g. paper, a blackboard or a screen) which permanently displays the representation of the mathematical expression. The permanence of the structure to explore and understand relieves the reader of the mental workload in retaining the information to be accessed [3], so that further mental resources can be employed in the comprehension of the mathematical meaning, rather than in retaining the syntactical structure.

Furthermore, the manner in which the information is presented (e.g. whether some portions are underlined or highlighted, how blanks are used to separate blocks, how the mutual relations among subexpressions are marked, etc.) can also help in the process of reading and understanding by sight [4], [5] and the layout of the information can suggest transformations and procedures to perform a certain task. This high level understanding of the expression is an “overall glance”, which can be gathered quickly by sight over the entire expression or over its parts (e.g. subexpressions, building blocks, etc.). This ability to get different views allows planning and adapting to the purpose the reading process. The representation on an external memory can be effective only when its parts can be accessed quickly and accurately. A visual representation on paper or on a screen in conjunction with the control provided by sight allows effective and active understanding.

Reading and understanding through speech output is affected by the lack of an external memory. The transient nature of the speech signal does not allow one to have a permanent representation of the structure to read. That causes an inability to get different views at a mathematical expression and to directly access specific portions. As a consequence, the listener tends to be passive.

Reading by touch is a more active style of exploration. The external memory is not absent, but it is extremely reduced with respect to the one accessible by sight. It is made up of the number of cells on a Braille display, which is generally about forty. Although rightward, leftward, upward and downward movements allow one to update the external memory with new portions of the mathematical expressions, at any one time, only a small portion of it can be accessed. Moreover, under the fingertips, at most two Braille cells can be perceived at any one time. Consequently, it is difficult to get an overall tactile glance at the whole expression or at its subexpressions, so planning the reading process is far more difficult than by sight. In the comprehension process, both by speech and Braille output, the amount of external memory is smaller than in the one by visual reading.

Therefore, the ability to scan, judge complexity and fixate certain portions of an expression is very difficult and time consuming, both listening to speech output and reading a Braille linear description of a mathematical expression. In the model for visual reading of mathematical expressions previously introduced, a small capacity of the external memory implies that a large number of expressions is too complex to be managed. Hence, the procedure is often aborted, restarted and repeated until the structure of an expression can be understood. So, input and editing techniques for mathematical expressions are of paramount importance to achieving high usability of mathematical notation, through speech and tactile devices. In particular, they affect the writing speed, which influences the overall efficiency, the ease in carrying out transformations and the prevention of typing mistakes, which influence both effectiveness and satisfaction. When a sighted person writes a mathematical expression, the flow of information is simultaneously controlled by sight. Not only what is being written can be read by sight, but also a rather large area around the focused piece of information. That allows one to have complete control over the input process and the transformations to carry out. Consequently, writing mistakes can be immediately located. Furthermore, during a step of simplification, a straightforward comparison with the previously written expression can be achieved by sight. Touch does not allow simultaneous control over what is being typed in, since the fingers are part of the typing process. Anyway, symbolic patterns can be accurately retrieved by tactile exploration. Hearing may allow synchronous control, but it does not allow the synchronous exploration of already written expressions.

Therefore, assistive tools to compensate for the lack of sight in exploring and processing mathematical expressions can be extremely important for university visually impaired students. At present, there are few computer programs which can be easily used to read, write and process mathematical expressions through high quality speech output, suitable for national languages and through braille output. The most well-known available programs will be introduced in the next section. Here, let us analyse the main problems in designing and implementing these programs. They especially concern:

- how to convert mainstream digital formats for scientific documentation into a semantic oriented format to be used for speech and braille rendering [6], [7]. Mainstream digital formats (e.g. LaTeX [8] and XML-based MathML [9] format) are mainly oriented to visual rendering or printing of mathematical expressions. In order to produce high quality speech [10], [11] and braille output, conversions have to be achieved without loss of information and it is often necessary to enrich the description with new elements which make clear the semantics. This process is not straightforward and it may lead to speech descriptions which can be not so easily understood;
- how to produce an unambiguous and expressive speech description of mathematical expressions which is suitable for many languages [1], [11]. Many experiments have been carried out up to now especially for the use of prosody in reading mathematical expressions [11]. Nevertheless, they mainly take into account the English language and there is no independent software module which can be straightforwardly embedded in a system to enable visually impaired to write, listen and process mathematical expressions;
- how to produce braille output. Braille is not a universal standard. There exist many braille notations, which are different according to the national traditions and local peculiarities. In addition to national differences, there are also differences due to the existence of two groups of braille codes: six-dot braille and eight-dot braille. Eight-dot braille was introduced when braille displays were manufactured. Braille displays are made up of eight dots braille cells. Thanks to eight dots, each cell can represent 256 different characters. Instead six dots were used in traditional braille so up to 64 characters in one braille cell could be represented. Eight dots braille code can be very useful to describe mathematical expressions in linear form because the resulting sequences of characters are more compact than those obtained with six dots braille codes. Compact braille expressions can be more easily read by touch and understood than long sequences of braille characters.

So, due to the wide spreading of braille displays and to the advantages deriving from using eight dots for mathematical notation, many visually impaired students got used with eight dots braille codes. Unfortunately, eight dots braille is not an official standard neither on a local basis nor internationally. Many visually impaired persons who are acquainted with reading on a braille display often choose personal dots combinations and invent personal rules to represent both text and mathematical expressions by using eight dots.
An overview of the main braille codes is provided:

- Austria and Germany. In 1930 the Marburg 6-dot notation was specified. It is still in use in German speaking countries. An 8-dot code for mathematics, SMSB, was made available for computer use since 1980. At the University of Karlsruhe, AMS, the ASCII Mathematik Schrift, which uses 8 dots, has been developed. Today, in German schools, also Eurobraille is in use, especially to write down expressions based on LaTeX syntax;

- Belgium. Dutch speaking Belgium uses the Woluwe mathematical code which is based on the Marburg system, but not identical. French speaking Belgium uses a code based on the system used in France. There is no official 8 dot system in use;
- Italy. The mathematical Braille code (6 dots) is standardized by Biblioteca Italiana per Ciechi in 1998. An official Italian 8-dots Braille code does not exist;
- France. A commission in charge of the evolution of the French Braille in general proposed several versions for mathematics. The version of 1971 was revised in 2001 and 2006. All versions use 6 dots;
- Slovak Republic. In the Slovak Republic there is an official Slovak national Braille code. This 6-dots code was standardized in 1996 and it contains Braille transcription of mathematical, chemical and physical symbols. However, standardized Slovak Braille code is on very basic level. It doesn't include symbols of high scientifical level. There is no official 8-dot mathematical braille code;
- Spain. The Spanish 6-dots braille code was drawn up by the Comission Braille Española. It was approved in June 1987 by the Representantes de las Imprentas Braille de Habla Hispana in Montevideo (Uruguay). There are few symbols for geometry. No official eight dots Braille code for mathematics is available in Spain;
- Portugal. The offical 6-dots code is relies basically on the CMU "Codigo matematico unificado para a lingua castelhana" of 1987 with some variations and integrations connected to the traditional Portoguese use. All the symbols and mathematical notations generally used in secondary school are available. Advanced mathematical notation is not described. No official eight-dots braille code is available in Portugal;
- USA. Mainly the Nemeth code is use. Dr. Abraham Nemeth began working on his math code around 1946; it was adapted several times and the latest official version dates from 1972. A chemistry code was added in 1998. It is a rather complex system as part of its syntax (contractions) is based on human interpretation of the formulae. Currently work is underway to come an updated system: the NUBS (Nemeth Uniform Braille System);
- UK. The Royal National Institute for the Blind has supported the development of a Unified English Braille code (UEB) which would incorporate codes for literary AND mathematical applications (Nemeth-like, but not identical).

3.2 Technical drawings

Drawings are highly used in teaching and studying scientific subjects (e.g. geometry, physics, automata theory, software engineering, etc.). Understanding and making drawings are very challenging activities for visually impaired students, especially when the necessary drawings are structurally complex and rich of textual labels or captions (e.g. directed graphs with labelled edges and vertices, two-dimensional shapes with labels on vertices and angles, etc.). In order to comprehend the reasons which complicate the understanding of graphics in a non-visual mode, first of all let us analyse how visual understanding works and which advantages come from a visual exploration of graphical representations. Literature about how sighted people explore and understand graphics, suggests some basic features which should be reproduced by whatever tool for the exploration of non-visual representations of graphics. A relevant contribution is given by Larkin and Simon [13], who compared the mental computation required in solving problems expounded by diagrams and problems represented as series of textual elements (e.g. characters, words, sentences, etc.). They found that the mental workload involved in the solution by diagrams is lower than the one spent to solve the problem presented through text. Two features of diagram understanding were regarded as the main reasons of the different mental workload: easiness to search and immediacy to recognize. Localisation of related parts in diagrammatic representations reduces the need for searching, and consequently it facilitates computation, since symbolic descriptions need not be generated or matched. It means that information represented over a two-dimensional plane can be more efficiently grouped and searched for meaningful items than text along a line. As for recognition, diagrammatic representations allow one to immediately understand meaningful shapes, namely relevant parts can be easily isolated and connected to related diagram components. For example, given a sinusoidal curve, it is straightforward to recognize by sight which are the symmetries, when it is displayed, whereas it takes a longer time to get this information from a textual description (e.g. through some points in a table). Further contribution is provided by a model which accounts for how visual images are perceived [14]. This model shows that the visual image is analysed hierarchically, from the overall structure down to the fundamental features or elements. It is observed that the clustering of elements or aggregations of basic elements occurs selectively, maximizing the number of connections between units which have important relationships. The importance of each relationship is quickly defined through a comparison with the other possible relationships (e.g. according to closeness as remarked by Palmer). What is natural in the exploration by sight often becomes difficult in the exploration through speech output and tactile devices. It is due mainly to the transient nature of the speech signal and to the possibility to explore by touch only small areas at any one time. However, it may be supposed that a tool which has to improve usability of non-visual descriptions of graphics, should allow users to exploit the same cognitive processes previously analysed for visual understanding of graphics. Therefore, at least four exploration features should be found in tools which provide non-visual descriptions of drawings:

- the possibility to easily recognize basic components or clusters in the drawing;
- the possibility to identify relationships between basic components or clusters;
- the possibility to easily search for components, either clusters or the basic ones;
- techniques to hierarchically explore the graphical representation.

Drawings making through non-visual perception is strongly related to the non-visual exploration process. Indeed, it is still necessary to identify positions and mutual relations among objects already located as well as directly reach precise positions in the workspace and the portions of drawing to be updated or connected to new ones.

Non-visual representations of drawings can be roughly divided into five categories: textual descriptions, audio descriptions, tactile drawings, audio-tactile representations and haptic feedback rendering.

Through textual descriptions, mainly qualitative information can be easily conveyed. For example, a blind student can immediately understand the main features of a function diagram through a textual description (e.g. a sinusoidal curve, a logarithmic curve, etc.), whereas quantitative information can be understood slowly (e.g. the number and coordinates of maximum points in a certain interval). In order to get quantitative information about a diagram, visually impaired students often rely on numerical and symbolic computation programs (e.g. by reading the function values in a certain interval to understand whether the function increases or decreases).

Audio diagrams are non-visual representations of graphics through a changing sound. For example, a higher sound provides information about an increasing function diagram. This technique is usually implemented together with textual descriptions

Tactile diagrams are an effective and efficient non-visual representation of two-dimensional drawings because they can convey synchronously the overall structure and the details. They can be divided into two categories: tactile graphics on paper which can be embossed through high quality embossers and drawings represented through refreshable devices. Tactile drawings can be effectively and efficiently perceived by touch if they are generated by taking into account rules [15], [16] concerning the size of tactile elements and the mutual relations.

Audio-tactile graphics combine tactile drawings with speech and sound feedback. They were experimented about twenty years ago to explore maps [17] and they have been getting widespread among visually impaired students who attend scientific studies. They are especially useful when a drawing is rich of textual labels or captions. For example, two-dimensional geometric shapes can be embossed on paper and speech-recorded messages can be attached to relevant spots (e.g. to audio label vertices and angles).

Haptic feedback devices [18] can be used to render drawings through force feedback. They are not yet widely exploited, but they can open up new opportunities.

3.3 Computation programs and programming environments

In scientific studies, two groups of programs are especially employed:

- symbolic and numerical computation programs;
- programming environments.

The main issues in using these programs through speech and tactile devices are presented.

3.3.1 Symbolic and numerical computation applications

The main accessibility issues concerning symbolic and numerical computation applications are related to the user interface. Generally speaking, these programs are made up of:

- an interpreter of a language specifically designed to express computations (e.g. "^" is often used to express powers);

- a kernel which performs computations;
- one or more front-end components which have many features to input, edit and process text and mathematical expressions;
- a protocol to enable client applications to communicate with the kernel.

The language uses almost always 128 different text characters to express mathematical expressions, so it doesn't pose problems to mainstream screen readers which can perform braille rendering according to the braille table loaded. Problems rise with the user interface employed by the front-end. It often implements visually oriented interaction paradigms (e.g. the main working window is split into many boxes containing the expressions to be computed or the results of a computation, vertical or horizontal bars are used to mark a portion of text or expression as computed or to be calculated, etc.). Furthermore, the text-based language is usually rendered in traditional mathematical notation by the front-end. So, for example, a fraction is usually represented as numerator / denominator through the text-based language and it is rendered by the front-end in traditional mathematical notation as a numerator over an horizontal line over the denominator. When a front-end renders expressions in traditional mathematical notation, the output can be hardly accessed through screen readers which produce speech or braille output. Instead, traditional mathematical notation is especially suitable for partially sighted students because it can be magnified and read. Many symbolic and numerical computation programs also have a front-end with a character user interface. It can be used through mainstream screen readers and it is often a good alternative to the main front-end. Furthermore, the communication protocol between the kernel and a client application enables expert users to develop specialized front-end components which take into account accessibility features.

3.3.2 Programming environments

Programming environments are sometimes used in laboratory courses at university. Even if a programming language can be learnt and proficiently used without relying on a programming environment, many operations can be easier and less time-consuming when a certain programming environment is used. Therefore, the programming language can usually be studied by the visually impaired student, but when the laboratory projects or exercises need a specific programming environment some problems may rise. Speech and braille accessibility issues to programming environments rise whether the graphical user interface doesn't comply with mainstream screen readers. Many operations (e.g. compile, debug and run programs) which are usually performed through the graphical user interface can often be performed also through a command line user interface. That is the strategy used by many visually impaired programmers.

4 ASSISTIVE TOOLS AND TECHNIQUES

4.1 Introduction

This section illustrates tools and techniques which are available to overcome the barriers introduced in the previous section. In particular, it presents tools and techniques for:

- reading, writing and processing mathematical expressions;
- exploring non-visual descriptions of technical drawings;
- making technical drawings through speech and tactile assistive tools;
- making non-visual descriptions of technical drawings;
- using symbolic and numerical computation programs through speech and tactile tools;
- using programming environments through assistive tools.

4.2 Tools for reading, writing and processing mathematical expressions

4.2.1 The LAMBDA system

4.2.1.1 Description

The LAMBDA [19], [20] system is the result of the European LAMBDA project (acronym for Linear Access to Mathematics for Braille Device and Audio-synthesis) in the framework of the IST program (further information can be found at www.lambdaproject.org). The LAMBDA system aims to facilitate reading, writing and processing of mathematical expressions through braille device and audio-synthesis, especially taking into account the needs of visually impaired students who share their learning experience with sighted students in an educational context (e.g. in a classroom, attending a lesson, taking an exam, etc.). In order to achieve high modularity and extensibility, the LAMBDA system is made up of many functional components, which interact to perform the required tasks. The main components are: the LAMBDA code, the mathematical editor, the LAMBDA font and the converters.

The LAMBDA system is designed to process text and mathematical expressions mainly through speech output and braille display without a necessary relation to embossing on paper. So, an 8-dots Braille code was chosen by the LAMBDA consortium. Especially 8-dot Braille codes are often incomplete and not officially approved by national Braille authorities. Therefore, in order to overcome these national differences, a set of rules was defined to uniformly describe Braille mathematical expressions in a linear form. Strictly speaking it was not defined a unique mathematical Braille code, rather it was developed a common markup language to linearly represent mathematical expressions so that they can be easily read and understood by means of eight dots combinations. It means that dots combinations representing letters and mathematical symbols are different from country to country, but they comply with the same set of linearization rules. Before coming to the definition of the LAMBDA code, the national codes used in the countries involved in the project, were compared and common features were grouped together.

The resulting LAMBDA code follows some leading principles:

- whenever possible the meaning of the linearly represented notation is made explicit. For example, powers have a base and an exponent. The exponent, once displayed, from a presentation point of view is the same as a superscript, whereas the semantics is different. The LAMBDA code makes explicit the semantics, therefore two different linear representations are used for the power and the superscript;
- it aims to achieve compact linear representations. That brings great advantages especially to Braille display readers, who have not to perform a lot of movements to get the meaning of the expression;
- eight dots configurations are used. It allows exploiting 256 possible one-cell characters, instead, by using 6-dot configurations, only 64 one-cell characters are available;
- it aims to preserve national dots configuration at least for the most common mathematical symbols. When it is not possible to use exactly the same dots configuration to represent a certain symbol, a similar one is employed. For example the national dots configuration is moved one dot lower or upper in the Braille cell;
- intuitive rules and dots combinations are designed. For example, prefixes are employed to change the meaning of a group of symbols (e.g. a prefix is used to mark up Greek letters), symmetric dots combinations are used to represent tags which enclose a subexpression (e.g. round brackets, square brackets, etc.) and also dots combinations hard to be recognized by touch are avoided (e.g. just one dot at the bottom of the Braille cell);
- rules which exploit the blank character are not used. For example, the blank character is not used to mark the beginning or the end of a structure.

One of the most important features of the LAMBDA code is the possibility to linearly describe new mathematical notations. Many branches of mathematics incessantly introduce new notations to better express and work with concepts. Some of these notations remain almost unknown and are used by small groups of researchers, but many others get widespread and are commonly taught in the educational curriculum of a student. Therefore, blind students may come across into totally new notations without a Braille and speech linear representation. The mechanism designed to extend the mathematical code is the following. The new notation is linearly described through tags. The tag structure has to match one of the linear structures used by the LAMBDA code. The names to be vocally output are assigned to each tag. In order to be usable in the editor these information have to be consistent with an XML description. To facilitate this process a tool is under development to be used in conjunction with the mathematical editor. It will drive the user step by step to modify or extend the recognized notations.

The mathematical editor is the functional component which implements the strategies devised in order to make easy to read, write and manipulate text and mathematical expressions by means of speech output and Braille display, in an educational setting. The impact on the users of these assistive was partly studied in the LAMBDA project, but further considerations are expected if the system wil get widespread. The main assistive features concern:

- the possibility to move the focus wherever in the editing area. It means that the focus can be moved directly to a specific position also after the end of line and the end of file. This mode is often used in many text editors (e.g. in VI is named {\bf virtual mode}), but it is not available in common Microsoft Windows word processors where the focus can be directly moved to positions adjacent to already input characters. This operative mode is supposed to be particularly effective when a certain two-dimensional layout has to be preserved (e.g. to arrange columnar layouts to solve arithmetic operations);
- the possibility to input the mathematical symbols from a list. All the symbol names are sorted in lexicographic order. The list of names is displayed. The user can choose the needed symbol by writing its name. While the user is writing the characters which make the name, the symbol which has a prefix matching with the input string is selected and its full name is vocally output. When the needed symbol is matched it is input by pressing the enter key. This strategy is supposed to reduce the necessity to remember the full name of all symbols or a specific short-cut key;
- mnemonic short-cut keys to input mathematical symbols. Short-cut keys can be customized;
- input based on the context. When a symbol which opens a structure is input, by pressing a key combination it is possible to close the last input symbol. For example, that allows to close multiple open parentheses;
- exploration of mathematical expressions by looking through their building block structure;
- selection, cut and paste operations on meaningful portions of the expression (e.g. selection of the numerator, denominator, argument of a function, etc.);
- a working paradigm to perform calculations with matrices [21].

All of the assistive features embedded in the editor can be extended or customized through a Python-based scripting language.

In order to make easy understanding by sight what the visually impaired student is writing, a special font is available in the LAMBDA system. It maps braille specific symbols (e.g. open fraction, close fraction, etc.) to shapes which can be understood by sight.

At present the LAMBDA system embeds a converter from MathML to the LAMBDA document and viceversa. It is still not totally complete. Nevertheless many expressions concerning many mathematical areas can be successfully converted.

4.2.1.2 Remarks

The LAMBDA system is one of the latest attempts to create a working environment which can be adapted to national needs. Anyway, because of the choices concerning the eight dots mathematical braille code, it is innovative with respect to many local traditions. Therefore, its real impact on blind students will strongly be related to how much the mathematical braille code will be appreciated and used. Furthermore, the exchange of documents with other applications is extremely important. Up to now, only some experiments have been done to import MathML expressions exported from MathType application. When the document exchanges between the LAMBDA system and mainstream applications, a complete working process will be available.

4.2.2 BlindMath

4.2.2.1 Description

BlindMath [22] is a scientific editor for blind students, developed by Università Federico II, Napoli in Italy. It aims to facilitate blind students to read and write text and mathematics by using mainstream screen readers and braille display. The blind student can write text and mathematical expressions by using the LaTeX syntax or through the Braille syntax. Input commands are available to help insert LaTeX structures or the Braille symbols. Output in traditional mathematical notation is provided while the blind student is writing. Speech feedback is provided through the speech synthesizer set with the screen reader.

4.2.2.2 Remarks

This software is being developed for Italian needs. Especially at present it embeds rules for the Italian 6-dots Braille code and a dictionary for Italian and English output. Further development could lead to internationalization of the system.

4.2.3 WinTriangle

4.2.3.1 Description

WinTriangle is a specialized RTF word processor able to display and speech render in English conventional text and the symbols commonly used in mathematical expressions. It evolved from the extended text editor of the DOS Triangle program. WinTriangle has menus and hot keys permitting access to and voicing of a number of Windows screen fonts including the Triangle.ttf font containing markup symbols which permit to display in linear form mathematical expressions. WinTriangle also uses markup and utilizes reading functions that enable reasonably straightforward composition and reading of tables and other two dimensional arrays. Braille linear output is provided through GS code. GS Code was developed by J. Gardner (Oregon University) and by N. Salinas (Kansas University). It is made up of special symbols having one to one correspondence with 8-dot American Braille, with the video symbol and name pronounced by voice synthesizer. In Nineties the Triangle DOS program was created to use the GS code to generate linear math expressioThens. syntax of GS is modelled according to LaTeX conventions.

4.2.3.2 Remarks

Wintriangle presents interesting features as for input techniques and editing mechanisms. Unfortunately it is mainly bound to the English language. Full converters are not available, so the document exchange is not yet completely working.

4.2.4 Math Genie

4.2.4.1 Description

The Math Genie [5], [23] is a voice browser which enables visually impaired to explore mathematical formulae. It was designed only for speech output; at present it supports braille output, too. It can be used both by a blind student and by a sighted teacher who do not need to have any specific knowledge in Braille. Math Genie is able to import MathML expressions. The graphical rendering is synchronised to the audio which makes communication easier with the teacher. It employs SVG (Scalable Vector Graphics), which ensures the availability of magnification features and color-contrasted highlighting which are indispensable for partially sighted students. The Math Genie offers the blind students several ways of reading the formulae, from default reading from left to right to an abstract way that highlights the hierarchical structure while folding away the sub-expressions. The user can navigate in the mathematical structure, moving by way of meaningful chunks. This is based on lexical clues, which represent the structure of the mathematical content. The current version supports English, French and Spanish for speech, and offers facilities to add any local language provided that a speech synthesiser is available with the requested interface. The Braille output currently supports the Nemeth code.

4.2.4.2 Remarks

Math Genie can be an excellent tool to teach visually impaired students how to explore mathematical expressions. Furthermore, it can be successfully used in conjunction with applications for manipulating formulae. Unlike many assistive tools for reading and writing mathematical expressions, Math Genie provides specific techniques for partially sighted students, which could be exploited in a complete working environment.

4.2.5 MaWEn

4.2.5.1 Description

MaWEn, which stands for Mathematical Working Environment [23], is a prototype application developed by Johannes Kepler University of Linz, Austria, and University Pierre et Marie Curie in Paris within the ongoing Micole European Union IST project [http://micole.cs.uta.fi]. It is described as follows by the project members. MaWEn is a comprehensive, collaborative, bi-modal software solution designed to address the following issues:

- to work on documents of mixed content, textual and mathematical;
- to simultaneously represent formulae in a Braille Mathematics code of the user's choice (MaWEn potentially supports any official Braille code as soon as it is implemented in the UMCL library), and in natural visual rendering;
- to support bi-directional pointing possibilities;
- to support navigation through formulae by collapse and expand functionality, synchronised with both views;

- to input/edit this mixed content, and especially mathematical formulae, such that the above-mentioned simultaneous representation persists;
- to support the student in doing mathematical manipulation.

In order to achieve this objective a MathML based model have been developed which supports synchronisation and all features described above.

4.2.5.2 Remarks

MaWEn is an ongoing project. Once the system will be available it will be experimented also by the @Science network members.

4.2.6 MathPlayer

4.2.6.1 Description

MathPlayer [24] is a plug-in for the Internet Explorer web browser. It was designed to display MathML in web pages. MathML is not an image format, so MathPlayer is able to interpret the markup and produce the output needed. In particular, it is able to dynamically display a mathematical expression that matches the document's font properties such as size and color and to generate speech output. Hence, if a user chooses to read a document using a larger font size than standard or chooses a particular color scheme (e.g. a high color contrast which facilitates reading for partially sighted people), the formula will also be displayed using that larger font size or color scheme. MathPlayer properly works with many programs such as JAWS, Window-Eyes, and Read&Write 7. The MathPlayer interface for speech currently being used by many screen readers restricts communication to simple text strings, which makes not possible the use of prosody. In order to generate pauses, MathPlayer uses commas and periods. MathPlayer supports the speech interface SAPI4 and SAPI5 and SSML1 tagged strings. Nevertheless, at present only some screen readers exploit the potentialities provided by these speech interfaces, especially by SSML.
At the moment, screen readers use an off-screen model, so users can only navigate through the spoken verbal description of the math without any structural navigation strategy. Design Science is working with several vendors to determine the best interface for their needs so that MathPlayer's other modes of navigation are available to users. Finally, MathPlayer allows users to copy a MathML expression and paste it in a MathML-aware program. This is particularly useful for computation, but might also be useful when used in conjunction with other software aimed at making math accessible (e.g. LAMBDA and MaWEn) or with mainstream applications used to process scientific documents (e.g. MathType or Scientific Notebook).

4.2.6.2 Remarks

MathPlayer opened up many opportunities to visually impaired. Embedding MathML expressions into web pages will make possible reading of scientific web resources which are at present available only as images. The web is very rich of scientific documentation which could become available also for speech and braille reading through MathPlayer. At the moment it presents some disadvantages concerning speech internationalization and braille output. In particular, only the English language is available and no MathML into national Braille codes converter jointly works with MathPlayer. So, the Braille reader reads on the Braille line the verbal description of the mathematical expression. Due to the necessity to enrich the verbal description with commas, periods and letters to generate speech output, the braille reader will not be able to read the mathematical expression correctly on the Braille line. An example follows:

$$\sqrt{a^2 + b^2} = \sin x$$

Fig. 1. Screen display of the expression

Speech output

Square root of ay squared plus bee squared, end root. Equals sine of x

Braille display output

Square root of ay squared plus bee squared, end root. Equals sine of x

At CSUN 2007, the @Science member Unione Italiana Ciechi (Verona) investigated about the future extensions of MathPlayer. Design Science is working at improving MathPlayer modularity. In particular, they are studying the possibilities to embed a MathML to Braille translator implementing the national Braille codes and speech output for national languages. On the long term, a player for MathML embedded into PDF will be designed and implemented.

4.2.7 UCML

4.2.7.1 Description

At the moment, there is not a set of MathML into national Braille codes converters which can be used in conjunction with mainstream MathML-aware applications to generate mathematical Braille output [25]. To address this issue the UMCL (Universal Maths Conversion Library) was developed [7]. UMCL is a programming library encapsulating various converters for various Braille codes in a single library usable through a simple and unique API. UMCL is an open source project, portable, and it was developed in standard C and has wrappers to different programming languages. This library allows developers of Mathematical applications to support more different Braille codes. The library can be used as well together with transcription tools (from mainstream notations to Braille and viceversa), as for software that needs real-time conversions (like formula browsers or editors). It will also make it possible to convert a document from a Braille national notation to another, increasing de facto the number of documents available for students and allowing blind mathematicians from various countries to exchange documents. Currently output modules have been developed for the French notations (revisions 1971 and 2001) and Italian. Beta versions of Marburg and British code are also already available.

4.2.7.2 Remarks

UMCL will be a very useful tool to go towards transnational exchange of scientific documentation in digital format. The MathML format ensures independence from national rules for Braille codes, whereas UMCL ensures client-side translation to the local Braille code. Integration with other assistive technologies is desirable once UMCL will be complete.

4.2.8 DBT

4.2.8.1 Description

Transcription into Braille and formatting of braille on paper pages involves issues beyond those affecting print. DBT (Duxbury Braille Translator, www.duxburysystems.com) provides translation and formatting facilities to automate the process of conversion from regular print to braille (and viceversa), and also provides word-processing facilities for working directly in the braille as well as the print. "Fonts" are used for displaying the braille on screen. DBT is designed for those who don't know braille and for those who know it. Actually, it provides assistance through WYSIWYG features in writing and in conversion. The main features of DBT which may be of help in scientific documentation transcription are:

- built-in interline printing to have ink-braille and print together. This makes an easy proofing and teaching tool;
- math/Science Code and Computer Braille translation for American, British, and French Braille;
- the ability to include tactile graphics files for mixed text-and-graphic documents;
- imports from popular word processors including Microsoft Word and WordPerfect, HTML, ICADD, DAISY/NISO/NIMAS, formatted and plain ASCII, earlier braille editors such as EDGAR and Polkadot, Duxbury's own historical file formats, etc.;
- the possibility to work in conjunction with Scientific Notebook (Mackichan Software www.mackichan.com) to generate braille text on paper through LaTeX source, edited in Scientific Notebook;
- American textbook layout according to Braille Authority of North America (BANA) standards, and likewise the Braille Authority of the United Kingdom (BAUK) customs for the same purpose;
- six-key chording for braille and print entry, not timing-based, compatible with most keyboards;

the Duxbury Braille Font for viewing braille dots within other programs.

4.2.8.2 Remarks

DBT is useful to generate Braille to be embossed on paper. Nonetheless, Braille on paper can be very useful in primary and secondary school, but at university it can be hard to use it for all writing and reading purposes. Moreover, by the time many Braille translators for national languages are missing. At CSUN 2007, @Science member Unione Italiana Ciechi (Verona) met Duxbury staff in order to propose collaboration for future development for translation into Italian Braille.

4.2.9 MathTalk

4.2.9.1 Description

MathTalk (developed by Metroplex, www.mathtalk.com) allows the user to input mathematical formulae by speech input. It includes voice commands for pre-algebra, algebra, trigonometry, calculus, and statistics. It works in conjunction with Dragon Naturally Speaking (developed by Nuance, www.nuance.com). It is optimized for the use with Scientific Notebook (developed by Mackichan, www.mackichan.com). Mathematical expressions input by MathTalk in Scientific Notebook can then be embossed on paper in those national Braille codes supported by DBT software. MathTalk can be used also in conjunction with MuPad graphing calculator (www.mackichan.com) to command display of diagrams. MathTalk is available only for speech input in English.

4.2.9.2 Remarks

MathTalk can be useful for sighted assistants to input mathematical expressions in digital format without learning complex working environments. It can be useful also for blind students who can read synchronously what they are writing by voice input. Moreover, those students with motion and sight disabilities could use it. No MathTalk demo release is available for evaluation purposes. A video and tutorial documentation can be found on MathTalk website. MathTalk staff was contacted by @Science co-ordinator in order to investigate future development for languages other than English. No further development is planned at the moment.

4.3 Exploring non-visual descriptions of technical drawings

4.3.1 Graphic Window Professional

4.3.1.1 Description

GWP [26] (Graphic Window Professional, distributed by Handytech, www.handytech.de) is a refreshable tactile display, especially designed to explore graphics. The GWP consists of a matrix with 16 * 24 dots working with piezoelectric actuators. Function keys on the GWP unit allow for zoom, navigation, and activation of several functions to navigate the two-dimensional graphic structure and to get information about orientation. At the moment, the GWP device works with:

- Maple software, which allows for graphic display (e.g. diagrams, geometric shapes, etc.);
- the screen reader JAWS, for operating the math program and for the output of coordinates;
- the custom software Plotexplorer which ensures communication between the components and which processes Maple's graphics data for display on the tactile display, and also provides a series of display aids that assist a blind user with an in-depth exploration of the mathematical graphics;

Many functions are available. The most important are:

- zoom and navigation. Once a graphic representation has been output from Maple to the tactile display, it is shown just as it is shown on the PC (full view). If the user zooms in on it, an enlarged portion of the full view is represented on the tactile display. This extremely useful to adapt the exploration process to the user needs;
- types of representation. It provides multiple types of representation which can help the user to understand the overall image or specific sections;
- blinking cursor output of coordinates. A blinking cursor (pin moving quickly up and down) indicates a dot on the tactile display that includes one or several anchors of a mathematical object. The numerical values of the central anchor indicated by the blinking cursor can be forwarded to JAWS for output. The values are announced by the speech output, and appear as pairs of numbers at the front of the Braille display line.
- marks. In order to find a certain place within a graph, markers are available. They are displayed as blinking dots so that they can be easily found exploring by touch.
- selecting objects. When multiple diagrams are displayed in the same window, the user can choose to explore one of them or all of them at a time.

4.3.1.2 Remarks

The GWP device could be very important for those blind users who are skilled in exploring by touch. Thanks to its optimized interaction with Maple, its use for advanced topics can be achieved. GWP device was experimented by blind @Science members at SightVillage 2007. After few minutes of use, also rather complex shapes (e.g. geometric shapes) could be understood in 1 or 2 minutes exploration. It was also experimented to create simple shapes by combining GWP with a mouse. That was far more difficult and the result was not achieved.

Further integration with mainstream applications and with other assistive tools (e.g. programs for scientific documentation processing) are desirable.

4.3.2 Audio graphing calculator

4.3.2.1 Description

The Audio Graphing Calculator (AGC) is designed for people with vision, learning or motor disabilities (distributed by ViewPlus Technologies, www.viewplus.com). It provides an alternative to the handheld scientific calculator by describing function diagrams through sound and scalable graphics. Its key features are:

- describing of graph shape through audio tones and cues;
- talking menus;
- scalable visual display;
- keyboard navigation;
- tactile output options;
- advanced matrix functions;
- powerful expression evaluator;
- ability to locate polar coordinates;
- display multiple graphs and find intersections.

4.3.2.2 Remarks

AGC software can be used both by blind and partially sighted students. Thanks to its self voicing functions it doesn't necessarily need screen reader support. That is very useful for those visually impaired students who are used to work with mainstream applications through magnification software without voice synthesizer. Sound feedback, even if not immediate, becomes extremely helpful in understanding a function diagram after training.

4.3.3 IVEO

4.3.3.1 Description

IVEO (developed by ViewPlus Technologies, www.viewplus.com) [27] is a system which allow for the exploration of audio tactile images. Images are embossed on paper without textual labels and they are put over a digitizer tablet. Textual labels are linked to specific spots. When the spot on the tactile image is touched, the linked textual label is read by a speech synthesizer. That allows for synchronous understanding of structure and messages making up a drawing.

4.3.3.2 Remarks

This exploration technique works fine especially with those images rich of labels and with a well-defined structure. For example, UML diagrams, boolean circuits, flow charts can be successfully explored by using this system.

4.3.4 Haptic tools

Haptic tools (e.g. the Phantom device, www.sensable.com) or force feedback joystick or haptic mouse (e.g. upcoming Falcon device http://home.novint.com) are promising technologies to enable blind people to access graphics. Their use is likely to concern:

- exploration of three-dimensional structures;

- qualitative understanding instead of collection of quantitative information about drawings rich of details (e.g. overlapping three dimensional shapes);
- exploration of figures with a predictable structure belonging to a well defined knowledge domain (e.g. automata);
- inclusion in multimodal working environments.

Recent works about the use of haptic devices by visually impaired people are:

- MICOLE project which is exploiting haptic feedback for a virtual audio and haptic environment [28];
- TeDUB project (www.tedub.org). In particular, it studied how to employ a force feedback joystick to explore UML diagrams.

In order to monitor the development of haptic technologies for visually impaired, some related events will be attended by @Science members (e.g. HCI 2007).

4.4 Making technical drawings through speech and tactile assistive tools

Technical drawings are not often generated by visually impaired themselves. The available techniques are:

- use of pen and plastic sheets over rubber to make raised shapes (e.g. the Sewell Raised Line Drawing Kit). This technique can be extremely useful in learning tasks (e.g. to prove Euclidean geometry theorems autonomously). Anyway, to be proficient for a blind with a pen and a raised line drawing kit it is necessary a long training;
- use of a symbolic languages to generate drawings. For example, many blind students generate EPS images through LaTeX commands. This is not a straightforward technique. The commands describe the image to be generated, but irelations among its making elements can be hardly understood. It is very useful to prepare documents for sighted persons (e.g. to be read by teachers or for teaching to sighted students);
- use of graphing calculators to generate drawings. Many graphing calculators and symbolic or numerical computation programs can generate drawings by using a set of primitives. It is a quick way to prepare drawings for sighted, but it is not a good technique to understand mutual relations among the components making the drawing and modify them according to certain features;

the images generated either by symbolic languages or by graphing calculators can be embossed on paper (e.g. through a braille embosser or a tactile plotter). The result is not always optimal due to the necessity to set the right dimensions to the image and to the parts making it in order to be properly perceived by touch. Moreover, when the tactile images are rich of labels, they seldom fit the right dimension to be perceived by touch without translation into braille.

4.5 Making non-visual descriptions of technical drawings

4.5.1 Piaf

4.5.1.1 Description

Piaf produces high quality tactile graphics using heat sensitive capsule paper. Piaf's controlled heat source causes any black lines, letters or shapes that are drawn, printed or copied onto the capsule paper to swell. The result is an instant tactile graphic.

It is able to handle up to A3 capsule sheets. Further information can be found at: http://www.quantech.com.au/products/quantum_products/tactile/piaf.htm

4.5.1.2 Remarks

This device was experimented at SightCity 2007 by @Science network members. Actually, it produces high quality tactile images. The process to make tactile images on capsule paper is rather easy: the image is printed or photocopied on a capsule paper sheet which is then processed by the Piaf device. The dimensions of tactile images and mutual relations among the elements making up the image are different from those useful for visual understanding. So, an image has to be adapted, usually enlarged, before being printed on capsule paper. Therefore, expertise in tactile image production is needed to make tactile drawings completely usable by visually impaired students. A drawback concerning the tactile images on capsule paper is the rather high cost of capsule sheets. Furthermore, the process could be improved by allowing for direct computer to capsule paper printing.

4.5.2 Tiger embosser

4.5.2.1 Description

The TIGER plotter (developed by ViewPlus Technologies, www.viewplus.com) [29] is a high quality embosser which is able to print high resolution tactile images. In order to obtain high quality tactile images, a 25.4 DPI resolution is necessary [15]. Tiger embossers are able to print with a 20 DPI resolution, which is near to the best one. Automatic conversion of colored and shaded images to tactile graphics with variable height dots, can be achieved, so that relevant shapes can be perceived higher than less important ones. It can be used in conjunction with mainstream Microsoft Office applications (e.g. MS-Word MS-Excel, etc.). It can be used also to emboss images produced with other drawing programs. A set of Braille fonts is available to add Braille labels to tactile images. It is difficult to add labels by using national mathematical Braille codes. A specific mathematical Braille code (Dotsplus code [30]) is provided to add mathematical symbols. It is regarded as useful by some blind students very proficient in reading Braille, but it is considered difficult to understand by the others.

4.5.2.2 Remarks

High quality tactile images are very useful in science learning. Especially, due to the possibility to emboss images generated by whatever program able to export mainstream image formats on low cost paper, this embosser is suitable to experiment during the learning process. For example, it is possible to make a function parameter change and understand by touch the differences between two diagrams. Furthermore, by adding color to interesting areas, also some rather complex images can be explored (e.g. Petri nets).

4.5.3 Thermoform

4.5.3.1 Description

In order to produce thermoform graphics, a sheet of plastic is heated and vacuumed on top of a model which represents the shape to be perceived by touch. High quality tactile drawings can be produced, especially if the model is very accurate. According to the model, variable height raised lines and areas can be obtained. Nevertheless the process to make a suitable model requires high skill in moulding and it is necessary to have a totally new model to represent as thermoform graphics a drawing slightly different from a previous one. Furthermore, the overall process is extremely expensive.

4.5.3.2 Remarks

Due to the high cost and to the difficulty in generating slightly different graphical representation, thermoform technique is seldom used in universities. It is mainly used by transcription centres to generate drawings which have a permanent nature (e.g. geographical maps, basic shapes to introduce geometry, etc.).

4.6 Using symbolic and numerical computation programs through speech and tactile tools

Some of the most widespread symbolic and computation tools can be accessed by visually impaired people:

- through a command line user interface which can be read by screen readers and which can be easily explored through a Braille display;
- through adaptations of the front-end.

In particular:

- MatLab (developed by MathWorks, www.mathworks.com) presents accessibility features. It provides support for screen readers and screen magnifiers. Command-line alternatives for most graphical user interface options are provided. Keyboard access is always an alternative to the use of mouse. A clear indication of the current cursor focus is available.

Information is available to assistive technologies about user interface elements, including the identity, operation, and state of the element. Non-reliance on color coding as the sole means of conveying information. It doesn't interfere with user-selected contrast and color selections and other individual display attributes. Documentation is provided in a format accessible to screen readers (mainly through HTML). (Further information is available at: http://www.mathworks.com/access/helpdesk/help/techdoc/index.html?/access/helpdesk/help/matlab_env/bqwp009-1.html);

- Mathematica (developed by Wolfram Research, www.wolfram.com) does not present many accessibility features. Anyway, it can be partially used through its command-line user interface or by importing and exporting XHTML+MathML files in conjunction with MathML-aware applications;
- Maple (developed by Maplesoft, www.maplesoft.com). It can be partially used by a command-line interface or by using the 1D Maple syntax both for input and for output. A special Java Access Bridge is needed to enable screen readers to access it (http://www.maplesoft.com/support/faqs/Maple9/Installation/4.aspx);
- open source computation programs such as Octave and SciLab. They can generally be accessed through command-line interface.

A good resource about accessibility of mathematical software is the BlindMath mailing list, which can be found at: http://www.nfbnet.org/pipermail/blindmath/

4.7 Using programming environments through assistive tools

There exist many programming environments. Only some of them are usually taught in university courses. The accessibility solution which is mainly widespread among visually impaired users is the employment of a powerful programming text editor, properly configured to make easy the use of some tools (e.g. compiler and debugger). Due to the quick evolving world of tools for programming, solutions vary rather quickly and there are also many blind programmers who develop their own adaptations (configuration files or scripts for screen readers) and make them available. An excellent resource about this problem is: www.blindprogramming.com. This website distributes many tools and documents about how to use programming languages and programming environments. It hosts a mailing list which is daily updated with contributions by experienced and novices.

5 QUESTIONNAIRE FOR UNIVERSITIES

5.1 Introduction

In order to investigate the state-of-the-art about the use of assistive tools for science learning at university in the countries involved in the @Science network, a questionnaire was prepared. It was distributed among network members who gathered information about their country and sent it back to the network co-ordinator. The questionnaire aimed at addressing the use of tools by two groups of students: partially sighted and blind students. Three sections were taken into account: mathematical expressions, graphical representations and symbolic or numerical computation software. In particular, one question was introduced to investigate national resources of specific documentation. The following section illustrates the results from the questionnaire distribution.

5.2 Questionnaire: “Assistive tools in scientific studies”

5.2.1 Blind students

5.2.1.1 Mathematical expressions

1. Which is (if any) the official 6-dots national mathematical Braille code?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	In Austria the Marburg Braille code is used. It is a 6-dots code. It is used for mathematics, too.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	“Handleiding Braillesymbolen wiskunde”, edited by Gilbert Notaert, Marc Suij, Emmanuel Vandekerkhove (year unknown; only available on paper). This is also known as the “Woluwe code” or “Woluwe Mathematical Braille code 1”. It is based on the “Internationale Mathematikschrift für Blinde” from Marburg and is to a large extent a summary of “Instruktieboek voor het brailleren van studiewerken” (1975) by the mathematics code working group from the Netherlands. Its goal is to describe codes used in secondary education. (http://www.esat.kuleuven.be/pub/bscw.cgi/d25697/Handleiding_Wiskundig_Braille.pdf)
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	Notation Mathematique Braille, 1971, revised in 2001 and 2007 by the "Commission Evolution du Braille Français".
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	In Italy the official 6-dots Braille code for mathematics is the Italian mathematical Braille code. It was officially approved in 1998 by Biblioteca Italiana per Ciechi.
NETHERLANDS	Please refer to Dedicon (http://www.dedicon.nl/). This 'library' prints the schoolbooks, using a derivation of Nemeth, with variations per braille book. The students do not learn to read and write Nemeth. They work with a laptop. Therefore the Nemeth-code is translated to the table they use in the laptop and produces incommunicative/’incommunicable’ signs on the screen. The smart students work themselves through the 'legenda' explaining the signs and use their own system for writing (linear, very much as you would insert a formula into Excel). The math teachers of the schools for the blind formed a working group, proposing to use a standardized version of this solution. This process has been going on for many years now, but no progress can be reported yet. More information: Mrs. Ans van Helden, Bartiméus Onderwijs, a.v-helden@bartimeus.nl.
IRELAND	BAUK
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS,	In the Slovak Republic there is an official Slovak national Braille code. This 6-dots code was standardized in 1996 and it contains Braille transcription of mathematical, chemical and physical symbols. However, standardized Slovak Braille code is on very basic level. It

BRATISLAVA	doesn't include symbols of higher scientifical level.

2. Which is (if any) the official 8-dots national mathematical Braille code?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	In Austria, Germany and Switzerland 8-dots Braille code is standardized as computer Braille. The mathematical Braille code is not standardized.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	No 8-dots mathematical Braille code is mentioned in the MATHS deliverables.
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	No 8-dots mathematical Braille code.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	In Italy there is no officially approved 8-dots Braille code.
IRELAND	No 8-dots Braille code.
NETHERLANDS	The Braille display of the laptop produces 8 dots, but no official 8-dots Braille code is approved by national authorities.
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	In Slovakia we don't have any 8-dots Braille code.

3. Do blind students mainly use one of the official mathematical Braille codes at university or do they rely on their own adaptations?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	Blind students mainly use LaTeX or HrTeX (Human Readable TeX) which is a LaTeX-like language, but easier to be read.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	No students who worked with mathematical Braille codes responded to the survey.
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	There aren't any general cases, because some students use the official Braille codes, other students rely on LaTeX, and some of them use their own adaptations.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	Blind students mainly use their own adaptations at university. Adaptations are based on 8-dots Braille codes available with mainstream screen readers (e.g. Jaws for Windows and Window Eyes). Some of them use LaTeX, but especially for presenting results to the professor. Processing of mathematical expressions is achieved through a simplified mathematical markup, which is not officially standardized and which is different according to the student's background knowledge.
IRELAND	As very few Blind students study Mathematics in Higher Education in Ireland, no information was reported.
NETHERLANDS	They never learnt any code.
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	Most blind students at university are writing maths using some of official Braille marks combined with some which are enough descriptive to them and which are readable (relatively) for teachers and other collaborators, as well. To better understand: because there isn't any official maths code in Slovakia, which enables access to scientific texts for the blind on a national level, students in high schools (mainstreamed) mostly even don't have text-books in Braille, development of Braille literacy usually ends with secondary school termination (about 15 years of age). In consequence of lack of written Braille sources, blind students do create their own marks or adaptation, which can be considerably strange for other people.

4. **Which tools (if any) do blind students use at university to write, read and process mathematical expressions through Braille output?**

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	Above all they use text editors or Microsoft Word. They read on the Braille display.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	N/A
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	Azerty layout/LateX.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	Especially, they use simple text editors, advanced programming text editors or Microsoft Word. Some of them still use Dos text editors (e.g. Quick Edit by Semware). They use to read on the Braille display instead of listening to speech output. Some students are experimenting the LAMBDA system and Blindmath.
IRELAND	I couldn't comment on this.
NETHERLANDS	Laptop with Braille display, Supernova or Jaws, also Emprint. LaTeX, Infty Reader (though lots of difficulties here).
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	Blind students studying sciences use braille-line (e.g. Tieman Braille Voyager; Alva Braille line). Sometimes students use an ordinary perkins-style type writer.

5. Which tools (if any) do blind students use at university to write, read and process mathematical expressions through speech output?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	Above all they use text editors and Microsoft Word. They listen to the output of the screen reader (e.g. Jaws for Windows).
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	The blind psychology student became blind at the age of 18, so he knew basic Braille, but not enough for mathematics. For his first statistics course, he asked a student who knew the subject matter to read the course materials out loud, and this was recorded. The second statistics course required more processing of calculations. For this, he used Microsoft Excel with the plug-in StatistiXL (http://www.soft3k.com/statistiXL-p7074.htm) to access statistical functions. Recently, he has been using more SPSS; apparently, someone in the UK is writing scripts (JAWS scripts) for SPSS.
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	Usually no specific tools. They say they don't know any tool or they know about tools but which don't exist in French.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	No special tool is used at university to listen to mathematical expressions. Screen readers are used with a customized dictionary.
IRELAND	I couldn't comment on this.
NETHERLANDS	I'm not a specialist on this issue; most speech output tools are 'under construction'. (e.g., LaTex to Speech, Nemeth to speech). A problem for many blind students is that there are many tools (being developed), but it takes too much time to try them out. Blind students averagely need more time to study, to arrange that books, materials from teachers are available, getting the assistive technology and assistance that is needed, and so on. In that situation, with examinations and other deadlines, it is impossible for them to try out a couple of tools - with no guarantee of success. If they find apt technology it often is expensive and an application for (state) subsidy/provision may take months. So they usually improvise a lot with the technology they have.
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	Mostly students use standard text editor, e.g. notepad included in the windows accessories (Bratislava, B. Bystrica), with screen reading software (Jaws for windows and brass for linux). A blind scientist developed special software HPSIO, which he uses for all activities. This software is Dos based and is supported by DOS based Braille line.

6. Which are the main difficulties met by blind students at university in working with mathematical expressions?

Austria, Linz University, Institute Integriert Studieren, Linz	They generally don't meet difficulties to read mathematical expressions or to write them for presentations as source LaTeX. They meet more problems to write and process mathematical expressions (e.g. in solving exercises).
Belgium, Katholieke Universiteit, Leuven	The blind student said that the main difficulty is that everything takes much longer. He also said that a good statistics program with a manual that explained how to use the program without a mouse would help a lot. Six years ago, he also contacted several software vendors about this, but they could not provide help if the requirements went beyond basic functions: for example, +, -, and cosine were not problematic, but summations were a problem (in 2001).
France, Université Pierre et Marie Curie, Paris	No specific answer.
Italy, Università degli Studi di Milano, Milano – Unione Italiana Ciechi, Verona	They remark the necessity to use an 8-dots mathematical Braille code both for processing calculations and for writing final documents. Some students remark the necessity for a system for scientific e-learning.
Ireland	In Ireland there is very low participation of Blind students in Higher Education. Those that do progress do not pursue Mathematical or Science based degrees due to a lack of knowledge in this area.
Netherlands	Both reading and writing, the latter in an unambiguous way and clear to sighted peers and professors). LaTeX is an editing tool. Everybody knows it; it is a ‘common language’, so ‘communicable’, but it is not meant to do math. So it is communicative, but a ‘best of worst’ solution. It requires much concentration (and deleting text-editing orders like ‘bold’) to work with and form a proper image of the formula in the head.
Slovakia, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava	Absence of official scientific Braille code, lack of written texts in an accessible form, problems with written communication with lecturers.

5.2.1.2 Graphical representations

7. **Are blind students used to read tactile graphics at university (e.g. embossed through graphical embossers, thermoform or swell paper graphics, etc.)?**

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	Blind students sometimes use swell paper graphics or embossed graphics.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	The blind student used some tactile graphics in the beginning, but he preferred descriptions because insight and understanding of the content is more important than knowing what a graphic looks like. [Note that this student became blind at age 18, so he had experience with graphics before that.]
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	Generally yes. Still some students have difficulties with tactile graphics.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	Blind students who attend scientific courses are rather used to read tactile images, both embossed on paper or drawn through a raised line kit. Few of them are able to read the shape of letters and numbers. They can read Braille labels on tactile images.
IRELAND	Blind students use graphical embossers to study Geography in University
NETHERLANDS	Yes, though it is a lot of work to print these well readable for blind students. So they get much less tables and other diagrams. With Excel and other programs it is possible to visualize a diagram corresponding with an expression; this can be easily printed with an Emprint/Tiger Embosser (sometimes provided at university, not at schools).
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	Reading tactile graphic needs to be experienced in this field. There are not many possibilities to provide tactile graphics. It means, that it can be difficult to read these properly for some blind students, they need to have an extra explanation and/or preferably assistance to be able to understand it. (Blind student from B. Bystrica) Another experience from student from Bratislava: I read graphs very rarely. Algebraic equations and other structures are better alternatives for me. In some cases (uml diagrams and so) I have to read graphical representations, but I don't like it. "Real" examples (e.g. diagrams which are really useful for seeing people, not such that are only "school examples") are very often unreadable for me.

8. **Do blind students use tools to prepare tactile graphical representations for their use (e.g. through the Sewell raised lines drawing kit or through rubber and plastic sheets or other tools)?**

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	Students are not taught to prepare tactile graphics by themselves so they seldom draw tactile representations at university. A tool to give directives to a Braille embosser to produce simple tactile drawings was developed at Linz university.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	None were found.
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	Some use rubber and plastic sheets.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	They are sometimes able to prepare tactile drawings for their own use through the plastic sheets on rubber.
IRELAND	Braille Embosser and Hot Spot Fuser are used
NETHERLANDS	Emprint at university; at schools this is being neglected, due to lack of time/possibilities to support the student; we have drawing kits with German foil, but students do not learn to draw diagrams properly with it. Sighted kids get grids with axes pre-drawn etc; blind students yet have blanco foils. We also use a geo-board (pins, holes and rubber bands).
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	For sketching some patterns or diagrams by themselves they use rubber and plastic sheets very seldom. Some of them are not able to read their own "drawings" properly later on which is the reason why they "try to avoid this wherever possible". Another alternative is use of cork and polystyrene and different kind of cords and pins for construction of relief pictures and diagrams. The blind scientist uses for this purpose his own software HPSIO.

9. Do blind students use specific tools to read graphical representations (e.g. a sound-based diagram viewer, a tool to explore value tables for functions, etc.)?

Austria, Linz University, Institute Integriert Studieren, Linz	The software MuPAD 3 was assessed at Linz university. It allows students to produce value tables of mathematical functions.
Belgium, Katholieke Universiteit, Leuven	None were found. The blind student worked with recordings of descriptions of graphical representations. These descriptions focused on the thought process that was followed while creating the graphical representations.
France, Université Pierre et Marie Curie, Paris	No.
Italy, Università degli Studi di Milano, Milano – Unione Italiana Ciechi, Verona	They mainly use mainstream computation programs to generate value tables for functions. Many of them use command line calculators, others use Derive, MatLab or Mathematica.
Ireland	No Knowledge on this
Netherlands	No (some may use the Graphical Calculator of Viewplus, or experiment with other tools).
Slovakia, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava	No, they don't use and don't know such tools. The blind scientist develops for this purpose his own software HPSIO.

10. Do blind students use assistive tools to produce non-visual descriptions of graphical representations (e.g. value tables for functions, descriptions of UML diagrams, etc.)?

Austria, Linz University, Institute Integriert Studieren, Linz	MuPAD 3.
Belgium, Katholieke Universiteit, Leuven	None were found.
France, Université Pierre et Marie Curie, Paris	Some students are used to describe UML diagrams in textual form. Generally blind students don't use specific assistive tools for that.
Italy, Università degli Studi di Milano, Milano – Unione Italiana Ciechi, Verona	Some of them use programming languages to generate non-visual descriptions of simple diagrams which then can be displayed as images.
Ireland	Unable to comment. No knowledge on this.
Netherlands	They will no doubt use the spreadsheets (as in Excel and data collecting software) if accessible (and if not exported to Excel). Not to my knowledge.
Slovakia, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava	No, they don't use such tools. The blind scientist develops for this purpose his own software HPSIO.

11. Do blind students use specific tools to produce graphical representations for sighted assistants or professors (e.g. LaTeX, Scilab, etc.)?

Austria, Linz University, Institute Integriert Studieren, Linz	LaTeX, MuPAD 3 and Excel in some circumstances.
Belgium, Katholieke Universiteit, Leuven	None were found.
France, Université Pierre et Marie Curie, Paris	Some students use classical Unix/Linux tools.
Italy, Università degli Studi di Milano, Milano – Unione Italiana Ciechi, Verona	LaTeX is used to generate drawings for sighted persons. Also programs such as MatLab and Mathematica are used to generate images. Students who attend courses in economy sometimes use Microsoft Excel.
Ireland	No knowledge on this.
Netherlands	LaTeX, Excel, Tiger/Emprint embosser
Slovakia, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava	Yes, some of them use LaTex for producing of graphical representations. The blind scientist uses for this purpose his own software HPSIO.

5.2.1.3 Calculus software

12. Which are the calculus programs mainly used in scientific university courses (e.g. Maple, Mathematica, MatLab, Scilab, etc.)?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	Some of them are used, but they are not indispensable to attend university courses.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	Programs used include: • LabVIEW (http://www.ni.com/labview/ - this is not for mathematics but for "the development of scalable test, measurement, and control applications"; it also has math and analysis functions); • Lisrel (http://www.ssicentral.com/); • Maple; • Mathematica; • Mathtype (for creating mathematical formulas for use in text processing, web pages, etc.); • MatLab; • SAS (statistical software); • SPSS (probably used more than SAS); • Statistica; • AG Fortran 77 Library (http://www.nag.co.uk/numeric/fl/fldocumentation.html)
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	Maple was cited.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	MatLab is especially used in engineering courses. Other programs are sometimes used (e.g. Mathematica), but they can be often understood without special adaptations.
IRELAND	I cannot comment on this as we have no knowledge or experience in this area.
NETHERLANDS	Various; each university makes its own choices. Accessibility often is a challenge. Students have no support on this matter; they often find out asking questions on lists.
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	Students use Matlab, Maple, Mupad on very different level. The blind scientist uses for this purpose his own software HPSIO.

13. Do blind students use specific assistive tools to use these programs or do they make their own adaptations?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	They do some personal adaptations. MuPAD calculus software is used because it is very accessible.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	N/A
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	Text mode form Maple with a Linux console screen reader (brltty).
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	Some adaptations are done by the students. No widespread adaptation is available (e.g. Jaws for Windows script or configuration file).
IRELAND	I cannot comment on this as we have no documented experience in this area.
NETHERLANDS	You have to know the proper settings, both in your screen reader software and in the software you use. Some make their own adaptions, macro's, etc.
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	Students use screen reader Jaws with braille display and a speech output. The blind scientist uses for this purpose his own software HPSIO.

5.2.2 Partially sighted users

5.2.2.1 Mathematical Expressions

14. Which tools (if any) do partially sighted students use at university to write, read and process mathematical expressions through speech output?

Austria, Linz University, Institute Integriert Studieren, Linz	No particular tool. Mainly screen readers.
Belgium, Katholieke Universiteit, Leuven	The PhD student used normal speech synthesis (ViaVoice, AT&T True Voice).
France, Université Pierre et Marie Curie, Paris	Jaws
Italy, Università degli Studi di Milano, Milano – Unione Italiana Ciechi, Verona	They don't use specific tools other than speech output generated by screen readers.
Ireland	JAWS (Screen Reading Software).
Netherlands	N/A
Slovakia, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava	No one partially sighted student in Slovakia reads mathematical expressions through speech output. They are not willing to learn adapted mathematical notation.

15. Which tools (if any) do partially sighted students use at university to write, read and process mathematical expressions through magnification?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	Software magnifiers.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	The PhD student uses desktop and portable electronic magnifiers, e.g. Reinecker UNO Light. In addition, he also used normal magnification (5x magnification) because books are sometimes hard to read (space between pages).
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	ZoomText
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	Only magnification programs are used.
IRELAND	ZoomText, CCTV
NETHERLANDS	N/A
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	Partially sighted students use big fonts, magnifying software and magnifying device (Magic, ZoomText, CCTV, Twinkle Bright).

16. Which are the main difficulties met by partially sighted students at university in working with mathematical expressions?

Austria, Linz University, Institute Integriert Studieren, Linz	To process them. To take notes.
Belgium, Katholieke Universiteit, Leuven	The PhD student never (or rarely) attended class but learned through self study. At home, he uses electronic magnifiers and these provided access to mathematical expressions (so there were problems with these expressions).
France, Université Pierre et Marie Curie, Paris	The formulas are often cut into 2 or 3 lines after magnification. Also the students have an eyes ache after reading on the screen.
Italy, Università degli Studi di Milano, Milano – Unione Italiana Ciechi, Verona	To take notes at the lesson, because it takes too much time. They sometimes have problems in written exams.
Ireland	It is a slow process to assimilate the information.
Netherlands	N/A
Slovakia, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava	Using personal hand magnifying tools they work with limited field of view.

5.2.2.2 Graphical representations

17. Do partially sighted students use specific tools to read graphical representations (e.g. magnification tools, etc.)?

Austria, Linz University, Institute Integriert Studieren, Linz	Software magnification tools and magnification features of mainstream programs.
Belgium, Katholieke Universiteit, Leuven	The PhD student uses electronic magnifiers and normal magnifiers (but normal magnifiers only for short time spans).
France, Université Pierre et Marie Curie, Paris	There aren't any specific tools apart some magnification tools. For example some students use an enlargement with Office Draw made by a transcription centre.
Italy, Università degli Studi di Milano, Milano – Unione Italiana Ciechi, Verona	They usually rely on magnification features available in the operating system or through magnification tools as ZoomText.
Ireland	CCTV
Netherlands	N/A
Slovakia, Comenius University, Faculty of Mathematics, Physics and Informatics, Bratislava	Yes, students use magnification tools hardware and software, CCTV.

18. Do partially sighted students use specific tools to produce graphical representations for their use (e.g. drawing software, etc.)?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	No specific tool is used.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	The PhD student uses a pen with a broad tip for personal notes, LaTeX combined with magnification software (Ai Squared ZoomText), and MatLab.
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	No significant answer
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	They usually prepare their own graphical representations either enlarged on paper or through some mainstream drawing programs. Some of them use Paint.
IRELAND	No knowledge in this area.
NETHERLANDS	N/A
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	Mostly students produce graphics, tablets, etc. by using PC (Excel, Mathematica) and magnifying software Magic.

5.2.2.3 Calculus software

19. Do partially sighted students use specific strategies to use calculus software?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	No specific strategy is documented.
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	The PhD student uses magnification software (4x magnification) on a 15 inch screen with a resolution of 800 by 600 pixels and inversed colours.
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	No significant answer.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	No particular strategy other than magnification and high contras settings.
IRELAND	No knowledge in this area.
NETHERLANDS	N/A
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	No, mostly not.

5.2.2.4 Documentation

20. In your country, are there documents collecting experiences and working strategies of blind or partially sighted students in scientific university studies?

AUSTRIA, LINZ UNIVERSITY, INSTITUTE INTEGRIERT STUDIEREN, LINZ	Accessible and usable scientific books
BELGIUM, KATHOLIEKE UNIVERSITEIT, LEUVEN	No such documents are known. The two students indicated that they were guided by their own experience. One indicated that he also consulted a forum for psychology students and international forums, and that he head about a European project (involving a Dutch and a British university, among others) 6-7 years ago, but did not know of any results. When looking for other experiences, it turned out that having an assistant who is able to provide clear explanations was the most common "solution", and that was also the solution that he had adopted.
FRANCE, UNIVERSITÉ PIERRE ET MARIE CURIE, PARIS	No.
ITALY, UNIVERSITÀ DEGLI STUDI DI MILANO, MILANO – UNIONE ITALIANA CIECHI, VERONA	Some documents are available as a result of the LAMBDA project (www.lambdaproject.org).
IRELAND	No study or information collected.
NETHERLANDS	Not to my knowledge.
SLOVAKIA, COMENIUS UNIVERSITY, FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS, BRATISLAVA	In general no. Two universities and special centres (Bratislava, Košice) try to collect experiences and working strategies of their own blind and partially sighted students. Comenius University in Bratislava coordinated co-operation in the field of development transcription rules for mathematics on the secondary school level a couple of years ago.

5.3 Remarks

After comparing the questionnaires, some remarks can be pointed out:

- most of the European nations have a six dots mathematical Braille code, officially approved by national Braille authorities. Nevertheless some of them are incomplete for advanced subjects. French and Italian six dots Braille codes have been recently revised;
- no eight-dots mathematical Braille code is officially approved by national Braille authorities;
- most students create their own maths adaptations or rely on LaTeX or LaTeX-like writing systems;

- mathematical expressions are mainly processed through text editors, especially through advanced ones (e.g. those used for programming). Some students use ordinary Braille typewriters. No particular tool was used to process mathematical expressions by speech output, except for mainstream screen readers;
- as for mathematical expressions, the main difficulties reported concern the use of LaTeX writing system to perform calculations. No big problem is met to use it to present results;
- tactile graphical representations are generally used, even if some problems were remarked about the experience of blind students with tactile graphics in secondary schools;
- most of blind students are not taught to prepare tactile drawings by themselves before university studies;
- blind students rarely use software to explore graphical representations through non-visual techniques. The mentioned programs are MuPad in Austria, Mathematica and MatLab in Italy and Audio Graphic Calculator in Netherlands;
- mainly textual descriptions or programs such as Excel, MuPad, Mathematica or MatLab are used to generate non-visual descriptions of graphical representations;
- mainly LaTeX and graphical calculators are used to produce graphical representations;
- Mathematica, MatLab, Maple, SPSS and MuPad are computation programs used at university. Blind students do not easily have access these programs, so they mainly use command-line tools to access them;
- partially sighted students do not use particular tools to read mathematical expressions by speech. They mainly use screen readers and magnification tools;
- partially sighted students remarked difficulties in processing mathematical expressions, especially as for the slow performance and disease after working for long through magnification tools on the screen;
- partially sighted students mainly use computation programs such as Mathematica, MatLab and MuPad to produce graphical representations for their use. Then, they read them through magnification tools;
- mainstream computation programs are also used by partially sighted students to perform calculations;

Almost in all countries, few documents are available about studying and learning techniques of blind and partially sighted students in university scientific courses.

6 CONCLUSIONS

The first part of this document introduced many assistive tools to support visually impaired students in university scientific courses. Some of these tools are mainstream tools with adaptations, other tools are specifically designed for visually impaired. At present, many tools belonging to the second group are still under development and they will have an impact on visually impaired people in the coming years. Other tools are very well-known in some nations, but they are almost unknown or not used in other nation, as it comes out from the questionnaires. That seems to be due to the lack of overall knowledge about available tools, to local peculiarities (e.g. the language) and to not standardized writing systems for mathematics (e.g. the lack of an official eight dots mathematical braille code, the use of many LaTeX-like writing systems, etc.). Questionnaires also highlighted the lack of documented studying experiences by visually impaired students at university. Documentation of experiences could lead to the definition of best practices and to transnational knowledge exchange.

APPENDIX 1: QUESTIONNAIRE "ASSISTIVE TOOLS IN SCIENTIFIC STUDIES"

a) Blind students

Mathematical expressions

1. Which is (if any) the official 6-dots national mathematical Braille code?
2. Which is (if any) the official 8-dots national mathematical Braille code?
3. Do blind students mainly use one of the official mathematical Braille codes at university or do they rely on their own adaptations?
4. Which tools (if any) do blind students use at university to write, read and process mathematical expressions through Braille output?
5. Which tools (if any) do blind students use at university to write, read and process mathematical expressions through speech output?
6. Which are the main difficulties met by blind students at university in working with mathematical expressions?

Graphical representations

7. Do blind students are used to read tactile graphics at university (e.g. embossed through graphical embossers, thermoform or swell paper graphics, etc.)?
8. Do blind students use tools to prepare tactile graphical representations for their use (e.g. through the Sewell raised lines drawing kit or through rubber and plastic sheets or other tools)?
9. Do blind students use specific tools to read graphical representations (e.g. a sound-based diagram viewer, a tool to explore value tables for functions, etc.)?
10. Do blind students use assistive tools to produce non-visual descriptions of graphical representations (e.g. value tables for functions, descriptions of UML diagrams, etc.)?
11. Do blind students use specific tools to produce graphical representations for sighted assistants or professors (e.g. LaTeX, Scilab, etc.)?

Calculus software

12. Which are the calculus programs mainly used in scientific university courses (e.g. Maple, Mathematica, MatLab, Scilab, etc.)?
13. Do blind students use specific assistive tools to use these programs or do they make their own adaptations?

b) Partially sighted students

Mathematical expressions

14. Which tools (if any) do partially sighted students use at university to write, read and process mathematical expressions through speech output?
15. Which tools (if any) do partially sighted students use at university to write, read and process mathematical expressions through magnification?
16. Which are the main difficulties met by partially sighted students at university in working with mathematical expressions?

Graphical representations

17. Do partially sighted students use specific tools to read graphical representations (e.g. magnification tools, etc.)?
18. Do partially sighted students use specific tools to produce graphical representations for their use (e.g. drawing software, etc.)?

Calculus software

19. Do partially sighted students use specific strategies to use calculus software?

Documentation

20. In your country, are there documents collecting experiences and working strategies of blind or partially sighted students in scientific university studies?

REFERENCES

1. R.D. Stevens, Principles for the Design of Auditory Interfaces to Present Complex Information to Blind People, PhD thesis, The Department of Computer Science, University of York, 1996
2. P. Ernest, A model of the cognitive meaning of mathematical expressions, British Journal of Educational Psychology, 57, 343-370, 1987,
3. W. Scheonpflug, W., The trade-off between internal and external information storage, Journal of Memory and Language, 25, 657-675, Elsevier, 1986
4. D. Kirshner, D., The visual syntax of algebra, Journal for research into mathematics education, 20, 274-287, Wiley, 1989
5. D.J. Gillan, P. Barraza, A.I. Karshmer, S. Pazuchanics, Cognitive Analysis of Equation Reading: Application to the Development of the Math Genie, ICCHP04, LNCS 2398. 477-485, Springer, 2004
6. G. Jaworek, Perspectives and Possibilities for the Automated Processing of Scientific Texts for Blind and Visually Impaired People, ICCHP 2002, LNCS 2398, pp. 401-402, Springer, 2002
7. D. Archambault, D. Fitzpatrick, G. Gupta, A. I. Karshmer, K. Miesenberger, E. Pontelli, Towards a Universal Maths Conversion Library, ICCHP 2004, LNCS 3118,pp. 664-669, Springer, 2004
8. L. Lamport, LaTeX: a document preparation system, ={Addison-Wesley Longman, Publishing Co., Inc., 1989
9. W3C Math Working Group, Mathematical Markup Language (MathML): Version 2.0, World Wide Web Consortium, 2003
10. L.A. Chang, Handbook for Spoken Mathematics (Larry's Speakeasy): Lawrence Livermore Laboratory, The Regents of the University of California Technical Report Co, 1983
11. T.V. Raman, AsTeR: Audio Systems for Technical Reading
12. T.V. Raman, Auditory User Interfaces: Toward the Speaking Computer, Boston, Kluwer Academic
13. J.H. Larkin, H.A. Simon, Why a diagram is (sometimes) worth ten thousand words, Cognitive Science, 11, 65-99, Cognitive Science Society, 1987
14. S. Palmer, Hierarchical structure in perceptual representation, Cognitive psychology, 9, 441, Elsevier, 1987
15. W. Schiff, E. Foulke, Tactual perception: a sourcebook. Cambridge, Cambridge University Press, 1982
16. T.P. Way, Automatic Generation of Tactile Graphics, PhD Thesis, University of Delaware, 1997
17. D. Parkes, Nomad: an audio-tactile tool for the aquisition, use and management of spatially distributed information by visually impaired people, Proceedings of the second international symposium on maps and graphics for visually handicapped people, 1988
18. S. Wall, S.A. Brewster: Hands-on haptics: exploring non-visual visualization using the sense of touch, CHI05, ACM Press, 2005

19. W. Schweikhardt, C. Bernareggi, N. Jessel, B. Encelle, M. Gut, LAMBDA: a European System to Access Mathematics with Braille and Audio Synthesis, ICCHP06, LNCS 4061, 1223-1230, Springer, 2006
20. A. D. Edwards, H. McCartney, F. Fogarolo, Vision: Lambda:: a multimodal approach to making mathematics accessible to blind students, ASSETS'06, ACM press, 2006
21. C. Bernareggi, Accessibility of two-dimensional structures in science learning, proceedings of the 2nd international Conference on automated production of cross media content for multi-channel distribution, Firenze University Press, 2006
22. A. Pepino, C. Freda, F. Ferraro, S. Pagliara, F. Zanfardino: "BlindMath" a new scientific editor for blind students, ICCHP06, Springer, 2006
23. C. Bernareggi, D. Archambault, Mathematics on the web: emerging opportunities for visually impaired people, W4A '07, Proceedings of the 2007 international cross-disciplinary conference on Web accessibility (W4A), ACM Press, 2007
24. N. Soiffer, MathPlayer: Web-based Math Accessibility, ASSETS'05, ACM Press, 2005
25. A.I. Karshmer G. Gupta E. Pontelli, K. Miesenberger, M. Batusic, B. Palmer, UMA: A System for Universal Mathematics Accessibility, ASSETS'04, ACM Press, 2004
26. P. Albert, Math Class: An Application for Dynamic Tactile Graphics, ICCHP06, LCNS, Vol. 4061, Springer, 2006
27. J. A. Gardner, V. Bulatov, H. Stowell, The ViewPlus IVEO technology for universally usable graphical information, Proceedings of the 2005 CSUN International Conference on Technology and Persons with Disabilities, Los Angeles, 2005
28. F. Winberg, Designing Auditory Displays to Facilitate Object Localization in Virtual Haptic 3D Environments, ASSETS06, ACM Press, 2006
29. P. Walsh, J. A. Gardner, TIGER, a new age of tactile text and graphics, Proceedings of the 2001 CSUN International Conference on Technology and Persons with Disabilities, Los Angeles, 2001
30. J. Gardner, "Dotsplus - better than braille?", Proceedings of the 1993 International Conference on Technology and Persons with Disabilities, Los Angeles, 1993