Deriving Accessible Science Books for the Blind Students of Physics

Georgios Kouroupetroglou and Hernisa Kacorri

National and Kapodistrian University of Athens,
Department of Informatics and Telecommunications,
Panepistimiopolis, Ilisia, GR-15784 Athens, Greece
e-mail: koupe@di.uoa.gr

Abstract. We present a novel integrated methodology for the development and production of accessible physics and science books from the elementary up to tertiary educational levels. This language independent approach adopts the Design-for-All principles, the available international standards for alternative formats and the Universal Design for Learning (UDL) Guidelines. Moreover it supports both static (embossed and refreshable tactile) and dynamic (based on synthetic speech and other sounds) accessibility. It can produce Tactile Books (Embossed Braille and Tactile Graphics), Digital Talking Books (or Digital Audio Books), Large Print Books as well as Acoustic-Tactile Books for the blind and visually impaired students as well as but for the print-disabled. This methodology has been successfully applied in the case of blind students of the Physics, Mathematics and Informatics Departments in the University of Athens.

Keywords: math accessibility, disabled students, Braille, inclusive education, Design for All
PACS: 01.40.E-, 01.30.M-

INTRODUCTION

The field of physics, and more general science, mathematics, technology and engineering have traditionally been inaccessible for the blind students. The education on those disciplines is highly based on visually-presented concepts and information. The lack of both proper access to educational resources and widespread availability of books in accessible formats in these domains comes with very difficult to read, write and learn physics and mathematics for blind persons. On the other hand, recent studies showed that blind and visually impaired students have the same range of cognitive abilities as sighted students and with proper inclusion and accessibility accommodations they can master higher-order science concepts as well as sighted students [1-4]. This problem starts in the primary school and gets progressively worse as pupils move towards higher education. Math gets more complicated and necessitates much more sophisticated and technology-based ways to be represented for people with total or partial visual loss. Essentially, access to science information, and most important to the relative educational books, has become the bottleneck which embarrasses the entrance of blind students in physics studies [5]. Thus, only rarely blind students choose to attain a high level of competence in physics and mathematics.

Making physics books accessible is a significant challenge, mainly due to the fact that, on one hand mathematics encompass a 2-dimensional and even a spatial nature and on the other hand both the Braille code and the synthetic speech, which are their common renditions, comprise inherently a linear nature. Furthermore, science books contain graphics, diagrams, drawings, pictures and photographs which have also to be delivered in an accessible tactile or acoustical format. Recently, significant progress has been made on the computer based assistive technology that facilitates the production of accessible science books [6-8].

The approaches to making math and science accessible can be classified into two types [6]:

a. Static Accessibility: The physics and science content is statically converted into a format that is reproducible either on computer based Braille embossers and other tactile devices, or on real time assistive devices, such as refreshable Braille displays and kinesthetic assistive devices. In this approach, the document is rather viewed as a passive entity, like a printed document presented to a sighted user, while the active component is represented by the

CP1203, 7th *International Conference of the Balkan Physical Union,* edited by A. Angelopoulos and T. Fildisis

blind or visually impaired student, who uses an appropriate assistive device to browse the document, move around it and read its content.

b. Dynamic Accessibility: The physics and science content is presented in a dynamic, interactive mode using synthetic speech or other sounds (including auditory icons, earcons or other sonic rendering). These approaches require a conversion process which allows the user to navigate through the mathematical content in accordance with its mathematical structure. In this case, the document itself becomes an active component; by performing intelligent transformation of the document, its semantic structure is exposed and information overload on the user is reduced.

Hybrid Accessibility essentially is a combination of the static and the dynamic accessibility.

Design-for-All or Universal Design constitutes an approach for building modern applications that need to accommodate for heterogeneity in user characteristics, devices and contexts of use [9-10]. While Universal Design does not necessarily solve all accessibility problems, it does incorporate a human factors "user-centered approach" to producing products (books in our case), so that they can be used by as many individuals as possible regardless of age, abilities, skills, requirements, situations, and preferences [11-12]. Thus in the domain of book design for all targets both non-disabled as well as all print disabled, i.e. persons who cannot effectively read print because of a visual, physical, perceptual, developmental, cognitive, or learning disability. Some have challenged the idea of Universal Design, arguing that the desire to make products that are highly flexible will result in products that are highly complex. However, the goal of Universal Design is not a single product, instead it is a design space populated with appropriate alternatives, together with the rationale underlying each alternative, that is the specific user and usage-context characteristics which each alternative has been designed for. A critical benefit of applying Universal Design is the economy of scale, i.e. decrease in the time and cost of production [13].

An extension of Design-for-All is the Universal Design for Learning (UDL) which helps meet the challenge of diversity by suggesting flexible instructional materials, techniques, and strategies that empower educators to meet these varied needs [14].

In this work we present a novel integrated methodology for the development and production of accessible physics and science books from the elementary up to tertiary educational levels. This language independent approach adopts the Design-for-All principles, the available international standards for alternative formats and the UDL Guidelines. Moreover it supports both static and dynamic accessibility. It can produce Tactile Books (Embossed Braille and Tactile Graphics), Digital Talking Books (DAISY [15] or Digital Audio Books), Large Print Books (for those with low vision) as well as Acoustic-Tactile Books for the blind and visually impaired students as well as but for the print-disabled.

METHODOLOGY

The original book may be in either hard copy or in inaccessible electronic format. The goal is to produce a book in alternative accessible formats for the whole community of print disabled.

Our methodology in deriving accessible science books includes four major stages (Figure 1): (I) book pre-processing to run into an appropriate electronic format, (II) editing of the mathematical/scientific expressions in order to have an intermediate universal accessible format, (III) elaboration of images and graphics to become accessible and (IV) production of the book in alternative accessible formats.

The following paragraphs describe the whole procedure is more details.

Book Pre-processing / Conversion into an Appropriate Electronic Format

This process involves the conversion of the science books into an editable and tagged document in a standard format. Book conversion into an electronic format is completed through the following steps: (1) scanning, (2) Optical Character Recognition (OCR) and (3) editing and formatting. It is depended upon the original book type whether the scanning and the OCR steps are required. Books original in an electronic format may bypass one or more steps of this process, while hard copy counterparts have to go through all the steps. For the accessibility of data tables we have adopted recently developed approaches [16-20].

The original hard copy book is scanned at 400 dpi and in black and white. Then, the scanned images are processed by OCR software like ABBYY FineReader engine [21]. The objects on a page, that are processed and recognized by the software, are reviewed by the editors. This step is important to identify reading patterns, columns, images and tables, which are not properly recognized by the OCR software. For instance, ABBYY engine many times misrecognize paragraphs inside images and tables. In this case, reviewers will have to manually correct content layout. If the content layout is left uncorrected, readers will encounter difficulties during reading process.

Since editing is generally tedious and time consuming, identifying potential errors at the OCR process is critical. Once the document verified and reviewed, it will be converted to an editable and tagged document such as Microsoft DOC. First, in the editing process the document has to be clearly formatted. Then reviewers searches and remove extra spaces and non-ASCII characters from the document. The formatting process involves reviewers revealing book structure by identifying pages, tables, foot notes, quotes, headings, captions, etc. In order to maintain uniformity over the derived accessible books and to increase editing performance and quality, automatic processes has to be designed and implemented.

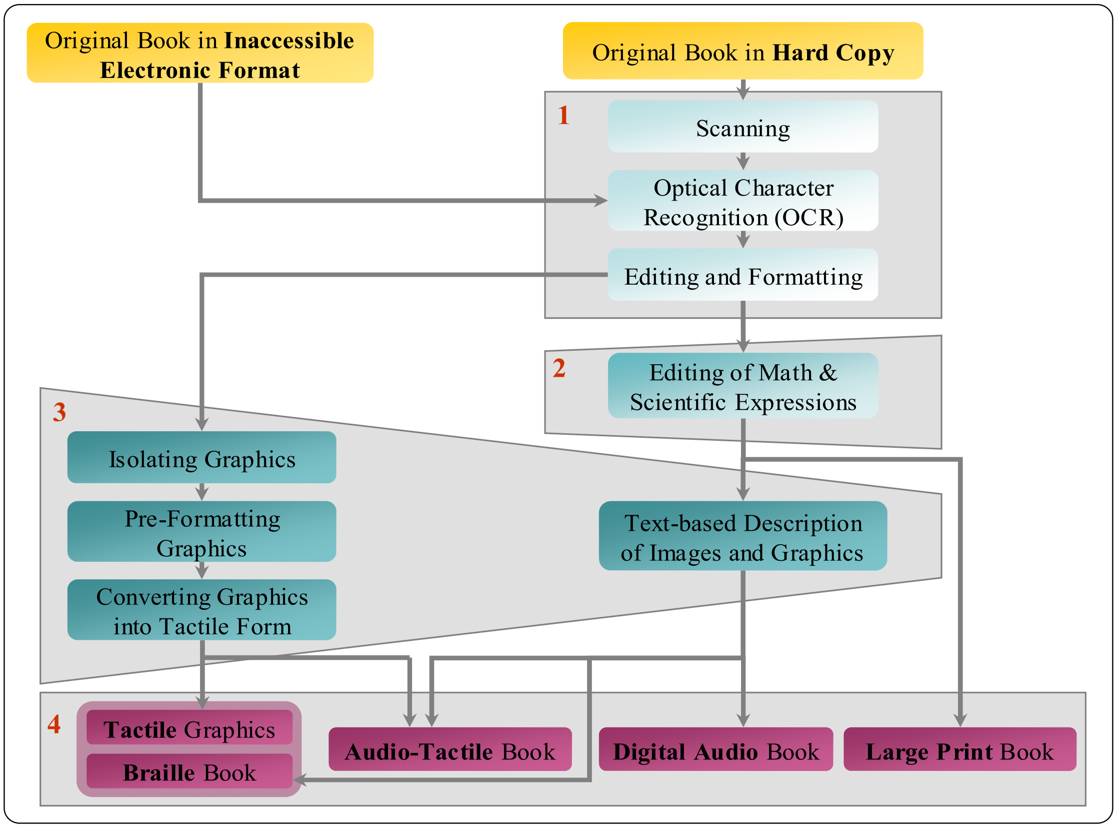

FIGURE 1. Science book conversion procedure into alternative accessible formats.

The steps that are escaped, in case that the primary format of the science book is electronic, depend on the document format source. In particular, it depends upon the percentage of the document content that can be retrieved. E.g, if the source is a PDF file that is created from images (scanning, photocopy, etc.) its conversion into an accessible format has to start from the OCR step. In case the structure and the content of the document can be retrieved from the PDF file, the OCR step can be skipped. In the case the book is in LaTex format, it constitutes a tagged document, and thus it can be easily converted into an accessible format using appropriate software tools.

Mathematical/Scientific Expressions Editing

For maths and science expressions four techniques dominate for their conversion into an accessible format: (1) the markup language MathML is used to provide access to math expressions through either MathPlayer [22] and/or screen readers, (2) LaTex is used to provide access through math-to-speech software tools in order to produce audio content, DAISY, Brialle, etc, (3) pre-recorded speech is used after readings the expressions and (4) Rule-Based Linearization (RBL) of math expressions is used to produce accessible content through screen readers. The LaTex approach is time consuming and requires professional LaTex editors. The technique of pre-recorded expressions does not allow easy navigation and pattern search inside the math formula. Due to above limitations, in our methodology we have used MathML and RBL.

MathML proposed by the WWW consortium [23]. It encodes both mathematical notation using *Presentation Markup* and mathematical meaning using *Content Markup*. Content Markup (strongly supported by OpenMath Society [24]) can be easily converted to Presentation Markup and seems to be ideal for audio rendering of mathematical expressions [25]. But, it is limited by the fact that: a) it includes a restricted set of math operators and functions and b) it is supported by a rather small number of editors. However, MathML provides an option to authors to choose any of these two markups, or even both of them in a hybrid mode.

Accessibility is one of the fundamental principles in MathML supporting: rendering into the acoustic modality by appropriate applications for reading maths (e.g. MathPlayer [22], MathTalk [26] and AudioMath[27]) that feeds common Text-to-Speech systems [7] [28], interpretation into any Mathematical Braille code (e.g. Nemeth [29]), print on a Braille embosser, display on a refreshable Braille display and navigation functionality in a mathematical expression. Today, MathML is an accepted standard in math applications, for example Maple and Mathematica. Thus, it is supported by various document standards like DAISY/NISO, ODF and Microsoft DOC. The InftyReader [30] OCR software intended for scientific documents could replace editors from having to enter mathematical formulas by hand, saving a lot of work.

In the cases the use of MathML is not possible, the next recommended method is RBL. Document content is produced by RBL when editors linearize the math formula using the set of symbols provided by the MS Word (comprising 90% of the applied scientific symbols) and a rule set similar to LatTeX language but much simpler. The main drawbacks of this approach are: (1) the linearization of the expressions in most cases creates a representation of the maximum length, which is harder to understand than the graphical representation, (2) the user has to be familiar first with the audio rendering of the symbols in English, (3) it is not a standard and (4) it does not meet the Design for All requirements since it is quite tedious for sighted people to read this expressions. However, RBL is language independent and both editors and users can be easily familiarized with it. Figure 2 provides a RBL example.

$$\frac{\alpha \frac{\beta \frac{2+\gamma}{3}}{\chi+1}}{\sqrt{a^2+b^2}}$$

```
frac { α * frac {β * ((2+γ)/ 3)} {χ + 1} \frac} {√(α^2 + β^2) } \frac
```

FIGURE 2. An example of Rule-Based Linearization.

Elaboration of Images and Graphics

Science books contain graphics (like diagrams, charts and drawings) and images (like pictures and photographs). All the above have to be converted in an accessible form. The conversion process in tactile form can be applied only in the case of rather simple graphics. The complexity and the small details in graphics reduce the degree of tactile perception. In those cases supplemental text description is used. As images can not be converted into a tactile form, text description is used instead.

The first step is to insert a caption label. This step is the same for both images and graphics. When it comes to images, a detailed description under the caption text is added. The description starts with the tag /D and ends with \D, where the letter D stands for the word Description. The expanse of the description is proportional to the volume of information that an image contains. For linear graphics the caption number works as an identifier of the graphic in its tactile form. A description, that defines whereas a tactile form such as Piaf is provided, is added under the caption starting with the tag / Piaf and ends with \ Piaf. The word stands for the device named P.I.A.F [31] used to produce tactile graphics. Hence, some of the graphics details such as numbers, letters or more complex expressions that will be removed on next step, have to be included to the text description. A set of rule is proposed for a unique description policy. Readers' navigation through the images and graphics are facilitated by the insertion of a table of images and a table of graphics. The automatic transcription of Tactile Maps has been described in [32].

The general procedure to convert graphics to tactile form include: (1) isolation of graphics for the rest content of the book, (2) pre-formatting of graphics and (3) convert graphics to tactile form using a device like P.I.A.F. Pre-formatting stands for replacing graphic details by their counterpart numbers which are produced according to a top-down and left to right graphic scan. An example of a tactile graphic is given in Figure 3.

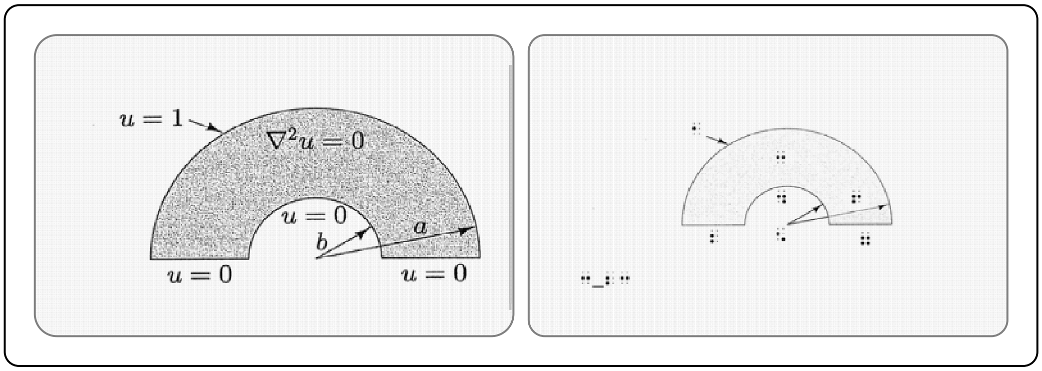

FIGURE 3. A scientific drawing (left) and its corresponding tactile diagram (right).

Book Production in Alternative Accessible Formats

During this stage one can produce Tactile Books (Embossed Braille and Tactile Graphics), Digital Talking Books (DAISY [15] or Digital Audio Books), Large Print Books (for those with low vision) as well as multimodal [33] Acoustic-Tactile Books for the blind and visually impaired students as well as but for the print-disabled.

The discrimination, perception and comprehension of synthetic speech (used in Digital Talking Books) by visually impaired students has been already studied [34-36].

For Braille embossing there are two options to use: either the Universal Maths Conversion Library (UMCL) [37] or a Braille translator like the Duxbury Braille Translator (DTB) [38] or WinBraille [39]. UMCL is a programming library that encapsulated conversion functions for different Braille. A number of appropriate software and/or hardware conversion tools are available for the production of a DAISY or Acoustic-Tactile Books [7].

CONCLUSION

We present a novel integrated methodology for the development and production of accessible physics and science books from the elementary up to tertiary educational levels. This language independent approach adopts the Design-for-All principles, the available international standards for alternative formats and the UDL Guidelines. It can produce Tactile Books (Embossed Braille and Tactile Graphics), Digital Talking Books (or Digital Audio Books), Large Print Books as well as Acoustic-Tactile Books for the blind and visually impaired students as well as but for the print-disabled. This methodology has been successfully applied in the case of blind students of the Physics, Mathematics and Informatics Departments in the University of Athens.

ACKNOWLEDGMENTS

The work described in this paper has been funded by the KAPODISTRIAS research program of the National and Kapodistrian University of Athens.

REFERENCES

1. M. Sahin and N. Yorek, "Teaching science to visually impaired students: A small-scale qualitative study". *US-China Education Review* **6**(4), 19-26 (2009).
2. D. Kumar, R. Ramasamy and G. Stefanich, "Science for students with visual impairments: Teaching suggestions and policy implications for secondary educators". *Electronic Journal of Science Education* **5**(3), (June 5, 2003).
3. McCarthy, C. "Effects of thematic-based, hands-on science teaching versus a textbook approach for students with disabilities" *Journal of Research in Science Teaching* **42**, 245-263 (2005).
4. M. Parry, M., Braizer and E. Fischbach, "Teaching college physics to a blind student" *The Physics Teacher* **35**, 470-474 (1997).
5. P. Stanley, "Assessing the Mathematics Related Communication Requirements of the Blind in Education and Career". *Lecture Notes in Computer Science (LNCS)* **5105**, 888–891 (2008).
6. A. Karshmer, G. Gupta and E. Pontelli. *Mathematics and Accessibility: A Survey*. University of Texas at Dallas (UTD) Technical Report, (February 2007).

7. D. Freitas and G. Kouroupetroglou, “Speech Technologies for Blind and Low Vision Persons”. *Technology and Disability* **20**(2), 135-156 (2008).
8. G. Kouroupetroglou and E. Florias. *Braille Scientific Notation in Greece-Application on Information Systems for the Blind*. Athens, Educational and Rehabilitation Center of the Blind (KEAT), 2003, ISBN 960-87918-0-4
9. C. Stephanidis, “User Interfaces for All: New perspectives into Human-Computer Interaction” in *User Interfaces for All - Concepts, Methods, and Tools*, edited by C. Stephanidis, Mahwah, NJ , Lawrence Erlbaum Associates, 2001, pp. 3-17.
10. C. Stephanidis, G. Salvendy, D. Akoumianakis, N. Bevan, J. Brewer, P.L. Emiliani, A. Galetsas, S. Haataja, I. Iakovidis, J. Jacko, P. Jenkins, A. Karshmer, P. Korn, A. Marcus, H. Murphy, C. Stary, G. Vanderheiden, G. Weber, and J. Ziegler., “Towards an Information Society for All: An International R&D Agenda”. *International Journal of Human-Computer Interaction* **10**(2), 107-134 (1998).
11. A. Newell and P. Gregor. “User sensitive inclusive design - In search of a new paradigm” in Proceedings of the Conference on *Universal Usability*, Arlington, ACM, 2000, pp. 39-44.
12. J. Abascal and C. Nicolle, “Moving towards inclusive design guidelines for socially and ethically aware HCI”. *Interacting with Computers* **17**, 484-505 (2005).
13. P.L. Emiliani, “Assistive technology versus mainstream technology: The research perspective”. *Technology and Disability* **18**, 19-29 (2006).
14. Universal Design for Learning, http://www.cast.org/
15. Digital Accessible Information System (DAISY) http://www.daisy.org/
16. E. Pontelli, D. Gillan, G. Gupta, A. Karshmer, E. Saad and W. Xiong, “Intelligent non-visual navigation of complex HTML structures”. *Universal Access in the Information Society* **2**(1), 56-69 (2002).
17. E. Pontelli, D. Gillan, W. Xiong, E. Saad, G. Gupta and A. Karshmer, A. “Navigation of HTML Tables, Frames, and XML Fragments” in Proc. of the ACM Conf. on *Assistive Technologies (ASSETS)*, 2002, pp.25-32.
18. D. Spiliotopoulos, P. Stavropoulou and G. Kouroupetroglou, “Acoustic Rendering of Data Tables Using Earcons and Prosody for Document Accessibility”. *Lecture Notes in Computer Science (LNCS)*, **5616**, 587-596 (2009).
19. D. Spiliotopoulos, G. Xydas, G. Kouroupetroglou, V. Argyropoulos and K. Ikospentaki, “Auditory accessibility of data tables using naturally derived prosody specification”. *Universal Access in the Information Society (UAIS)*, (in press) (2009).
20. D. Spiliotopoulos, G. Xydas, G. Kouroupetroglou and V. Argyropoulos, “Experimentation on Spoken Format of Tables in Auditory User Interfaces”, in Proc. of the 3rd Int. Conference on *Universal Access in Human-Computer Interaction*, 22-27 July 2005, Las Vegas, Nevada USA, **3**, pp 451-460.
21. ABBYY Software House, http://www.abbyy.com
22. Design Science, Math Player, http://www.dessci.com/en/products/mathplayer/
23. W3C Math Home, http://www.w3.org/Math/
24. OpenMath, http://www.openmath.org
25. P. Sandhu, *The MathML Handbook*, Charles River Media, 2002.
26. R. Stevens, A. Edwards and P. Harling, “Access to mathematics for visually disabled students through multimodal interaction”, *Human-Computer Interaction* **12**, 47- 92 (1997).
27. H. Ferreira and D. Freitas, “Enhancing the Accessibility of Mathematics for Blind People: The AudioMath Project”, *Lecture Notes in Computer Science (LNCS)* **3118**, 678-685 (2004).
28. K. Fellbaum and G. Kouroupetroglou, “Principles of Electronic Speech Processing with Applications for People with Disabilities”. *Technology and Disability* **20**, 55-85 (2008).
29. P. Stanley and A. Karshmer, “Translating Mathml into Nemeth Braille code”, *Lecture Notes in Computer Science (LNCS)* **4061**, 1175-1182 (2006).
30. M. Suzuki, F. Tamari, R. Fukuda, S. Uchida, and T. Kanahori, “INFTY – An integrated OCR system for mathematical documents,” in Proceedings of the ACM *Symposium on Document Engineering*, 2003, pp. 95–104.
31. P.I.A.F (Pictures in a flash) http://www.labcomputers.net/Products-P.I.A.F.htm
32. K. Papadopoulos, “Automatic Transcription of Tactile Maps”. *Journal of Visual Impairment and Blindness (JVIB)* **99**(4), 242-245 (2005).
33. G. Kouroupetroglou and D. Tsonos: “Multimodal Accessibility of Documents” in *Advances in Human-Computer Interaction*, edited by S. Pinder, Vienna, I-Tech Education and Publishing, 2008, pp 451-470, ISBN 978-953-7619-15-2
34. K. Papadopoulos, V. Argyropoulos and G. Kouroupetroglou, "*Discrimination, perception and comprehension of synthetic speech by visually impaired students: the case of similar acoustic patterns*", *Journal of Visual Impairment and Blindness (JVIB)* **102**(7), 420-429, 2008.
35. V. Argyropoulos, G. Sideridis, G. Kouroupetroglou and G. Xydas: "Auditory Discriminations of Typographic Attributes of Documents by Students with blidness", *British Journal of Visual Impairment* **27**(3), 183-203 (2009).
36. K. Papadopoulos, A. Koutsoklenis, E. Katemidou and A. Okalidou, “Perception of Synthetic and Natural Speech by Adults with Visual Impairments” *Journal of Visual Impairment and Blindness (JVIB)***103**(7), 2009
37. D. Archambault, D. Fitzpatrick, G. Gupta, A. Karshmer, K. Miesenberger, E. Pontelli, (2004). “Towards a universal maths conversion library” *Lecture Notes in Computer Science (LNCS)* **3118**, 664 – 669 (2004).
38. Duxbury Braille Translator, http://www.duxburysystems.com
39. WinBraille, http://www.indexbraille.com/