Euromath: **Enabling Mathematical Communication Between Teacher and Student Using UEB**

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# Abstract

For many students, mathematics represents a significant educational challenge. This is exacerbated in the context of blind students who must not only learn the concepts underpinning this discipline, but must also become proficient in the UEB linear representation. In this paper we outline a new tool, based on UEB, which aims to reduce the barriers of communication between the student and their teacher. We describe a web-based editor named Euromath and the newly designed conversion library which enables translation of mathematics presented in MathML into Unified English Braille (UEB).

# Introduction

One of the main goals of students' education is the acquisition of skills that will determine their functioning in the so-called community of knowledge and their success in the labour market. In 2006, the European Parliament (EP) described, defined, and issued recommendations concerning the acquisition of key competences in individual subjects and general knowledge by young people completing their compulsory education. Among the four subject-defined competences are those pertaining to mathematics and basic scientific and technical skills, as well as IT competences. The need to acquire mathematical abilities concerns amassing the aptitude to develop and use mathematical thinking in solving problems arising from everyday situations, with an emphasis on process, action, and knowledge.

For many blind students active participation has proven to be difficult [1, 2, 3, 4]. there are many reasons for this, and it is beyond the scope of this paper to explore these in depth. However one of the primary barriers to successful engagement by many blind students in STEM (Science, Technology, engineering and Mathematics) subjects is the lack of available and accessible solutions to assist in working with this type of content [5, 6]. In an attempt to rectify this situation partners at Dublin city University (Ireland), royal visio (the Netherlands) and NASK (Poland) have been working in collaboration to develop a web-based editor known as EuroMath. this software solution (based on award-winning work described in [7]facilitates creation of exercises, worksheets and other resources by a teacher who uses the traditional printed notation, and the presentation of this material in UEB. The tool also enables the blind student to answer questions, complete exercises etc. using UEB, and to have them translated back to standard printed notation. Underpinning this application is a new and lightweight converter which converts expressions prepared in MathML (Mathematics Mark-up Language) to UEB (Unified English Braille) and vice versa. This lightweight software framework is still at the prototype stage; however, it underpins much of the Euromath application. It should be noted that as well as enabling students to browse using refreshable Braille Displays, it is also possible for paper-based versions of the material to be embossed.

## About Euromath

The overarching goal of the EuroMath project [8] is to design an innovative multi-tool ICT platform to support teachers and learners with visual impairments in math instruction. Access to EuroMath solutions will be freeware. The project attempts to meet ICT needs that will level the playing field for learners with visual impairments in gaining math competencies aligned with the elementary and secondary education curricula in the partner countries (Ireland, Poland and the Netherlands). Both learners educated in the inclusive and mainstream settings, along with their teachers, will also benefit from the outcomes of the project.

The Euromath platform is based on open standards and web technologies. the editor will enable text, mathematical objects, as well as graphics, to be added to documents using a variety of input methods. Once complete, the document is then saved as an EPUB3 format which can either be perused by the student in the Euromath application, or exported for use in other E-Readers.

It should be stressed that the student may choose a variety of modalities with which to interact with the content produced as part of the EuroMath application. It is possible to explore using Braille (UEB as well as the BNN notation used in Poland), synthetic speech (using screen readers such as NVDA or JAWS) and large print; or indeed combinations of the above. It is not the intention of the developers to be in any way prescriptive by dictating which method a student should use to access the material. Rather, it is the intention to provide as many modalities as possible.

As has been stated previously, the EuroMath platform is a web-based editor which works in most modern browsers. It has been tested on Mozilla Firefox, Google Chrome, Microsoft Edge, and Safari. At the time of writing, we do not recommend using Safari with the platform as there are some unresolved issues. Like other such tools, the Euromath editor has a very standard look-and-feel. It contains menus, toolbars, and an area wherein one may input the desired content. Some of the functionality which the platform includes is:

1. The ability to input mathematics using AsciiMath and to have it translated into uEB.
2. The ability to input mathematics using Unicode characters and to have this material translated into UEB
3. The ability to input using UEB notation (either via a QWERTy-based keyboard or an external Braille display) and to have it translated into Printed representations.
4. The ability to insert graphics in SVG format, and to explore them using touch-screen enabled devices. Note that it is also possible for blind users to prepare simple graphics through a simple command-language, and the specification of coordinates and dimensions.
5. The ability to emboss the material onto paper.

## Paper Organisation

In the remainder of this paper, we will describe the issues which the Euromath application aims to solve. Section 2 briefly describes some research which forms the basis of the EuroMath Project. Section 3 describes a sample scenario of use, whilst sections 4 and 5 outline the implementation and testing of the UEB2MathML, and MathML2UEB converters which form the backbone of the translation process. The paper concludes with some thoughts on the future work needed to complete the project.

# Previous Research

One of the key decisions which must be made when considering the design of a suite of tools to provide access for blind and visually impaired people is the means of presenting the information to the target user. In order to implement this ideal, the notion of what information to present needs to be decided on first, followed by how to present this material. It is therefore important to understand the reading process, in order to fulfil the dual purpose of determining both what and how to present the relevant information to the user.

A key feature which is present in the visual reading process is the role of the printed page. This medium affords the reader not only the facility to act as an external memory, but also facilitates a highly refined control over the flow of information. In his Ph.D. thesis, Stevens [9] states that Raynor

describes reading as: “…the ability to extract visual information from the page and comprehend the meaning of the text” [10]. Stevens also tells us that reading can be divided into three main domains:

* The process of understanding what has been read.
* The input of information from a physical, external source, into the reader's memory via the visual system;
* The recognition of words and their integration into higher level structures such as sentences.

Unlike linguistically-oriented material, the presentation of mathematics in a manner which is accessible poses significant challenges. Karshmer et al. [11] highlight the two-dimensional nature of visual or printed mathematic equations, which is difficult to convey through both linear systems of synthesized speech and Braille. The spatial representation of equations can encode essential semantic information very necessary to understanding the mathematic construct.

The primary issue when translating mathematics from print to Braille or audio-based output is that of transforming a two-dimensional representation, where the spatial arrangement of symbols juxtaposed with white space gives rich semantic and syntactic understanding, into a linear presentation. If we consider the fact that the sighted reader has the entire scope of a two-dimensional page, whereas the reader using Braille will only have a linear representation with which to interact, then it can be inferred that it will be easier for the sighted user to locate, and extract, salient features of the equation which will aid in its understanding. Sighted users can therefore utilise printed material as a form of external memory and do not need to memorize the structure and layout of an equation. This conclusion is supported by the results of a series of cognitive experiments examining equation reading in sighted users, conducted by Gillan et al [12] , which found that sighted subjects process operators and numbers more intensively than parentheses. This is perhaps unsurprising as the spatial structure of the equation (which is implied through the use of parentheses and other graphical symbols and delimiters) is unambiguous and persistent when presented visually. This suggests that working with mathematical material in a non-visual medium will result in an inevitable increase in cognitive load as this structural information must now be held in memory. This strongly implies that any method of presenting the spatial structure of an equation in a non-visual manner must be as easy as possible to cognitively process.

This brings its own unique challenges. As well as transforming the material into a spoken or Braille representation, the developer of any system must supply mechanisms to enable the user to read mathematics in its entirety, or indeed to decompose the material into chunks for easy navigation. That so many attempts have been made to solve this particular problem is a testament to its intransigence.

# Sample Scenario of use

Before describing the implementation details of our converter, we present an illustrative example detailing how it fits into the overall framework of the EuroMath application, and how both teacher and student might use both the converter itself and indeed the overall EuroMath application as a whole.

Let us assume that a teacher wishes to prepare some material for their blind student. She goes to the EuroMath application website where a blank document appears. Text and mathematics may now be entered. the teacher has a choice to use AsciiMath [13], Unicode characters, or indeed Braille to enter the mathematical content. At this juncture, the teacher has a choice. they can:

1. emboss the document;
2. Save the document which their student can then access.

let us now turn to the student. She receives the file and can open it in the EuroMath application. the text and mathematics appear in UEB which they can explore using their Braille display. If the teacher has included exercises, then the student may use the functionality which enables input of mathematics using UEB which is then converted, and available for her teacher in standard printed notation.

# Converting to and from UEB

this section of the paper contains details pertaining to the implementation of our converter. For those who are not programmers, or who are not interested in the technical details we recommend ignoring this section and skipping to the next one, as it is not necessary to read this in order to gain an overview of our work.

## Objective

The main goal of this development effort is to develop an easy to use lightweight converter which is independent of external libraries. Unlike other translation libraries such as LibLouis [14], the intention behind our approach is to facilitate the rapid deployment and integration with web-based software systems. to that end, we chose to develop our converters using the Javascript language, and to do so in a manner which meant that it was not dependent on any external libraries.

## General Description

During the Euromath project, two converters and two translators were developed. One was designed to take a math equation in the MathML format and to translate this into UEB, whilst the other performed the reverse. Converting UEB to MathML and vice-versa is based on a paradigm of both character replacement and parsing of the derived content.

the UEB2Mathml library is responsible for converting mathematical expressions from UEB to MathML. the reason for this choice was twofold:

1. MathML is an open standard and is used in a wide variety of contexts for the display of mathematical content.
2. Using this output format enables various types of navigational strategies to be build on top of our converter. For example, the MathJax [15] library (used for the display of equations on the web) already has excellent keyboard navigation built in.

This version accepts a single mathematical equation and does not convert embedded equations wrapped with text. thus, we envisage that this converter will be used as part of other components of a software system.

In the first translation phase, the converter initially replaces all Braille symbols with their ASCII equivalent. Since UEB implements many mathematical and technical) concepts utilising the vast range of combinations of single symbols, initially the group of UEB symbols is converted. The second stage is responsible for parsing the obtained ASCII string from left to right and converting it to the appropriate MathML representation. It should be noted that as well as the size of the symbol-group that defines conversion order, another priority system has been considered. Based on this priority system, symbols are converted based on the following Indicators, Terminators, Closures, unit and currency, Operators, and alphanumeric symbols.

In the case of MathML to UEB, a similar process occurs. Here, the MathML entities are first translated into an ASCII equivalent. following on from this, the string thus produced is transformed into UEB.

## Limitations

As with all projects which are in their infancy, ours has some limitations and we feel that it would be remiss not to acknowledge them. They are summarised below.

1. In the case of fractions we recommend enclosing the numerator and denominator separately in brackets.
2. In the case of polynomial expressions we recommend enclosing subscripts and superscriptss separately in brackets.
3. In the case where a radical sign must be used, we ask users not to omit the ending indicator.

# Testing and Evaluation

A mixed-methods approach was carried out to test and evaluate our converters. A set of automated tests took place as well as an analysis involving human participants. Details of the approach as well as a discussion of results are provided below.

## Mathematical Content

\More than 200 common mathematical expressions were collected. The test-set was gleaned from many resources pertaining to the Irish mathematics curriculum. the materials covered the following facets of mathematics taught in Ireland:

* Algebra;
* Shapes;
* Terminology;;
* Geometry;
* Function (Integral & Logarithm.

## Phase 1.

The equations were created in MathML , and then automatically read in to the MathML2UEB converter. the resulting UEB output was stored in a simple text-file. This text file of UEB formulae was subsequently sent as input to the UEB2MathML converter. The two MathML files (i.e., the original source and the one gleaned from the back-translation process) were then compared and any differences noted and subsequently (if needed) fixed.

## Phase 2

The second phase of testing involved the use of a second Braille translator; namely Duxbury. The equations used in Phase one were translated by Duxbury into UEB and again saved as plain text. this material was then passed to our UEB2MathMl converter and the MathML obtained. At this point, manual verification took place. It was possible to compare:

1. The UEB obtained from the Duxbury translator against our converter.
2. The MathML obtained by back-translating the duxbury-generated UEB (using our own converter) with the original source MathML.

## Discussion of Results

The obtained results indicate all UEB expressions were successfully converted to MathML. However, the limitations described previously should be born in mind when considering these results. the recognition and translation of symbols (in both directions) was extremely high. Three expressions failed when converted from MathML to UEB. Furthermore, comparison results show extra brackets in the output from the converters. whilst it may be the case that these brackets may avoid ambiguity, they do cause a departure from the original source material. these issues will be resolved during the next phase of development.

# Conclusions and Future Work

This paper presents a very brief overview of work carried out as part of the EuroMath project to translate equations produced in the MathML format to Unified English Braille (UEB) and vice versa. The approach taken focussed on the development of a self-contained and lightweight implementation which did not rely on any external dependencies.

whilst initial test-results are favourable, we wish to stress that this library is very much at the initial stages of development, and is merely a prototype. Findings reveal that transcription of symbols is extremely accurate, however the addition of extra brackets and issues around layout need to be resolved before it can be considered "production-ready". It is our hope that this effort marks the beginning of a programme of research which will, when completed, enhance the educational and professional opportunities for readers who use Braille. UEB, in contrast to other Braille codes, is still in its infancy and we believe that the work outlined here marks a small step in the process of producing fast, accurate and reliable content for those who wish to study or work in areas where mathematics plays a role.

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