EuroMath: A Web-Based Platform for Teaching of Accessible Mathematics

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Abstract. 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. However, for many persons who are either blind or vision-impaired, there remains considerable barriers to equal participation in disciplines which rely on mathematical content. This paper describes the EuroMath project which has, over the past three years, developed a web-based solution to enable mathematical communication between teachers and students. Note that we do not stipulate whether the student or teacher is the individual with the visual disability. Rather, we assume that said individual can fulfil either role. To this end, the EuroMath platform has been designed to enable the person who is blind or vision-impaired to create mathematical content or acquire it from others.

Keywords: Accessible mathematics · Braille · STEM accessibility

1 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.

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 and resources to assist in working with this type of content. To rectify this situation partners at Dublin city University (Ireland), royal Dutch visio (the Netherlands) and NASK (Project coordinator, Poland) have been working in collaboration to develop a technological platform known as EuroMath. This web-based solution facilitates creation of math-based exercises, worksheets and other resources by a teacher who uses the traditional printed notation, and the presentation of this material in various accessible formats such as speech, large print, Unified English Braille and the Braille notation used in Poland (BNM). The tool also enables the blind student to peruse mathematical material, complete exercises, and answer quizzes etc. using their preferred input modality, and to have them translated back to standard printed notation.

The goals of this project are:

- To enable blind and vision-impaired students and their teachers to communicate mathematical concepts in a manner and using modalities which are most appropriate to their needs.
- To ensure that the blind and vision-impaired student can access the platform using technology with which they are already familiar such as their screen reader, note-taker, and/or Braille display of choice.
- To ensure that all project artefacts are built on open standards.

This work builds on previous efforts, entitled Platmat [1] which focused on the development of a suite of windows-based tools to provide access to mathematics for blind and vision-impaired students and their teachers in Poland. This award-winning project demonstrated that the techniques underpinning the EuroMath project were effective in providing communication mechanisms for mathematical content. The EuroMath platform seeks to provide a freeform editor which incorporates textual, mathematical and graphical elements. During the initial phases of design and exploration, it became apparent that many students did not, in fact, use traditional Windows-based computers to engage with their educational resources. Thus, a primary concern became how best to facilitate access to the content using a variety of devices and Operating Systems; not to mention input and output modalities. Thus, the EuroMath platform was developed using open web standards to cater for the diverse usage patterns of the demographic.

As well as providing a platform for the preparation and manipulation of mathematical material the EuroMath platform also seeks to provide a portal for the sharing of content. This portal has several functions which are:

- To enable a teacher to save learning content which can then be accessed by their students;
- To provide a mechanism for students to upload their solutions to problems and exercises provided by their teacher;
To enable teachers to share examples of best practice which others may use in turn to teach their students.

The remainder of this paper will focus on the platform itself. It provides a brief overview of the state-of-the-art on which this project is based. It will also describe the design and implementation of the platform as well as the steps taken to evaluate its efficacy. We conclude with a discussion of the impact this work may have in the context of both teachers and students and outline some plans for future development.

2 State of the Art

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 [2] states that Raynor [3] describes reading as: “…the ability to extract visual information from the page and comprehend the meaning of the text”. 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 [2].

These design decisions have enormous implications for the presentation of mathematical material in an educational context. It is imperative that students be afforded the opportunities to learn and/or manipulate formulas, rather than diverting large amounts of additional cognitive effort to memorising content. In [4], it has been shown that reading equations to blind students does involve a significantly increased cognitive load. Thus, the goal of any system should be to ensure that, to the greatest extent possible, this is reduced.

3 Platform Design and Implementation

3.1 Initial Research

Prior to embarking on the implementation phase, research was conducted into the state of educational activity in respect of mathematics in the partner countries; namely Ireland, the Netherlands and Poland. It is beyond the scope of this paper to describe the
findings of this work in detail; however, the reader is directed to [5] for further information. What was discovered was that for many blind students both the design of the curriculum and a lack of access to relevant technologies were amongst the major barriers to completion of studies. It also emerged that devices such as Braille notetakers (such as those manufactured by Humanware and Hims Inc.) were very much utilised by the students in question. This report greatly informed and guided the design process for the EuroMath platform.

3.2 Design and Implementation

As was stated in the introductory section, a key principle of this research was that all components and related artefacts should be based on open standards and web technologies. To this end, the editor was designed using components built in accordance with the w3C web standards. The user interface components are all built using HTML, CSS and JavaScript whilst underlying internal representations of mathematics have been built on MathML. This ensures interoperability with other web-based technologies and ensures compatibility with screen readers and other Assistive Technology commonly utilised by blind and vision-impaired people.

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. There are several different types of material one may add to a document in this platform. They include text, mathematical equations and graphics. Each of these are presented in a manner which is accessible to users both with and without vision.

The EuroMath editor has been designed to satisfy several key criteria. Firstly, Students should be able to interact with mathematical content using a variety of input and/or output modalities. To that end, it is possible to explore using Braille (UEB as well as the BNM 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. To facilitate this, the following have been implemented:

- An editor based on Tiny MCE [6] which has been significantly extended to enable the input and the display of mathematics. The extensions have been achieved through the use of provided APIs and customisation of underlying CSS code.
- A lightweight JavaScript converter developed as part of the EuroMath project to translate from MathML to Unified English Braille (and vice Versa).
- A converter which enables translation of Mathematical content to and from BNM.
- Incorporation of the MathJax [7] library which enables perusal of the information using synthetic speech.
- Components which enable mathematics to be input using AsciiMath [8], Unicode, or Braille.
- The ability to input using Unified English Braille notation (either via a Qwerty-based keyboard or an external Braille display) and to have it translated into Printed representations.
– The ability to insert graphics in SVG format, and to explore them using touchscreen enabled devices. Note that it is also possible for blind users to prepare rudimentary graphics through a simple command-language, and the specification of coordinates and dimensions.
– Interoperability with external tools such as Desmos [8].
– The ability to emboss textual, mathematical and graphical material onto paper.

4 Example Use Case

Whilst recognising other stellar efforts in this space such as [10, 11] The EuroMath platform seeks to provide a freeform editor which incorporates textual, mathematical and graphical elements in a single document. The following is a simple scenario of use.

During the Covid-19 pandemic, a teacher in a mainstream school wishes to create exercises for her student who is blind. Because of the social distancing requirements imposed, it is not possible for the teacher to provide the exercise in a face-to-face manner. She decides to use the EuroMath platform. To this end, she opens the website and is greeted with the EuroMath interface.

The teacher writes some explanatory text in which she describes the assignment for the day. She then adds some mathematical content using the Unicode editor. The EuroMath platform renders the textual and mathematical content into Braille; the student’s preferred modality. This exercise is then saved onto the Euromath Portal.

The student logs onto the EuroMath Portal and downloads his exercise. He accesses the content using Braille, and answers the questions using the same modality. The EuroMath platform translates the textual and mathematical material back into the standard printed notation with which his teacher is familiar. This is then saved to the portal by the student. She can now look at the student’s work and provide appropriate feedback.

5 Evaluation

The evaluation methodology has been based on a multi-phased approach. Firstly, internal review took place to determine whether each of the components worked as expected. This necessitated testing with a variety of screen reader and browser combinations, as well as utilising devices such as notetakers which are commonly used by blind and vision-impaired people. It should be noted that two of the developers on this project were themselves blind and have extensive experience of the screen reader and browser technologies used to verify the functional completeness of the components of the EuroMath platform. Once all issues had been resolved, then the second phase, comprising expert review from stakeholders, took place.

In this series of evaluations, a functional description of the project was provided to teachers of mathematics. Whilst some had experience in teaching this material to blind and vision-impaired students, it was not deemed to be a prerequisite for participation. It was felt that, as this platform would be used in a mainstream educational setting, input
from individuals who had no prior knowledge of teaching mathematics to those with visual disabilities was deemed to also be desirable. Teachers were simply asked to explore the functionality of the platform, and to use it to prepare lessons, or any other types of document containing mathematical content they thought appropriate. They were asked to envisage scenarios in which they might use this system in a classroom situation, or to provide homework and/or quizzes to their students for completion in an independent-learning situation. They were asked to engage with the platform over a period of weeks, and to note their responses on a survey which was then returned to the project partners. They were permitted to contact partners to seek guidance on any aspect of the platform which was not clear. During this phase students were also given access to the platform and were also asked to complete and return the same survey. In this discussion, results will be described in the context of Irish participants comprising 3 mainstream teachers of mathematics, one blind student, and one teacher with expertise in teaching students who are blind or vision impaired.

Whilst acknowledging the lack of a laboratory-based controlled set-up, it was felt that a more long-term study of this nature would yield better results. Firstly, this approach gave the participants time and leisure to explore the platform using their own equipment and circumstances of use. Secondly, it provided a broader more nuanced set of opinions on the overall usability and suitability of the system. At this juncture, it is only appropriate to acknowledge a glaring limitation in the evaluation described here. We are aware that no inferences can or should be drawn from results gained from only one blind student. Consequently, no statistical data is provided here as we feel that it would be unsound, and unreproducible should others attempt to duplicate our efforts. Thus, we present the findings as anecdotal only. In justification for this lack, we wish to point out that, owing to the restrictions imposed by the Irish government, it was not permissible for evaluators to enter schools and consequently the original face-to-face data-gathering exercises had to be abandoned. It is our intention to undertake the originally scheduled evaluations with younger blind and vision impaired students once restrictions have been lifted and they, and their teachers, return to school.

The context of use for the three mainstream teachers was as follows: A student was undertaking a first-year mathematics course as part of a degree programme in an Irish university. The EuroMath project was proposed as a solution to provide access to learning resources, exercises and assessments for this semester-long module. The evaluation had several key objectives:

- Could teachers and other relevant support staff/content creators provide the same, or analogous resources to the blind student?
- Could the blind student receive and access the resources?
- Could the blind student use the EuroMath platform to complete the exercises and/or assignments provided?

Results gleaned from all participants were extremely positive. In the Irish context teachers with experience of supporting blind and vision-impaired students recognise the potential that the EuroMath platform offers. The ability to remotely deliver material to the student was considered a significant bonus. What was noteworthy in the
feedback, however, was the comments on the newly developed converter for Unified English Braille. Again, comments from teachers suggest that given the newness of this Braille code, accurate translation of mathematical material is not widely available. For teachers in the mainstream educational context, the most noted feature was that the EuroMath platform negated the need for the teacher to learn Braille in order to communicate with their students who were blind. This, it was felt, represented the removal of a significant stumbling block in the educational process. Teachers provided materials to their blind students who were able to interact with the content thus prepared. Indeed, it is noteworthy that the blind student who took part in the evaluation process successfully used the EuroMath platform in order to access their learning content. Both student and teachers did uncover functional bugs which have been addressed in the post-evaluation phase.

6 Conclusion

The overarching goal of the EuroMath project has always been 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 outcomes of the evaluation undertaken in the three partner countries, and described here in the context of Irish responses, certainly demonstrate an appetite for the EuroMath concept. That a cohort of mainstream teachers and a blind student were able to prepare and access materials using the platform, and consequently guarantee that said student could complete a first year university module in mathematics speaks to the efficacy of the platform, however more work needs to be carried out with younger students to ensure that it is suitable for those with less technical experience.

Given the modular design of the platform, we see no reason why, with the addition of minor modifications, it cannot be extended to cater for the curricula in other countries. Of most relevance, however, is that as the EuroMath platform, being web-based, is ideally suited to online/remote delivery of learning material. As has been seen from the dramatic shift to this type of educational provision caused by the Covid-19 epidemic, the need for tools which can ensure equal participation of blind and vision-impaired students in an online educational setting are vital. EuroMath is perfectly positioned to cater for the needs of face-to-face or remote learning, and thus can offer students and teachers alike the opportunity to overcome the educational challenges which have, thus far, formed a significant barrier for many blind and vision-impaired students.
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