Education and STEM on the Web

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Abstract

Difficulty accessing digital educational material in the fields of science, technology, engineering and mathematics (STEM) hinders many students from receiving an education according to his/her preferences and fully enjoying the opportunities offered by our technology-enhanced society. Web resources enhance the delivery of STEM content by offering interactive and visual models, dynamic content, videos, quizzes, games and more. STEM content can be delivered in several ways including visually, vocally, or through a 3-D printed Braille bar or other assistive technology. In this chapter we focus on the accessibility of STEM Web content for students with disabilities who are prevented from fully accessing digital visual resources, precluding a fully inclusive education. This chapter offers an overview of the state of the art of accessibility of STEM content on the Web, focusing especially on the experience of blind students. Existing issues and the authors' opinions in the field are aimed at motivating future research and development.

1 Introduction

Technology now shapes our life in every field, including education. Accessibility is crucial for any student, including those with disabilities. The challenge is delivering the full content in different formats and rhythms, to effectively reach individual perceptive channels and offer an environment in which to interact easily, enabling learning.

The design of digital frameworks for science, technology, engineering, and mathematics (STEM) education should address the needs of students who experience 'learning difficulties', utilizing a multidisciplinary approach from different perspectives, integrating several components and carefully considering recent findings in cognitive psychology and neuroscience (Robotti et al., 2017). Studies in cognitive science shed light on the complexity of the brain and perception processes in problem solving and mathematical skills, by showing a correlation between mathematics outcome, working memory and verbal skills (Devine et al., 2013). It is remarkable that the integration of sensorial, perceptive, tactile and kinesthetic experiences contributes to the creation of mathematical thinking and the development of abstract concepts (Arzarello, 2006). Lack of visual perception, especially from birth, may impact on the acquisition of spatial skills, which are related to mathematics outcome (Rourke & Conway, 1997).

In the Digital Age, an accessible education implies delivering the same educational digital content to students with different abilities via diverse perception channels and assistive tools (Basham et al., 2013). Accessible teaching is crucial for enabling learning in the digital environment; this involves perception, understanding, experience and the ability to interact with active and dynamic interface elements. However, in spite of a number of studies on accessibility, applications and assistive tools, various barriers still undermine access to STEM education, hinder careers and influence the overall quality of life of persons with disability (Israel et al., 2013).

Difficulty accessing mathematics and STEM content in general are often experienced by individuals with visual, cognitive and learning disability. The introduction of digital learning environments can further increase the difficulties experienced. Sightless people have the most evident form of impairment in accessing digital graphic materials, but other students such as people with intellectual and developmental disabilities or dyslexia may also experience important difficulties. For instance, the abstract nature of symbols and math formulae, the representation of equations, and the visual structure of tables and diagrams are all challenges for blind students. Data need to be sequentialized, to be perceived by the aural or tactile channel, and embossed paper can help a student perceive borders and the main features (e.g., geography/geometry charts). Educational materials and environments developed to support students in the learning process should be designed in an accessible and effective manner. While technology and innovation are evolving, including in the accessibility field, STEM education still presents many barriers for users with disability. Here we intend to analyze the current status and potential prospects to offer a contribution to the field.

In the following, we mainly focus on the needs of totally blind people, who are severely penalized by poor usability of STEM web content and digital environments. They experience great difficulties since the interaction via keyboard, screen reader and voice synthesizer requires more time (serialization) and cognitive effort (the structure is mixed with the content) compared to other disabilities.

First we introduce an overview of STEM education for people with disability, then discuss accessibility in education with special attention to STEM via Web. Next, some applications for facilitating access to and manipulation of math content for blind students are illustrated. Last, a discussion on open issues, future research directions, and the authors' opinions regarding this field end the chapter.

2 STEM Education for people with disability

Students with sensory or motor disabilities are often discouraged from pursuing STEM careers since they frequently have poor skills for accessing university

STEM studies due to inadequate preparation and limited post-secondary accommodations (Rule & Stefanich, 2012). This limitation penalizes people with disability, denying equal participation in the right to follow a full education program.

College enrollment and STEM participation of individuals with ASD (Autism Spectrum Disorder) vs other categories of disability have been investigated by Wei et al. (2013). Despite showing one of the lowest overall enrollment rates, college students with ASD are most likely to pursue STEM majors. This result confirms that students with ASD who have the ability to study are more likely than the general population and other disability groups to study STEM (Wei et al., 2012).

Different disabilities can affect individuals in different ways, and since disability is a complex issue, this means that even people who share the same disability might not experience the same problems. This might also account for the difficulties encountered when designing for various disabilities. Nevertheless, some common challenges are shared by various disabilities (Jenson et al., 2011).

This chapter focuses on students who have difficulty reading printed text, such as those with blindness, low vision, and learning disabilities, and who often rely on speech for information input. It is very important to understand how different abilities can affect an individual, including which assistive technologies may benefit them and which formats of learning materials are compatible with their disability.

Visually impaired students who wish to attend university courses and/or perform a job requiring involving scientific texts, encounter enormous difficulties, and even when they have a high IQ score are often forced to choose other activities. Villanueva et al. (2017) report a narrative survey concerning 60 blind students in STEM education.

The common core of STEM is mathematics: “From physics to economy, through chemistry, biology, computer science, mathematical expressions are at the heart of modelling and understanding science” (Archambault, 2009).

Mathematical language contains two components: meaning and notation (Pierce, 2012). The algebraic expressions converted to spoken language by popular screen readers could be misinterpreted if the semantics of the notation typical of mathematics (such as parentheses, scope of operators, fraction, power, root, functions) are not communicated. Ambiguities create an obstacle for the acquisition of basic mathematics, science and technological topics for people with visual disability. The first problem is due to poor rendering of math content on the web, due to old browsers or assistive technologies. Fortunately, in recent years the interpretation of math formulae has been gradually incorporated by popular screen readers.

In order to understand the studies and the opportunities available for people with disabilities who access STEM, it is crucial to comprehend the main problems encountered. We hereby intend consider the main lacunae in the education of people with disabilities, with special attention to Web tools and content. Different disabilities imply different adaptation of the material to suit the assistive technology or the individual’s learning needs. Material and content available in learning systems or virtual environments require specific personalization, especially when more than one disability is present (Nganji et al., 2015).

2.1 Visual Impairment

A whole range of disabilities affects vision, including partial sight, low vision, color blindness, and total and legal blindness. Since e-learning involves a significant use of the sense of sight, people with visual impairment risk being excluded if the learning environment is not designed to be accessible, providing an appropriate assistive technology to compensate for vision loss and/or personalizing learning for students with this disability. Various assistive technologies help visually impaired persons access online information -- screen magnifiers enlarge content on the screen, screen readers read content to the user, and Refreshable Braille Display Devices provide information by stimulating the sense of touch. For more information, please refer to the chapter “Assistive Technologies” (Nicolau et al.).

An important consideration when designing for individuals with disabilities in Web-based learning environments is to ensure that accessibility requirements are followed closely. Simple requirements such as alternative texts for images are very important, but for more complex content this might not be enough to assure a suitable support for learning purposes.

Particular attention and care are required when designing accessibility for STEM topics since it is quite complex to make scientific content usable via assistive technology. For people with severe visual impairment or who are totally blind, appropriate formats of learning materials include Braille, tactile representations, audio and digital text. Audio allows use of the sense of hearing to assimilate the information while screen readers can be used to read out the text. Braille is more suitable for those who have been blind from birth and tactile formats may be very important for understanding certain elements and concepts that are more easily perceived via touch. Color-blind individuals instead can exploit any format and enjoy images and videos.

Suitable support is needed to provide totally blind people with equivalent and effective STEM materials. Since some low-vision users rely on a screen reader to interact with the user interface, in the following we refer to screen-reader users.

Digital content and applications are becoming increasingly useful for visually impaired people, provided they are very confident with the devices, applications as well as assistive technology, and accessibility is guaranteed by the developers and designers. In this perspective, visually impaired students need to acquire a range of technology skills. The use and maintenance of assistive technology is then part of the curriculum for students with visual impairment.

Science, technology and mathematics are widely based on graphical and visual content. Making this content completely and truly accessible via screen reader is a challenge; sometimes audio descriptions or alternative text for certain graphical content might not be inadequate to fully explain a concept.

Moreover, handling formulae and graphical functions can be very difficult for a blind person. This occurs especially when practicing and performing exercises (Karshmer et al., 1999). Unfortunately, the screen reader is unable by its nature to make fully accessible formulae, graphics and any other scientific content.

Mathematics is visual in nature and thus can present many challenges for visually impaired students. Specific teaching modalities and adaptations are needed for those students who have impaired vision, for numerous activities and topics (Cooper et al., 2008; in't Veld and Sorge, 2018; Karshmer et al., 1999; Wedler et al., 2012) such as numbers & counting, algebra, patterns & functions, geometry & spatial sense, measurement, probability and analysis of scientific data collection, and chemistry, to mention only a few examples.

The main accessibility difficulties for a screen reader user when learning STEM topics can be summarized as follows:

Reading, writing and transcribing formulae. Formulae by their nature are complex and structured, so scientific images are usually used to deliver information. For this reason, it is necessary to fully understand their meaning and their educational value when interacting with such content. An alternative description might not be enough for satisfactory understanding, especially when the student is performing exercises. The student should be able to explore, interact and use formulae in an effective way. Various applications have been created to compensate for poor Assistive Technology Readiness. However, the copy and paste editors are still difficult to use for totally blind users, so different assistive tools for writing and solving formulas, equations, etc. are needed.

Understanding complex tables, Graphs and Diagrams. When learning and doing exercises, a STEM student must access graphical content and tables. As mentioned for formulae and equations, a short description would not be suitable for educational purposes. Furthermore, tables can be very complex and structured so they are not easy to explore in a sequential way. Assistive technology is not yet suffiently mature to support such exploration. In addition, when practicing, students should use editors and virtual environments to interact with graphical content and structured data. Unfortunately, those environments can be poorly accessible for screen reader users.

Interacting with virtual and simulation tools. Nowadays several tools offer students the opportunity to manipulate complex objects as well as observing simulations and reproduction of scientific phenomena. Those environments are a valuable support for any learners, except for screen reader users. Although many of those tools are available on the Web, current accessibility guidelines are not adequate to ensure their use via assistive technology. Thus, visually-impaired students may be excluded from these activities.

Several tools to make digital textual content accessible are available on the market. However, in the scientific context (formulae, graphs, tables) the problem is still far from being resolved. As a consequence, even PDF scientific documents offer accessibility issues (Armano et al., 2018). On one hand, the speech synthesizer engines are unable to process images and formulae; on the other hand, the

Braille display (the component translating the digital content appearing on the screen) is only able to reproduce formulae written with specialized software. Moreover, the OCR (Optical Character Recognition) scanning of text containing formulae is still difficult and graphs, diagrams, and images are often of low quality and difficult to access. The Infty project (http://www.inftyproject.org) is developing an integrated mathematical document reader system "InftyReader" using an OCR approach.

2.2 Hearing Loss

Hearing loss refers to unilateral o bilateral reduced acuity or total loss of hearing. Fortunately, some assistive technologies can now help compensate for some hearing loss. These include assistive listening devices such as hearing loops, which work by amplifying sound and are effective in managing hearing loss. There are also augmentative and alternative communication devices such as touch screens with symbols and specific apps, which can improve an individual's ability to communicate and participate in interactions. People with such impairments would benefit from content that makes use of the sense of vision such as text-based materials and videos with captions. More information is available for the reader in the chapter "Hearing Loss and Deafness" (Kushalnagar).

Math skills of students with hearing impairment are delayed respect to their hearing peers, mainly due to difficulty understanding math language (Ray, 2001, Swanwick et al., 2005). Hearing children learn the language from birth and understand everyday language. This favors the understanding and use of mathematical language (Flexer, 1999). They learn every day, while a child with hearing impairment has to learn many skills in a structured way. The implication for teachers is that they need to be aware of, and focus on, those areas of learning or language skills that deaf/hearing-impaired children find particularly challenging because it is more difficult for them to simply pick up those skills from their environment.

2.3 Learning Difficulties

Learning difficulties can involve students with different needs, including dyslexia, the most common disability amongst higher education students (Mortimore et al., 2006). Dyslexia is a neurological disturbance that can affect several areas, resulting in poor spelling, reading, writing and decoding skills, spatial/temporal abilities (e.g., difficulties orienting), motor abilities, and memory.

A previous study suggested that most students with learning difficulties, especially individuals with dyslexia, experience the most difficulty exploiting the visual-verbal channel (Stella & Grandi, 2011). Träff & Passolunghi (2015) offers a very interesting overview on developmental dyslexia. The theoretical triple code model (Dehaene, 1992) and next, the developmental model of numerical cognition suggests that language and phonological abilities underlie the development of early mathematical skills (Von Aster & Shalev, 2007). Recent research evidence confirms that reading and phonological difficulties have a negative impact on the ability to acquire age-adequate skills in some areas of mathematics. Specifically, tasks such as word problem solving and multi-digit calculation are challenging for students with dyslexia Träff & Passolunghi (2015). Specific difficulties are experienced by students with Developmental Dyscalculia (DD), a learning difficulty specific to mathematics involving 3-6% of the population (Szucs et al., 2013).

There are various assistive technologies available for students with dyslexia to improve reading and writing on the web (readable typefont, app for conversion/personalization of font/background, line spacing, online cognitive maps, and so on), visual and diagramming tools to help with organization and memorization. They would also benefit greatly from audio and video. The ability to pause, stop, replay and forward audio and video clips and to use them alongside their notes would be very helpful to them. More information is available in the chapter "Technologies for Dyslexia" (Rauschenberger et al.).

Complex mathematical expressions can be particularly challenging for students with dyslexia. Reducing the amount of complexity of equations/formulae/expressions dynamically collapsing/expanding sub-parts facilitates interaction and solution building. Responsive equations enable a new approach to assisting users with learning disabilities. Specifically MathJax facilitates the reading of math expressions by

1. Offering collapsing/expanding features to simplify the structure of formulae, and facilitates reading and comprehension. The default state of collapse of an equation depends on context parameters such as screen size, page size, zoom factor.
2. Enabling the interactive exploration of sub-expressions via mouse click, keyboard, or touch events
3. Offering synchronized and customizable highlighting for sub-expressions (Cervone et al., 2016).

3 STEM Education on the Web

Nowadays technology offers many opportunities for learners and students. Applications and learning resources are available on the Internet to support education. From the more common sources, such as electronic documents, eBooks, etc., to advanced tools like Virtual Learning Environments (VLE), Learning Management Systems (LMS), apps, and so on, several educational sources are available in the Internet. Unfortunately, due to their nature, digital materials and environments may be not suitable for interaction via assistive technologies, especially screen readers. This occurs for any type of content, including even simple text, depending on how it has been designed. The situation becomes even more complicated when dealing with more complex content such as formulas, graphics, graphic simulation and so on. In this section we analyze the main resources available on the Web to support education and learning, especially in STEM. More specifically, we refer to them in terms of their accessibility rather than their content.

3.1 Math Framework on the WEB

Math content, such as books, formulae, equations, and exercises, can be published on the Web using MathML (Mathematics Markup Language), a specialized markup language defined by the W3C (World Wide Web Consortium) for representing mathematical content in the HTML5 source code.

It enables the inclusion of formulae in documents and the exchange of data between mathematical software (W3C, 2015). Unfortunately, only new versions of the popular browser are fully MathML compliant. Old browsers are lacking in native implementation of MathML, thus rendering solutions such as SVG or HTML converters are unable to exploit web accessibility standards such as ARIA (Cervone et al., 2016).

To solve this compatibility problem, a decade ago, the MathJax Consortium started the development of a JavaScript rendering engine for displaying mathematics content in all browsers, for efficient and effective publishing of Mathematics on the Web (Cervone et al., 2016). Visual editors enable the copy&paste function between MathJax and other math editors including Office, LaTeX, and wiki environments (http://www.mathjax.org).

Recently the MathJax team has introduced the semantic interpretation and enrichment of MathML presentation, in order to enhance accessibility features:

- efficient reflow of content in small screens and magnification
- selective and synchronized highlighting and interactive exploration of sub-formulae, very useful for dyslexic readers
- dynamic speech text generation for offering a seamless reading experience to blind users, independent of the adopted platform or assistive technology Cervone et al. (2016).

Another emerging extensible standard for defining the semantics of mathematical objects is standard for OpenMath, coordinated by the OMS (OpenMath Society). It is very important to understand the differences between OpenMath and MathML:

- “OpenMath provides a mechanism for describing the semantics of mathematical symbols, while MathML does not.
- MathML provides a presentation format for mathematical objects, while OpenMath does not” (http://www.openmath.org).

It is important to remark that these technologies are complementary; OpenMath facilitates the automatic processing of math content and can be exploited to build interactive documents and apps.

MathPlayer is a math reader that enables math to be accessed via assistive technology, through both speech and Braille. MathPlayer is based on MathML technology and supports both visual rendering and screen reader interaction in compatible browsers (Soiffer, 2007). This offers a powerful environment for accessing Math content. More details are available for the reader in the chapter “Mathematics and Statistics” (Soiffer).

3.2 Electronic documents and eBooks

On the network, more and more digital documents and eBooks are available for various purposes. For visually impaired people these materials are very interesting because they offer new opportunities to access content and information, provided they have been designed in an accessible manner. Several formats are used to deliver digital documents and eBooks. EPub (Electronic Publishing) and PDF (Portable Digital Format) are two formats widely used on the Web for delivering content.

EPub is the distribution and interchange format standard for digital publications and documents based on Web Standards. EPUB defines a means of representing, packaging and encoding structured and semantically enhanced Web content — including XHTML, CSS, SVG, images, and other resources — for distribution in a single-file format. EPUB enables publishers to produce and send a single digital publication file through distribution and offers consumers interoperability between software/hardware for unencrypted reflowable digital books and other publications (http://idpf.org/epub). Since ePub 3 is based on the open Web platform and HTML5, accessibility may benefit from the work done by the Web Accessibility Initiative (WAI), and many of the features of EPUB 3 will be useful for persons with disability without additional work from the publisher. However, there are specific accessibility aspects to be considered outside of traditional publisher workflows.

When considering scientific content, e.g., math and formulas, graphics, tables and so on, the things are a little more complicated. Images, rich content and other complex features of an eBook by their very nature may be inaccessible to visually impaired individuals. Some images or graphics contain even richer information than the text and as a consequence, people who cannot see the image can lose out on extra information. This can be a significant issue when considering educational contents and concepts.

Although ePub is an HTML-based format, MathML is not yet supported by e-readers and assistive technology such as screen readers. Similar issues also occur for PDF documents; formulas are still inaccessible even when the source document is in LateX format. Studies such as those by Armano (2018) are investigating how to solve the accessibility of PDF documents including formulas.

More details about accessible publishing are available for the reader in the chapter “Alternative Documents and Publications” (Conway and Mace).

3.2.1 Alternative descriptions

Text and audio description are the most widely used ways to provide access to images and greatly increase the accessibility of an image for a visually impaired reader. Writing image descriptions is a skill and there are a number of resources available to help everyone in the supply chain prepare these descriptions, which can vary greatly depending on the requirement of the given context.

Images can be very challenging. Figure 1 shows a set of four complex images from the textbook CK-12 Biology 1, published in 2010 by the CK-12 Foundation. This image is quite complicated to describe. Its alternative description is “Composite picture illustrating the range of different image types from graphs to flow diagrams and pictures”. This is enough to give an idea of the content, but at the same time does not provide enough semantic and useful information about its effective content.

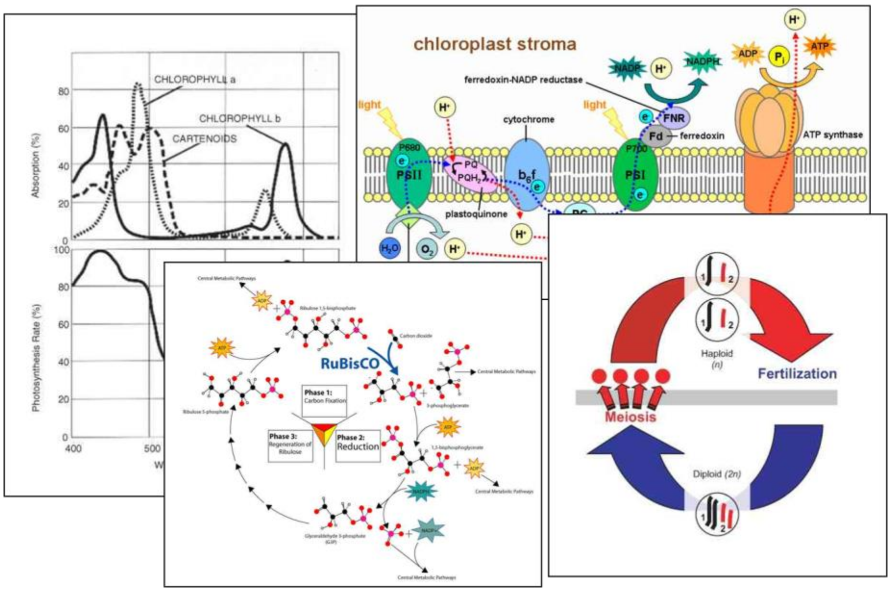


Figure 1 – Example of a complex image (source: CK-12 Foundation)

Image description and alternative texts are best created at the authoring stage since the author knows what the image is trying to convey. Images can help sighted people understand textual explanations and are, in fact, accessibility aids themselves in many instances. An accessible image provides a different approach to the visual content, helping both sighted and blind readers access all key points and interpret what the image is supposed to convey.

Creating successful image descriptions is truly a skill, especially concerning educational topics. For this reason, there are several indications, suggestions and guidelines available on the Web on accessible images and how to create them (Landry, 2016; W3C, 2015). The Publishing Forum (IDPF) has established Accessibility Standards that call for detailed description of images but do not offer guidance in their preparation. Publishing guidelines have arisen to fill this gap, but lack a focus specifically on science, technology, engineering, and math content. The Image Description Guidelines (DIAGRAM Center, Benetech) and Effective Practices for Description of Science Content within Digital Talking Books (National Center for Accessible Media) both offer best practices and sample descriptions for accessible STEM content in educational publications (Gould et al., 2008).

By their nature, some image types are much more complex to describe than others. Typically these include art, music, maps, and mathematics and science. In scientific books, mathematical symbols and formulae are often produced as images, making them inaccessible to blind readers. If the symbols were produced in MathML or LaTeX, they can be accessed by screen reader.

Image descriptions can be included in digital publications (e-books, PDFs, ePubs, HTML) through a variety of methods and markup including alt, longdesc, prodnote, describedby, visible text, hidden text. However, not all description delivery methods work on all devices. In addition, the choice of authoring tool (whether Word, InDesign, Dolphin Publisher, or the like) can affect how the markup is applied. Therefore, the publisher has a number of choices to make depending on the content, workflow, and formats. Tools such as Poet Image Description Tool (http://diagramcenter.org/poet.html) have been proposed as an open Web resource to facilitate the creation of image descriptions within the DAISY format and so within EPUB 3, the mainstream format of choice for accessible content.

3.2.2 Audio descriptions

Audio descriptions are an additional audio track of narration that deliver information about important visual features, such as body language, changes in scenery or context, charts and diagrams. Audio-description tracks can pre-recorded by persons or via text-to-speech (TTS) engine.

There are two kinds of audio descriptions (W3C, 2018):

- *Open audio descriptions* are embedded in the program audio track, cannot be turned off and thus are announced to everyone
- *Closed audio descriptions* can be turned on/off by users

Frequently, graphs are used in scientific material since they simplify complex information and make it possible to see trends. If for sighted users, they are particularly explicative; for people who cannot see, this type of information may be a serious matter if the alternative content is not well provided. In this case it is crucial to offer narrative audio descriptions to give the blind user more complex and complete alternative information. Suggestions on how to prepare descriptions for audio books have been proposed in Gould et al. (2008).

3.3 Distance learning

Interactive and dynamic learning materials spread quickly in the field of education. GeoGebra is a very popular web application that has become part of the math curriculum for secondary school students in several countries. It allows teachers to create and share and students to learn and practice online exercises, supporting math achievement. The accessibility of the GeoGebra website was tested against the success criteria A and AA of WCAG 2.0 applying heuristic evaluation of a set of selected webpages in two different platforms by two evaluators. Results showed that most of the success criteria levels were not met, by indicating that GeoGebra is still poorly accessible for people with disabilities (Shrestha, 2017).

Learning Managements Systems (LMSs) still present accessibility issues for traditional tasks, such as loading educational content. Three popular open source LMSs – i.e., Moodle, ATutor and Sakai – have been evaluated in terms of accessibility according to WCAG recommendations (Iglesias et al., 2014). The study revealed accessibility problems for common activities by teachers and learners. Thus, no specific functionality for supporting STEM topics and materials is considered.

The main accessibility issues affecting visually impaired interaction are related to graphical tools, toolbars and formatting palettes, lack of support to upload and add STEM content, and collaborative and cooperative interaction.

Laabidi at al. (2014) have enhanced the popular e-learning platform Moodle, creating its accessible version ‘‘MoodleAcc+’’ defining generic models that may be instantiated on specific needs of the student, and offering a set of tools for authoring and evaluating accessible educational content (for Learner and Author Assistance, Accessible Course Generation, Platform Accessibility Evaluation).

Fortunately, Moodle’s accessibility is steadily increasing over time. Armano et al. (2016) evaluated the accessibility of Moodle v. 2.7 for visually impaired people, focusing on mathematics. Four visually impaired individuals with different degrees of impairment carried out various tasks performing different roles, by using different assistive technologies (NVDA and VoiceOver screen readers, Braille displays and magnifiers), operating systems (Win 7, Win 8, Mac OS X) and browsers (Internet Explorer 11, Firefox 41, Safari 8). Participants were able to complete the required tasks, suggesting that Moodle can be considered accessible for the visually impaired.

With regard to distance learning in a synchronous modality, virtual environments are not yet sufficiently mature to be really accessible, especially via screen reader. Virtual Learning Environments (VLE) or Virtual Classes include tools and simulation environments able to offer rich multimodal Web-based functionalities to the students.

Progress in technology has encouraged the development of virtual reality and simulation environments that allow learners to perform exercises and experiments to practice on specific topics, such as those of science, engineering and mathematics. Evolution in graphical processing, multimedia and multimodal interaction opens up new and interesting scenarios for students who, individually or collaboratively and constructively, can apply, experiment and test thanks to the increase in augmented reality, artificial intelligence, and advanced tools for computational processing and graphics.

While this offers students important new opportunities, it creates new barriers and obstacles for those with serious disabilities, such as students with visual impairment. First, graphical virtual environments are currently far from being accessible to blind users as their content is mostly visual (Maidenbaum et al., 2016).

Secondly, these environments offer functionalities and commands with important accessibility limitations and issues. A VLE includes more components, such as a Virtual Class and a Virtual Laboratory, and offers students a collaborative environment.

Accessibility problems and limitations encountered when interacting via screen readers and magnifying software affect both relatively simple functionalities such as screen sharing, and more complex procedures such as simulation in three-dimensional environments.

The main functionalities to consider in accessibility support for VLE on the web are:

Screen sharing. This modality is increasingly used to show participants the slides and documents prepared for presentation and lessons. As a consequence, not all the topics presented are described, leading to obvious difficulty for non-sighted users who are automatically excluded from this activity. These limitations especially affect scientific and mathematics topics, which are more difficult to understand only through vocal descriptions by the presenter/teacher. Literary content is easier to comprehend even when what is shown on the screen cannot be seen. It is different for more complex content such as mathematics and science.

Collaborative environments. Several actions and activities are required to be carried out in a collaborative way in real time from two or more learners. Nevertheless, the Web pages have been designed keeping accessibility in mind, the functionalities specifically designed to support a collaborative approach still present several accessibility issues. Google Docs and other tools are examples. When editing cooperatively simultaneously with other participants, several issues arise for screen reader users. This occurs even with simple text; we can then imagine what happens with content such as science, engineering and math. At this time, research in this field to support full accessibility via screen reader is still limited.

Communication and interaction. Several tools for distance learning and virtual environments offer the opportunity for participants to state their presence in the class, to ask a question, and so on. These functionalities are usually made available by installing a plug-in for on-line conferences, like that of Adobe Connect or other Web conferencing tools offering communication tools, especially for instant messages. Writing more complex content such as expressions, functions or any other science and math content can be a challenge due to the limitations of the tools available for editing such content.

3.4 Tutorials and Videos

Numerous sources online are made available through audio and video content in order to make the learning process easier and more immediate. Complete tutorials or online lectures are arranged through multimedia materials (e.g., Web pages embedding clips and videos to explain more specific concepts).

Video tutorials are increasingly used on the Web for various purposes. Science and math content are presented through tutorials and videocasts. Those materials are often inaccessible, since the visual content is not described to the user. Usually, a disabled learner can obtain information from the audio description but what is explained via graphical content is lost. As with graphical and more complex content, audio description may not be enough to permit the student to understand and learn specific concepts. Therefore, when providing STEM content via tutorials in video formats, specific audio descriptions should be provided to offer additional information aimed at improving content comprehension by people with a disability, such as blind users. Audio descriptions are largely used for visually impaired people, especially for films (Pettitt et al., 1996). Audio Description allows persons with visual impairment to hear what cannot be seen on film and video, in museum exhibitions, or at theater performances, in a wide range of human endeavors (Snyder, 2005). Applying audio description to STEM content would be very useful for improving educational support via tutorials and video content available on the Web.

3.5 Interactive Environments

Several online tools support training activities to help students learn and practice numerous activities and consolidate technical concepts. Usually, those tools are designed to be visually oriented in order to facilitate interaction. Many of them offer the opportunity to learn while following Web learning programming or simulation environments. For example, tools such as Scratch (https://scratch.mit.edu/), Blockly (https://developers.google.com/blockly/) and Code Monster (http://www.crunchzilla.com/code-monster) are designed for enabling visually oriented coding, in order to simplify interaction and avoid syntax errors. They are based on an intuitive click-and-drag modality, through which it is possible to easily compose fragments of code by using graphical and colored elements and blocks. Fortunately, an accessible version of this visual programming environment is offered by Google Accessible Blockly, a web application that exploits hierarchical menus, to facilitate interaction when navigating via screen readers. However, Milne and Ladner state the importance of providing accessible tools for all, by making existing block-based environments universally accessible instead of creating a different accessible version. By addressing the main accessibility problems detected in visual programming environments these authors created Blocks4All, an accessible visual programming environment optimized for touchscreen devices (Milne and Ladner, 2018).

Generally speaking, using an interactive environment such as an Integrated Development Environment (IDE) can be a challenge for a disabled person. For example, interacting via screen reader with an IDE can be difficult or impossible for a blind person. Potential difficulties or inaccessible tasks include: (a) getting an overview of the main parts and classes available in the code; (b) localizing the errors in the debugging phase; (c) recognizing indented code, especially when a specific syntax is not used for blocks; (d) delivering the software to test it in a simulation framework; (e) operating with blocks and objects via drag-and-drop; and so on. This is crucial when learning the coding or developing a software. To break down these barriers other studies and projects focus on accessible teaching and specifically accessible coding, as discussed in detail in [Diagram Center, 2017]). In particular, Quorum (https://quorumlanguage.com/), a programming language offering a fully accessible Integrated Developer Environment (IDE), is a very interesting approach in this field. Quorum enables one to write a program exploiting the accessible SODBeans (Sonified Debugger) IDE. SODBean allows for a self-voicing, fully integrated development environment for Netbeans, a popular Java IDE. Quorum allows the programmer to specify that the output should be spoken aloud in addition to text and graphic format. This is extremely helpful to a blind user to catch bugs in the code but also very useful to quickly include speech output in a program [Diagram Center, 2017]).

A similar approach can be adapted to many other contexts. For practice in chemical concepts and experiments, several tools and virtual labs are available on the Web (http://www.acs.org/).

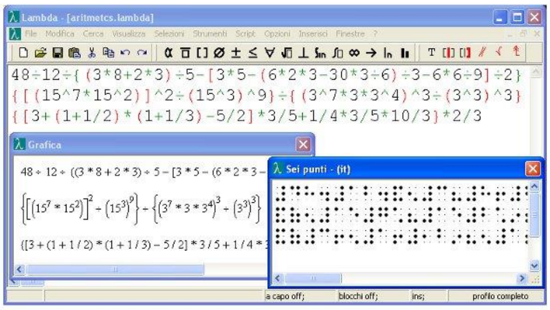
The engineering field also offers numerous tools to support learning. For example, EasyEDA (https://easyeda.com/) and PartSim (http://www.partsim.com/) are Web tools that support the student learning circuit design. Unfortunately, in this case as well the approach is totally graphic and interaction via mouse creates obvious problems for people who are blind.

Many specific tools reproduce virtual labs or simulations, as previously mentioned. In the last decade a number of fully software-based virtual laboratories in different fields have been developed. In most cases they are specific for a certain educational context and do not offer the possibility of generalizing to a platform applicable to a broader class of engineering disciplines. These laboratories offer different levels of technical complexity. Some examples are available at https://phet.colorado.edu/. Potkonjak et al. (2016) offer a review in this field.

4 Tools Enabling Math Access for the Blind

Exploiting MathML standards, some applications have been proposed to help blind students access math via screen reader, in order to enhance interaction in the desktop environment.

STEM is one of the main drivers in a growing economy. For this reason, governments have taken action to encourage STEM education for the entire population. Europe is also promoting math accessibility through projects and actions. Benefits of ICT for delivering mathematics are still limited for visually impaired people. The EU LAMBDA project created a system based on the functional integration of a linear mathematical engine and an editor for text visualization, writing and processing. The Lambda Mathematical Code derives from MathML and was designed for interacting via Braille devices and speech synthesizer. It is automatically convertible, in real time, into an equivalent MathML version and then into popular math formats (LaTeX, MathType, Mathematica). The editor enables one to write and manipulate math expressions in a linear way and provides some compensatory functions. LAMBDA targets high school and university students (Armano, 2018). Unfortunately this assistive tool is not a web application; it needs to be installed in the PC and requires a fee.



```
48÷12÷{(3*8+2*3)÷5-[3*5-(6*2*3-30*3÷6)÷3-6*6÷9]÷2}
{[(15^7*15^2)]^2÷(15^3)^9}÷{(3^7*3*3^4)^3÷(3^3)^3}
{[3+(1+1/2)*(1+1/3)-5/2]*3/5+1/4*3/5*10/3}*2/3
```

Figure 2 –Lambda Environment (source: www.lambdaproject.org/)

Karshmer et al. (2004) propose the UMA system to support math accessibility for blind people. The UMA system includes translators that freely inter-convert mathematical documents transcribed in formats used by unsighted persons (the Braille code for scientific expressions, Nemeth and Marburg) to those used by sighted people (LaTeX, Math-ML, OpenMath) and vice versa. The UMA system also includes notation-independent tools for aural navigation of mathematics.

Similarly, Isaacson et al. (2010) created MathSpeak, a tool for supporting students who have difficulty in reading print MathSpeak applies a set of rules for conveying mathematical expressions in a non-ambiguous manner. It includes an engine that can easily translate STEM materials into a non-ambiguous form, which can be announced via a high-quality synthesizer. It vocally announces mathematics content by adding semantics to interpret its visual syntax (such as parentheses) and to remove ambiguity from spoken expressions. Also, this technology has the potential to increase accessibility to STEM materials. A test with 28 users has shown its efficacy. However, as observed by these authors, access is only the first step in the long process of making STEM accessible to all.

Word integrates an editor (LeanMath) enabling the writing of formulas for visually impaired people, via keyboard shortcuts. LeanMath aims at reinforcing and refreshing lean thinking. Its main application is as an editor for MathType equations in MS Word, a very popular authoring system. Another application providing accessible math input and output for the blind is WAVES (Web Accessible Virtual Electronic Scratchpad) which enables the rapid selection of mathematical symbols, voice output for expressions, and MathML conversion (http://diagramcenter.org/).

5 Discussion

Based on the main barriers encountered by people with disability, research and industry have been proposing techniques and tools to overcome some of the issues experienced by disabled learners in STEM education. Unfortunately, many of those solutions are not based on the Web because the tools proposed are dated and the technology at that time was not yet mature for these purposes. Two topics deserve more research and technological effort to enable easy interaction of the blind with math, and STEM content in general: operating with (1) math and formulae, and (2) graphical elements and structured objects.

Operating with Formulae and Web Math via Screen Reader

Bernareggi et al. (2007) introduce the interaction issues encountered by a screen reader user when reading and writing formulae and expressions. Speech and Braille understanding of mathematical expressions are somewhat different from visual comprehension. Mathematical notation usually uses two-dimensional structures (fractions, matrices, etc.). A two-dimensional layout can be understood quickly with a rapid overall glance, providing information about the structural elements making up the expression, then by examining details, horizontally or vertically. The sighted reader can immediately and accurately access any specific part of the expression. On the other hand, reading and understanding a mathematical expression through speech output or Braille are impeded by the lack of a solid representation of the structure to explore. These modalities necessarily linearize contents, which makes it difficult to achieve overall understanding and to quickly and easily access specific sub-expressions. Reading a Braille representation of a mathematical expression is mainly a sequential process.

Math expressions can be understood effectively and efficiently through tactile and auditory perception only when the reader can rapidly and effortlessly access specific parts of the expression and extract the overall structure. Various mathematical and/or scientific Braille notations have been developed in different countries (UNESCO, 1990).

MathML has offered new possibilities for generating speech and Braille representations and giving readers the functions required for optimal understanding. When math formulae are expressed through MathML, software agents can parse the structure to generate speech or Braille alternative descriptions and can allow exploration via keyboard. Moreover, MathML content can be accessed to output high quality speech (using prosody, for example).

Recently Da Paixão et al. (2017) have evaluated the effort required by blind users when exploring mathematical formulae, by applying two task models with GOMS (Goals, Operators, Methods, and Selection rules) and KLM (Keystroke-Level Model) to a set of mathematical problems and resources, by selecting optimal paths to simulate the behavior of experienced blind users. Between the three selected screen readers, JAWS, ChromeVox and NVDA (NonVisual Desktop Access), JAWS performed better than ChromeVox and NVDA, although the within-formulae navigation still is poor, making mathematical learning and problem solving on the Web a very complex task for blind users.

Tools have been accordingly proposed to support formula exploration via screen reader (Ferreira et al., 2004; Schweikhardt et al., 2006).

The screen reader NonVisual Desktop Access (NVDA) powered by MathPlayer offers an accessible interaction with Word and PowerPoint via speech, and Braille. MathPlayer can be integrated in the MS Office environment, extending the Word & PowerPoint button ribbon for self-voicing, which is useful not only for blind students but also for users with other disabilities such as dyslexia.

However, although some solutions have been investigated to support access to math and formulae on the Web, they still do not allow writing and manipulating expressions for exercises and practice. Web pages and applications as well as the assistive technology should (1) natively support the reading and exploration of formulas, and (2) allow any user regardless of their abilities to edit and manipulate expressions. OpenMath promises to fill this gap, making documents incorporating math content truly operable. An inclusive effort of different research teams would be valuable for harmonizing and exploiting the full potential of emerging technology for accessibility.

Graphics, Diagrams and Tables

Accessing graphics, diagrams and any other non-textual representation for STEM content is still an open issue; nevertheless there are various suggestions proposed for preparing alternative image descriptions. For complex images, textual or narrative description might not be enough for full understanding of a certain concept. In addition, alternative descriptions must be prepared for any graphical element. This implies that a blind student cannot perceive any STEM concept available on the Web, unless an alternative description has been provided by the developer. For example, a blind student cannot perceive the function originating from any formulae. Alternative descriptions are related only to static graphical objects, and not to dynamically generated ones. A similar issue is related for tables, especially when they are rich in content, very structured and not easy to understand even when sequentialized.

This represents an ongoing interaction issue that is very important for the Web, especially in the education field. Studies such as Taibbi et al. (2014) propose new modalities to support blind students explore functions using audio feedback. AudioFunctions is an iPad app that adopts three sonification techniques to convey information about the function graph. Indeed, early research studies have been carried out, implementing Web tool prototypes to allow blind users to comprehend simple drawings, as well as to create graphics (Roth et al., 2000; Yu et al., 2003).

Exploring and navigating complex and very structured tables can be a challenge. The screen reader announces the content, including the data tables, serializing the structured content as speech. A benefit of the table structure is that users can use table screen reading commands to move their cursor along the rows and columns of the table. Using table navigation mode, the element comparison becomes a simple matter of moving the cursor up and down the column. Table navigation mode allows a screen reader user to move within the logical structure of the table. The screen reader is able to facilitate this exploration since the information is presented as a logical sequence of the cells according to the table structure.

Thus, appropriate table structure is very important to truly guarantee accessibility via screen reader. However, tables with many columns and rows for navigation and especially comparison of the elements require great effort via screen reader. Exploring very complex tables, a blind person might encounter crucial difficulties in data navigation. As a consequence, several studies have investigated possible strategies for improving such activity (Gardiner et al., 2016; Kildal et al., 2006). Nevertheless, satisfactory data table exploration is still an unresolved issue.

In summary, although various studies have been carried out in the field, people who are blind are still far from finding effective and satisfactory solutions to use in their education, especially in online and collaborative environments.

6 Future Directions

Research and development in this field will exploit technology and innovation to improve STEM education on the Web via a multimodal approach.

First, browsers and assistive technologies should appropriately support fluent reading of math formulae via screen reader and Braille display. MathML is a valuable tool for including formulae and expressions along with the Web page code. However, its support needs further investigation and implementation. Browsers, assistive technology and app developers must work on suitable interaction with the MathML standard. A small step is required for reading: appropriate detection of the included MathML by both browsers and assistive technologies. Further effort would enable the editing of expressions as well as formulae. This is particularly useful for helping students with disability practice and perform exercises, in the evaluation and testing processes as well as when participating in courses on the Web. In this context, integration with the semantic aware OpenMath standard could aid in exploiting the full potential of the Web in delivering accessible math and STEM in general.

Another important direction for research concerns the support of function and graphic perception. Assistive technologies as well as computer environments need to be redesigned in order to enhance accessibility support for reading complex tables, or graphics and diagrams. The (vision-impaired) learner should be easily able to read and comprehend fluently a complex object and, importantly, to be able to write and reproduce the concepts learned. Editors and environments should be redesigned in order to offer new multimodal interaction to help all users obtain semantic information and build objects and graphical elements as well.

In some cases the most appropriate alternative to an image is a tactile version. Tactile perception can provide some additional details, which may not be easily transmitted via alternative or audio descriptions. For instance, a math function may be clearer if perceived by touch rather than via audio description. Apart from children's books, tactile images are not a part of mainstream publishing for books or the Web, but this is an exciting area where technologies as diverse as 3D printing and haptics could create opportunities for accessibility in STEM education. Several studies (Papazafiropulos et al., 2016; McDonald et al., 2014) offer examples of how 3D printing can support learning for people who are blind. The procedure for preparing digital models to be 3D printed includes simplifying the digital content in order to obtain a version that produces an easily perceived tactile image. In this perspective, an on-line repository with a collection of simplified reproductions as well as a Web-based tool able to guide simplification of a graph or math function could aid STEM education. Furthermore, a plug-in for the browser designed to quickly 3D-print a function, diagram or any other graphical object is a potential direction for visually-impaired students.

For instance, a suitable algorithm and procedure implemented via a plug-in could allow the student to easily print a math function or graphic as it is detected when learning on the Web. In addition, a science object such as an atom or a detail of a more complex graphical element could be easily reproduced for touch via a 3D printer.

7 Author's Opinion of the Field

More integrated action is needed to enable careers in STEM by people with disability. From a technical perspective, more assistive tools are necessary to deliver accessible STEM content to people with disability, especially via assistive technology. In the author's opinion, co-design together with people with disability is crucial for creating accessible and usable tools. Most accessibility problems result from the evolution in graphic user interfaces, especially with regard to virtual environments. In addition, even simpler tools are increasingly oriented toward a complex or visual approach. Assistive technologies are not yet fully mature for interacting with tools for virtual and simulation environments. The tools should be designed to be accessible to everyone, but at the same time a step forward in assistive technology is needed to effectively include people with disability.

Most web applications are mainly devoted to the notation part of math language, enabling the correct perception of math content, while the accessibility of tools for helping students with disability decode the meaning of math and simplify logical processes in solving exercises is still in progress.

In the authors' opinion, more technology should enhance learning: mobile and web apps, robotics, the IoT with the ability to merge physical, tangible devices and virtual resources should shape the future of STEM teaching. Games such as logic games, chess, circuitry and so on are natural motivators, and by offering enjoyable challenges for children can improve problem-solving and train their logic skills, thus preparing them for STEM. The Web is an essential learning tool, and LMSs would integrate simple accessible tools for practices and problem solving. All this is possible if accessibility support is truly effective.

8 Conclusion

This chapter has analyzed the current status of accessibility support for STEM education on the Web. After an introduction to the field, the main issues related to people with disability when accessing the STEM content have been considered in order to understand the effective needs of these students. We have mainly focused on visually impaired people, although other disabilities are discussed. More specifically, the focus was on key problems encountered by visually impaired students because STEM materials and technology aiming to enhance education present great problems when using a screen reader. Accessing scientific material can be a great challenge for screen-reading learners.

In conclusion, despite the evolution of technology and progress in research, STEM education on the Web still presents numerous obstacles for people with disability. It is urgent to create additional assistive tools in a multidisciplinary and multisensorial approach, from different perspectives involving psychology and neuroscience, to enable accessible teaching and encourage STEM learning and careers for people with disabilities.

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