Education and STEM on the Web

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Abstract

Difficulties in accessing to digital educational materials in the fields of science, technology, engineering and mathematics (STEM) mine the right of any students to receive an education according his/her preferences and to fully enjoy of opportunities offered our technology-enhanced society. Web resources are increasingly simplifying the delivering of STEM contents by offering interactive and visual models, dynamic contents, videos, quizzes, games and more. STEM content may be delivered in several ways including visually, vocally, through Braille bar or other assistive technology, 3-D printed. In this chapter we focus on accessibility of STEM Web contents for students with print disability that could be penalized by obstacles in accessing digital visual resources, impeding a fully inclusive education for all. After a brief introduction, an overview of the current state of art of accessibility of STEM contents on the Web is reported, highlighting current accessibility barriers focusing on print disability, and especially on sightless experience, are illustrated. Discussion and suggestions for future research complete this chapter.

Introduction

Technology is shaping our life in every field, including education. Accessibility is crucial for any student, regardless any disability. The challenge is delivering the full content in different formats and rhythm, to effectively reach the individual perceptive channels and offer an easy environment to interact, enabling the learning.

The design of digital frameworks for Science, technology, engineering, and mathematics (STEM) education has to address needs of students experiencing 'learning difficulties', in a multidisciplinary approach from different perspectives, integrating several components and carefully considering recent findings emerging from cognitive psychology and neuroscience (Robotti et al., 2017). Studies in cognitive science in fact, shed a light on the complexity of the brain and perception processes in problem solving and mathematical skills, by showing a correlation between mathematical outcome, working memory and no verbal skills (Devine, Soltesz, Nobes, & Gabriel, 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).

In the context of the digital Age, an Accessible Education implies the ability to deliver 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 numbers of studies on accessibility, applications and assistive tools, at the moment various barriers still mine the access to STEM education, obstacles careers and overall influence the quality of life of persons with disability (Israel et al., 2013).

In this chapter, we consider accessibility in the education with a special attention to STEM via Web. Difficulties in accessing mathematics and in general STEM contents are often experienced by impaired people such as individuals with print disability, learning difficulties, and motor deficits. After an overview of difficulties experienced by print disability students, we especially focus on totally blind students, who are severely penalized by poor usability of STEM online web contents and environments. Sightless persons experience great difficulties since the interaction via keyboard, screen reader and voice synthesizer requires more time (serialization) and cognitive effort (the structure is mixed to the content) compared to other disabilities. More, missing the sight perception, especially from the born, possibly impact on the acquisition of spatial skills, which are related to mathematics outcome (Rourke & Conway, 1997).

Sightless people have the more evident form of impairment in accessing digital graphic materials, however other students may experience important difficulties, such as people with intellectual and developmental disabilities or dyslexia. For instance, the abstract nature of symbols and math formulae, the representation of equations, the visual structure of tables and diagrams are all challenges for students who are blind. Data need to be sequentialized, to be perceived by the aural or tactile channel, or paper Embossed (charts for geography/geometry) can help to perceive borders and main features. How the 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 is evolving, including accessibility field, STEM education still present numerous barriers for print-impaired users. Herein, we intend to analyse the current status and potential prospective to give a contribution in the field.

STEM Education for people with disability

Students with sensory or motor disabilities are often discouraged from pursuing STEM careers since frequently they are a poor skill to access university STEM studies due to previous inadequate preparation and limited post-secondary accommodations (Rule & Stefanich, 2012). Actually this limitation penalizes people with disability unbalancing the equal participation to the right to receive a full education program. College enrolment and STEM participation of individual with ASD versus other disability categories have been investigated by Wei et al. (2013). Although having one of the lowest overall enrolment rates, the college students with an ASD are most likely to pursue STEM majors. This result confirm that students with ASD, who have the ability to perform studies, are more likely than the general population and other disabilities groups to study STEM (Wei et al., 2012).

Different disabilities may affect an individual in different ways and, being disability a complex issue, means that people with the same disability might not have the same experience. This might also account for the difficulties of designing for various disabilities. Nevertheless, there are some common challenges shared by more disabilities (Jenson et al., 2011).

This chapter focuses on individuals with print disabilities and how they might affect an individual, including what assistive technologies might be available to them and which formats of learning materials could be compatible with their disability.

Print disabilities include all people having difficulty in reading printed text such as individuals with blindness, low vision, and cognitive impairment, who often rely on speech for information input.

The common core of STEM is represented by mathematics: "From physics to economy, through chemistry, biology, computer sciences, Mathematical expressions are in the heart of modeling and understanding Sciences" (Archambault, 2009).

Math contents, such as books, formulae, equations, exercises, can be published on the Web by using MathML. A first problem is due to uncorrected rendering of math content on the web, due to old browser or assistive technologies. The mathematical language includes two components: the meaning and the notation (Pierce, 2012). The algebraic expressions converted in spoken language by popular screen readers could be prone to misinterpretation if the semantic 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 print disability. However, since 2014 the interpretation of math formulae has been gradually incorporated by popular screen readers, with different performance. Da Paixão et al. (2017) 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 mathematical problems and resources, by selecting optimal paths to simulate 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 results

poor, making mathematical learning and problem solving on the Web a very complex task for blind users (da Paixão et al., 2017).
Various applications have been created to try filling the gap of poor assistive Technology Readiness.

Math Framework on the WEB

The W3C Consortium developed a specialized markup language MathML (Mathematics Markup Language) the Web's technology for representing mathematical formulae in the HTML5 source code. It enables the inclusion of formulae in documents and the exchange of data between mathematical software (W3C, 2015). Unfortunately, not all browsers offer the MathML rendering natively. Only new versions of the popular browser are fully compliant. Old browsers still lack in native implementation of MathML, thus mining accessibility on the basic level. In fact MathML rendering solutions on the web, such as SVG or HTML/CSS converters, cannot exploit web standards such as ARIA to support intermediary solutions (Cervone et al., 2016).

To solve this compatibility problem, a decade ago, the MathJax Consortium started the development of a JavaScript library for rendering Mathematics in any browser, which enables rendering of Mathematics on the Web (Cervone et al. 2016). MathJax is a JavaScript rendering engine for displaying mathematics contents in all browsers. Practically speaking, a plugin can be added to popular CMSs (such as WordPress), in order to easily create websites including STEM contents with MathJax. It is also possible directly using MathJax by inserting into the webpage a snippet with the reference to an online javascript library source (f.i. <script src='*CDN_path*/MathJax.js?config=TeX-MML-AM_CHTML' async> </script>) (www.mathjax.org). Visual editors enable the copy&past function between MathJax and other math apps including Office, LaTeX, and wikis environments.
Recently the MathJax team has introduced the semantic interpretation and the enrichment of MathML presentation, in order to enable advanced accessibility features:

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

A new emerging extensible standard for defining the semantics of mathematical objects is standard for OpenMath coordinated by the OpenMath Society, http://www.openmath.org.

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."

This implies that the technology are complementary and that OpenMath facilitates the automatic processing of math contents and can be used to build interactive document and app.

In order to understand the studies and the opportunities available for people with disabilities in accessing to STEM, it is crucial understanding what are the main issues encountered by them. We hereby intend consider the main lacks in the education of people with disabilities, with a special attention to the tools and contents based on Web-technologies and available on line, as well. Different disabilities imply different material adaptation to be suitable for the assistive technology or learning modality according to the individual needs. Materials and contents to be made available on learning systems or on virtual environments can require specific personalization especially when more than one disability is present (Nganji et al., 2015).

Vision Impairments

A whole range of disabilities affecting vision can be grouped into this category. These include: partial sight, low vision, colour blindness, totally and legally blind.

Since e-learning involves a significant use of the senses of sight, those with visual impairment may be excluded if care is not taken to design the learning environment accessibly, provide an appropriate assistive technology to compensate for vision loss and/or personalize learning for students with such disability.

Fortunately, various assistive technologies help persons with visual impairment to access information online. These include screen magnifiers, which help magnify content on the screen, screen readers which are usually based on text-to-speech to read content to the user, and Refreshable Braille Display Devices which provide information to the user by stimulating the sense of touch.

An important consideration when designing for an individual with disabilities in web-based learning environments is to ensure that accessibility requirements are strictly followed. Simple requirements such as alternative texts for images are very important, but for more complex contents might not be enough to assure a suitable support for learning purposes. Particular attention and care is required , when designing accessibility for STEM topics since is widely complex to be made scientific contents effectively usable via assistive technology. For people with severe visual impairments or who are totally blind, appropriate formats of learning materials include Braille, audio and digital text. Audio because they can make use of the sense of sound to assimilate the information while screen readers can be used to read out the text. Color blind individuals instead can exploit any formats and enjoy of images and videos.

A very suitable support is needed to provide to totally blind people equal and effective STEM materials. However, also some partially sighted people rely on a screen reader to interact with the user interface. Thus we prefer referring to screen reading users in defining the most accessibility issues encountered when interacting with STEM materials and tools.

Blind or low-vision students need to acquire a range of technology skills. A variety of assistive technology devices as well as strategies for instruction are available to support people with this disability. The use and maintenance of Assistive Technology is then part of the curriculum for students with visual impairments.

Science, technology and mathematics are widely based on graphical and visual contents. Make those contents completely and truly accessible to totally blind or via screen reader is a challenge. Sometimes audio descriptions or alternative text for certain graphical contents might not be adequate or sufficient to give a thorough concept. Having accessible and effective materials for studying is not so easy for a student who is totally blind. Moreover, handling formulae and graphical functions can be very difficult for a screen reading person. This occurs especially when practicing and performing exercises (Karshmer et al., 1999). Unfortunately, assistive technology like a screen reader is not able for its nature to make fully accessible formulae, graphics and any other scientific content.

Mathematics are visual in nature and can therefore present many challenges for students with visual impairments. There are adaptations that can be made to the various areas of mathematics to make them accessible to students who are blind or visually impaired. Thus, specific teaching modalities and adaptations are needed for those students who have vision impairments, for numerous activities and topics (Cooper et al., 2008; 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, chemistry, only for mentioning a few examples.

The main accessibility problems for a screen reading user when learning STEM topics can be summarized in:

Reading, writing and transcribing formulae. Formulae for their nature are complex and structured. So scientific images are usually used to deliver information. For this reason, it is necessary fully understanding their meaning and their educational value when interacting with such a content. Thus, an alternative description might not be enough to provide a satisfactory understanding, especially when performing exercises. The student should be able to explore, interact and use formulae in an effectively way. Previously we discussed tools for rendering and exploring formulas, such as MathJax, MathSpeak and Lambda. However the copy and paste editors are difficult to use for a totally blind users, thus different assistive tools for writing and solving formulas, equations, etc. are needed.

Comprehending complex tables, Graphs and Diagrams. For learning and making exercises and practicing a STEM student have to access graphical contents and tables. As mentioned for formulae and equations, a short description could not be suitable for an educational purpose. Furthermore, tables can be very complex and structured so that it is not so easy to explore efficiently in a sequential way. Assistive technology is not yet mature for supporting such an exploration. In addition, when practicing, students should use editors and virtual environments to interact with graphical contents and structured data. Unfortunately, those environments could be poor accessible for screen reading users.

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

Several tools to make accessible digital textual contents are available on the market. On the contrary, in the scientific context (formulae, graphs, tables) the problem is still far to be satisfactorily solved. As a consequence, even PDF scientific documents offer several accessibility issues. From one side, 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 able only to reproduce formulae written with specialized software. More, the OCR (Optical Character Recognition) scanning of text containing formulae is until today still difficult and graphs, diagrams, images, often result of low quality and difficult access. The Infty project (http://www.inftyproject.org) is developing an integrated mathematical document reader system "InftyReader" using OCR approach.

Visual impaired students, wishing to attend university courses, as their right, and/or to perform a job requiring ability to deal with scientific texts, encounter huge difficulties and also in presence of high IQ score, are often constraint to chose others activities. Villanueva et al. (2017) report a narrative survey concerning 60 blind students in STEM education.

Hearing Impairments

Hearing impairment refers to unilateral o bilateral reduced acuity or total loss of hearing. Fortunately today, some assistive technologies can help compensate for some hearing loss. These include: assistive listening devices such as hearing loop which work by amplifying sound and have been found to be 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 communication and ability to 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.

However math skills of students with hearing impairment are delayed respect to their hearing peers, mainly for difficulty in understanding the math language (Ray, 2001, Swanwick et al., 2005).

Hearing children learn the language from birth and understand the everyday language. They learn everyday incidentally while child with hearing impairment have to learn many skills. This favors the understanding and usage of the mathematical language (Flexer, 1999). The implication of this 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 incidentally acquire those skills from their environment.

Dyslexia

Dyslexia is neurological disturb that may impact in several areas including poor spelling, reading, writing and decoding skills, spatial temporal abilities (e.g., difficulties in orienting), motor abilities, and memory. Dislexia is the most common disability amongst higher education students (Mortimore et al., 2006).

Previous study has suggested that most students with learning difficulties, especially individuals with dyslexia, experience main difficulties in 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 video and text. The ability for them to pause, stop, replay and forward audio and video clips and to use these alongside their notes would be very helpful to them.

Complex mathematical expressions can be particularly challenging for students with dyslexia. Reducing the amount of complexity of math equations/formulae/expression dynamically collapsing/expanding sub-parts facilitates the 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 (Cervone et al., 2016):

1. Offering the 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, offering the user control over via mouse click, keyboard, or touch events
3. Offering synchronized and customizable highlighting for sub-expressions.

Applications for supporting the Access of STEM Contents for the Blind

Some tools have been proposed to support blind students in accessing math via screen reader, on desktop environment. STEM is one of the main drivers for growing economy. For this reason, several actions have been undertaken by governments in order to fuel STEM education, in the whole population. Also Europe is fuelling the math accessibility through projects and actions. Benefits of ICT on 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 it was designed for interacting via Braille devices and the speech synthesizer. It is automatically convertible, in real time, into an equivalent MathML version and, then into the 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 secondary to university students (www.lambdaproject.org, Armano, 2018). Unfortunately this assistive tool is not a web application, it needs to be installed in the PC and requires a fee.

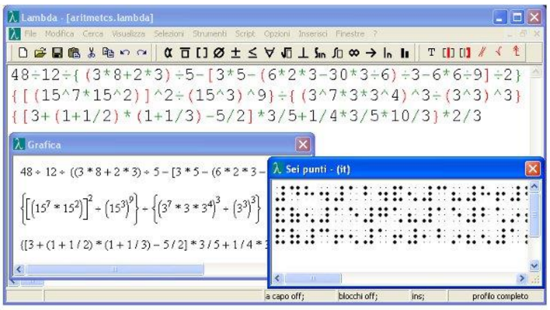

Figure 1 –Lambda Environment (www.lambdaproject.org/)

Karshmer et al. (2004) propose the UMA system to support accessibility of math for blind people. The UMA system includes translators that freely inter-convert mathematical documents transcribed in formats used by unsighted person (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 print disabilities. 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 the non-ambiguous form, which can be announced via a high-quality synthesizer. It announces vocally mathematics contents by adding semantics to interpret its visual syntax (such as parenthesis) and to remove ambiguity from the spoken expressions. Also this technology has the potential for increasing the accessibility to STEM materials and careers in related fields A test with 28 users has demonstrated its efficacy. However as observed by these authors removing one communication barrier is only a first step in the long process for making STEM accessible for all.

Word integrates an editor (LeanMath) enabling the writing of formulas for visually impaired people, via keyboard shortcuts. LeanMath truly transcends the numbers by reinforcing and refreshing lean thinking for the very purpose of figuring to improve. Its main application is as an editor for MathType equations in MS Word, a very popular authoring system. Another Windows application providing accessible math input and output for 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/).

STEM Education on the Web

Nowadays technology offers numerous opportunities for learners and students. Applications and several sources are available on the app stores as well as on the Web to support numerous activities in the education. From the more common sources, such as electronic documents, eBooks, etc., to more advanced tools like Virtual Learning Environments (VLE) or Learning Management Systems (LMS), Web apps, and so on, several sources are available around the network. Unfortunately, for their nature, all these electronic materials could be not suitable to be used via assistive technologies, especially the screen reader. This occurs for any type of contents, including even the simple text due to it has been designed. Just think how the situation complicates when considering more complex contents like formulas, graphics and so on. In this section we analyse the main resources and digital materials available on the Web to support education and learning especially in the STEM fields. More specifically, we refer in terms of their accessibility rather than their contents.

Electronic documents and eBooks

On the network, more and more digital documents and eBooks are available for several purposes. For print-impaired people these materials are very interesting because they offer new opportunities to access contents 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 largely used on the Web for delivering contents.

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 allows 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). So ePub 3 is based on the open Web platform and HTML5. As a consequence, 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 contents, e.g. math and formulas, graphics, tables and so on, the things are little more complicated. Images, rich content and other complex features of an ebook by their very nature can be inaccessible to those with a vision impairment. 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 as well.

Alternative descriptions

Text and audio description are the most widely used way to provide access to images and can greatly increase the accessibility of an image depending on the impairment of the 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 can vary greatly depending on the requirement of the given context.

The image below is quite complicate to describe. The alternative description associated to the image is "Composite picture illustrating the range of different image types from graphs to flow diagrams and pictures". As we can see, it can be enough to have an idea of the contents, but at the same time is not sufficient to provide semantic and useful information about its effective contents.

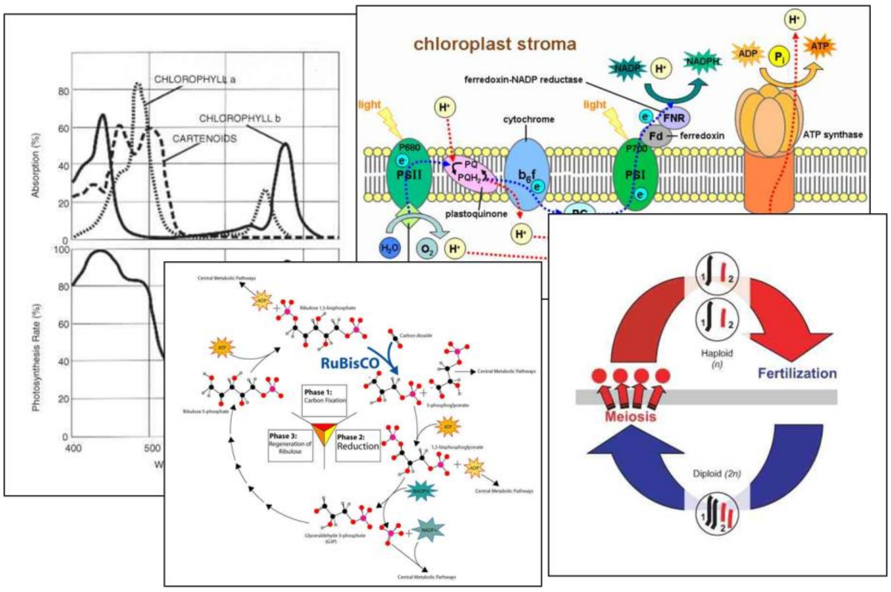

Figure 2 – Example of a complex image (CK-12 Foundation)

Images can be very challenging. In Figure 2 a set of 4 complex images from the textbook CK-12 Biology 1, published in 2010 by the CK-12 Foundation is shown. Image description and alternative texts are best created at authoring stage since the author knows what the image is trying to convey.

Images can help sighted people make more sense of explanations in text 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 non-sighted readers to access all key points and to interpret what the image is supposed to demonstrate.

Creating successful image descriptions is truly a skill, especially when considering educational topics. For this reason, there are several indications and suggestions and guidelines available on the Web on Accessible images and how to create them (Landry, 2016; W3C, 2015). 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 thus far 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: arts, Music, Maps, and Mathematics and science. In TextBooks, Mathematical symbols and formulae are often produced as images, making them inaccessible to blind readers. If the symbols have been produced in MathML or LaTeX, they can be accessed by screen reader.

Image descriptions can be included in a variety of digital publications including e-books, PDFs, ePubs and HTML through a variety of methods and markup including: alt, longdesc, prodnote, describedby, visible text, hidden text. However, unfortunately 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 like Poet Image Description Tool (http://diagramcenter.org/poet.html) have been proposed as an open Web-based 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.

Audio descriptions

Audio descriptions are additional audio track of narration that deliver information about important visuals 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 into 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 materials 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 is crucial to offer narrative audio descriptions for giving to the blind user a more complex and complete alternative information. Suggestions on how to prepare descriptions for audio books have been proposed in Gould et al. (2008).

Wiki, Interactive learning Environment and Learning Management Systems

Although accessibility guidelines for the Web have been available for almost twenty years and over (i.e. WAI WCAG1.0 on 1999), Web contents still present many issues for people with disability.

Interactive and dynamic learning materials are spread out quickly in the field of education. GeoGebra is a very popular web application become part of math curriculum for students of secondary schools in several countries. It allows teachers to create and share as well as to student to learn and practice online exercises, favoring math achievements. The accessibility of 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 the majority of the success criteria levels were not met, by indicating that the GeoGebra is still poor accessible for people with disabilities (Shrestha, 2017).

With refer to the Learning Managements Systems (LMSs) still include accessibility issues for traditional tasks, like inserting educational contents. Three popular open source LMSs – i.e. Moodle, ATutor and Sakai – have been evaluated in terms of accessibility according to the 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.

Main accessibility issues affecting the visually-impaired interaction can be related to: graphical tools, toolbars and formatting palettes, lack of support to upload and add STEM contents, 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 accessibility of Moodle is steadily increasing over time. Armano et al. (2017) evaluated the accessibility of Moodle v. 2.7 for the visually impaired people, focusing on mathematics. Four visually impaired, with different degrees of impairment performed different tasks performing different roles, by using different assistive technologies (screen readers NVDA and VoiceOver, braille displays and magnifiers), operating systems (Windows 7, Windows 8, Mac OS X) and browsers (Internet Explorer 11, Mozilla Firefox 41, Safari 8). Participants were able to complete the required tasks suggesting that Moodle can be considered accessible to visually impaired.

Distance and Virtual Learning Environments

Herein we refer to the distance learning in a synchronous modality. Virtual Learning Environments (VLE) or Virtual Classes include tools and simulation environments able to give rich multimodal Web-based functionalities to the students.

Progress of technology has encouraged the development of virtual reality and simulation environments that allow the learners to perform exercises and experiments to practice on specific topics, such as those of science, engineering and mathematics. The evolution in the 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 increasing of augmented reality, artificial intelligence, as well as advanced tools computational processing and graphics.

While this opens up important new opportunities for students, it creates new barriers and obstacles for those with serious disabilities, such as students with vision impairments. Firstly, graphical virtual environments are currently far from 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 include more components, such as a Virtual Class, a Virtual laboratory, and offer to 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 even more complex procedures, such as simulation in three-dimensional environments.

The main functionalities to consider in the Web support for VLE in terms of accessibility are:

Screen sharing. This modality is more and more used to show to the participants the slides and documents prepared for the presentation and lessons. As a consequence all the presented topics are not described with obviously difficulties for non-sighted users who are automatically excluded for this activity. These limitations are especially affecting scientific and mathematical topics, which are more difficult to be understood only through the descriptions by voice by the presenter/teacher. A literary content is easier to comprehend even if what is shown on the screen cannot be seen. Differently it occurs for more complex contents like mathematics and science are.

Collaborative environments. Several actions and activities are requested to be carried out in a collaborative way in real time from two or more learners. Nevertheless the Web pages have been designed by keeping in mind the accessibility, the functionalities specifically designed to support a collaborative approach still present several accessibility issues. Google Docs and other tools are possible examples. Editing cooperatively simultaneously with other participants arise several issues for screen reading users. This occurs only for simple text. We can think what can occur for contents like science, engineering and math. At the moment, 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 to the participants to state their presence in the class, to ask for getting the role to make a question, and so on. These functionalities are usually available by installing plug-in for on-line conferences, like that one offered by Adobe Connect (https://www.adobe.com/products/adobeconnect.html) or other Web conferencing tools offering communication tools, especially for instant messages. Writing more complex contents like expressions, functions or any other science and math contents can be a challenge due to the limitations of the tools available for editing those contents.

Tutorials and Videos

Numerous sources available on line are made available through audio and video contents in order to make the learning process more immediate and easy. Complete tutorials or online lectures are arranged through a mixed material, both via written contents on the Web page, and clips and videos to better explain more specific concepts.

Video tutorials are increasingly used on the Web for numerous purposes. Scientific and math contents are presented through tutorials and videocast catchable from the Web. Those materials are often inaccessible, since the visual contents are not described to the user. Usually, a disabled learner can get information by the audio description but what is shown via graphical contents is lost. As introduced for graphical and more complex contents, audio description might not be enough to understand and learn given specific concepts. Therefore, when providing STEM contents via tutorials in video formats, specific audio descriptions should be provided to give additional information aimed at improving the content comprehension by people with some disability, like blind users. Audio descriptions are largely used for visually-impaired people especially for films (Pettitt et al., 1996). Audio Description allows persons with visual impairments to hear what cannot be seen on film and video, in museum exhibitions, at theatre performances, in a wide range of human endeavour (Snyder, 2005). Applying audio description to STEM contents would be very useful to improve tutorials and video contents available on the Web as educational support.

Specific Tools

Several tools are widely available on line to support specific activities and learning of certain concepts. Usually, those tools are designed to be visually-oriented in order to facilitate the interaction for the learner.

Many tools offer the opportunities the learn certain concepts while doing. About learning programming, several tools are available on the Web.

Thus, there are available various tools to learn and practice numerous activities and concepts. For example, tools designed for learning or supporting the coding are mainly visually-oriented. Scratch (https://scratch.mit.edu/), Blockly (https://code.google.com/archive/p/blockly/) and Code Monster (www.crunchzilla.com/code-monster) are examples of tools belonging to this category. 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 coloured elements and blocks. Such an activities is not accessible because not performable via screen reader and keyboard. As a consequence, visually-impaired users, especially those who are totally blind, are excluded for the usage of this type of tools. Probably they need a specific education on the coding by using traditional editors and accessible coding environments.

A similar approach can be adapted to many other topics and concepts. For practicing chemical concepts and experiments several tools and virtual labs are available on the Web (www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/simulations.html).

Also in the engineering field there are numerous tools available to support learning of many concepts. For example, EasyEDA (https://easyeda.com/) and PartSim (www.partsim.com/) are Web tools to support the student in the circuit design. Unfortunately, also in this case the approach is totally graphic and interaction via mouse with obvious issues for people who are blind.

Many specific tools aim at reproducing virtual labs or simulations, as mentioned before. In the last decade a number of fully software based virtual laboratories in different fields have been developed. In most cases they are specific to an educational context and do not offer possibilities for generalization to a platform applicable to a wider class of engineering disciplines. These laboratories have different levels of technical complexity. Some examples are available at https://phet.colorado.edu/en/simulations/category/new. Potkonjak et al. (2016) provide a review in this field.

Discussion

Based on the main barriers encountered by people with disability, research and industry have been proposing techniques and tools to provide a support to overcome some issues encountered by the disabled learners in the STEM education. Many of those solutions are not, unfortunately, based on the Web because of the tools proposed are dated and the technology at that time was not satisfactorily mature to these purposes. Between many matters, two main ones deserve most research and technological effort to be solved enabling the easy interaction of blind with math, and STEM contents 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) introduces very well the interaction issues encountered by a screen reading user when reading and writing formulae and expressions. Speech and Braille understanding of mathematical expressions is somewhat different from visual comprehension. Mathematical notation usually uses two-dimensional structures (e.g. fractions, matrices, etc.). A two-dimensional layout can be understood at first sight 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. Reading and understanding a mathematical expression through speech output or Braille, on the other hand, is impeded by the lack of a solid representation of the structure to explore. These modalities necessarily linearize contents, so that this makes it difficult to achieve overall understanding and to quickly

and easily access specific subexpressions. Reading a Braille representation of a mathematical expression is mainly a sequential process.

Math expressions can be understood effectively and efficiently through tactile and auditive 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 opened up new possibilities for generating speech and Braille representations and for 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 the exploration via keyboard. Moreover, MathML content can be accessed to output high quality speech (using prosody, for example).

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

MathPlayer™ (Soiffer, 2007) 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 speech in the compatible browsers. MathPlayer4 makes available buttons in Word & PowerPoint on Windows for self-voicing, which can be also useful for other disabilities like people with dyslexia.

However, while some solutions have been investigated in order to propose a support to access Web math and formulae, these do not allow to write and manipulate expressions for exercises and practice. Web pages and applications as well as the assistive technology should (1) support natively the reading and exploration of formulas, and (2) allow any user regardless their abilities to edit and manipulate expressions. OpenMath promises to filling in this gap making documents with math contents really operable.

Graphics, Diagrams and Tables.

Accessing graphics, diagrams and any other non-textual representation for STEM contents is still an open issue, nevertheless the proposed suggestions for preparing alternative image descriptions. For complex images, as mentioned in the previous, a textual or narrative description might not be suitable for efficiently understanding a certain concept. In addition, alternative descriptions require to 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. Therefore, a user who is blind cannot perceive, for example, the function originating from any formulae. Alternative descriptions are related only to static graphical objects, and not for the dynamically generated ones. A similar issue is related for tables, especially when they are rich of content, very structured and not easy to understand even sequentialized.

This represents an interaction issue still existing and very important for the Web, especially in the education field. For this reason, research has been investigating possible solutions aimed at overcoming such a problem. Studies like (Taibbi et al., 2014) propose new modalities to support blind students in exploring functions by 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-based tool prototypes to allow to 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 for a screen reading person. A screen reader speaks the contents, 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, comparing elements becomes a simple matter of moving the cursor up and down in Column. Table navigation mode allows the screen reader user to move within the logical structure of the table. The screen reader is able to facilitate this logical movement because the information is presented as a logical sequence of the cells according to the table structure. So firstly an appropriate table structure is very important to guarantee a truly accessibility via screen reader. However, tables with many columns and rows navigation and especially comparison of the elements require a lot of effort by the screen reading user. Furthermore, for very complex tables the blind person might encounter crucial difficulties in the data navigation. As a consequence, several studies have been investigating possible strategies to improve such activity (Gardiner et al., 2016; Kildal et al., 2006). Nevertheless, a satisfactorily data table exploration is still an uncovered issue.

Summarily, although several studies have been carrying out in the field, people who are blind are far from having effective and satisfactory solutions to be used in the education, especially to be exploited in online and collaborative environments.

Future Directions

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

Firstly, browsers and assistive technologies should appropriately support a fluent reading math formulae via screen reader and braille display as well. MathML is a valuable tool to include formulae and expressions along the Web page code. However, its support needs further investigation and implementation. Browsers and assistive technology developers must work on the suitable interaction with the MathML standard. With regards to the reading of that standard the step to do is little: an appropriate detection of the included MathML is needed by both browsers and assistive technologies like the screen reading software. A most effort should be carried out to support the editing of expressions as well as formulae. This is particularly useful to support the students with disability in practicing and performing exercises. This could be effective also in the evaluation and testing processes as well as for the courses on the Web. In this context, an integration with the semantic aware OpenMath standard, it would be desirable, for exploiting the full potential of the Web in delivering accessible math and STEM in general.

Another important direction for research is about 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 (visually-impaired) learner should be easily able to read and comprehend fluently a complex object, and importantly (s)he should be able to write and reproduce the learned concepts. Editors and environments should be redesigned in order to offer new multimodal interaction to support all users to get semantic information and build objects and graphical elements as well.

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

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

Author’s Opinion of the Field

More integrate actions are needed to enable accessible careers in STEM by people with disabilities. From a technical perspective, more assistive tools are necessary to deliver accessible STEM content to people with disabilities, especially via assistive technology. In author’s opinion, codesign with people with disability is crucial to create accessible and usable tools. The most accessibility problems is coming from the evolution in the graphic user interfaces, especially with regards the virtual environments. In addition, even the simpler tools are increasingly ori-

ented for a complex or visual approach. The assistive technologies are not fully mature to interact with tools for virtual and simulation environments. The tools should be designed to be accessible to everyone, but at the same time a forward step in the assistive technology is needed to go towards an effective inclusion of people with disability in the STEM. Currently, a real accessibility in this field is far from a truly inclusion.
Most of web applications, we previously discussed are mainly devoted to the notation part of the math language enabling the correct perception of math content while the accessibility of tools for assist student with disability decoding the meaning of math and simplifying logical processes, in solving exercises are still in progress.
In authors' opinion, more and more technology should enhance learning: mobile and web apps, robotics, the IoT with the ability of merging physical, tangible devices and virtual resources should shape the future of STEM teaching. Especially Games such as logic game, chess, circuitry, and so on, that are natural motivators, by offering challenges for kids can contribute to improve problem solving, to train logic abilities stimulating STEM attitude. The Web is an essential learning tool, LMSs would integrate simple tools for practices and problem solving. All this may be provided accessibility support is truly effective.

Conclusions

In this chapter, the current status about the accessibility support for STEM education on the Web has been analysed. 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 by the disabled students. We mainly focused on print-impaired people, even if other considerations are discussed. More specifically, the focus was on key problems encountered by the visually-impaired because STEM materials and technology proposed to enhance the education present great problems when using a screen reader. Accessing scientific materials can be a very challenge for the screen reading learners. Despite evolution in technology and progress in research as well, STEM education on the Web still presents numerous obstacles for people with disability. It is necessary to create additional assistive tools to enable accessible careers in STEM by people with print disabilities.

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