A Systematic Mapping of MathML-Enabled Editors for Users with Visual Impairment

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Abstract. The teaching and learning processes in science, technology, engineering and mathematics (STEM) pose challenges that are particularly hard to overcome when some part involved is visually impaired. Despite the fact that these areas tend to be generators of many jobs, people with this disability often prefer to study other careers, in which they do not require intensive use of STEM. This paper presents a systematic mapping of the technologies that have been proposed to solve this problem, usually in the form of editors that allow the inclusion of mathematical symbology. In addition, we introduce EULER (Editor of Universal Learning Resources), a software tool which allows for accessible editing and sharing of learning resources for mathematics in compliance with the standard MathML format, in order to easily exchange information between sighted and visually impaired people. EULER has been designed to allow it for adapting to areas other than mathematics, such as chemistry or physics. The results of this study show that most of the identified proposals have limitations, either regarding the lack of use of the MathML standard or they are not designed to grow towards other areas of STEM aside from mathematics.

Keywords: STEM editor · Mathematics software · Math education for visually impaired people · Math software accessible

1 Introduction

The study, understanding and mastery of mathematics is a necessity and advantage to carry out STEM studies. But also, it is well known that mathematics and related subjects have been seen as difficult and complex, which makes some people prefer to avoid STEM studies.

At the labor level, STEM-based professions have been among the most valued, with higher growth projections, job stability and high income ranges.

However, for some populations the use and mastery of mathematics is related to barriers that go beyond cognitive and intellectual aspects. A clear example of these populations are people with visual disabilities, who in order to carry out

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studies or work based on mathematical tools must solve various difficulties by graphically representing them.

The foregoing has led research groups and academics, interested in the subject of inclusive technologies as well as inclusive education, to work on the study of some conditions and the design of technological proposals that support the elimination or mitigation of some barriers.

In the activities of these groups, an urgent and recurrent task is to know the state of the art of technological developments at an academic level and at an industry level. For this reason, systematic mapping is a highly valuable research support tool.

In this particular work, the results of a systematic mapping study carried out on the subject of mathematical editors for people with visual disabilities are presented. The objective is to provide researchers, developers of inclusive technologies or those interested in the subject with a quantitative overview of the projects or research of inclusive mathematical publishers and specifically aimed at the visually impaired population.

The work presents in Sect. 2 the work methodology summarizing the principles of systematic mapping (Sect. 2.1), the scope of the study and the research questions addressed in the search processes (Sect. 2.2). Then Sect. 2.3 presents a summary of the data obtained from the searches. Section 2.4 summarizes the classification of the results. Section 3 presents the main results of the study. Section 4 summarizes some important findings and the final Sect. 5 presents the conclusions reached by the authors.

2 Methodology

Empirical studies are used more and more frequently due to the possibility of validating the evidence as well as the sources of information, these are based on data collected through observation or systematic searches that allow them to be validated.

These studies also become a valuable tool for decision makers, investors, and researchers, as they allow *quantitative* or *qualitative* results to be seen, depending on the methods used, as well as providing high-value summary information to gain insight into the context of a topic of interest. These studies require less time than the previous ones and are recommended where there is a lack of relevant primary studies of very high quality [2].

In the case of systematic mapping, they are quantitative studies, with a limited scope, based on a systematic or ordered and documented process, which seeks synthesized and integrated results that demonstrate professional practice, mainly in terms of publication frequencies [9].

2.1 Systematic Mapping

A systematic mapping seeks to achieve a summarized vision from a qualitative approach of the publications made on a specific topic, in a range of time and scope. The process is based on the activities enumerated in Fig. 1.

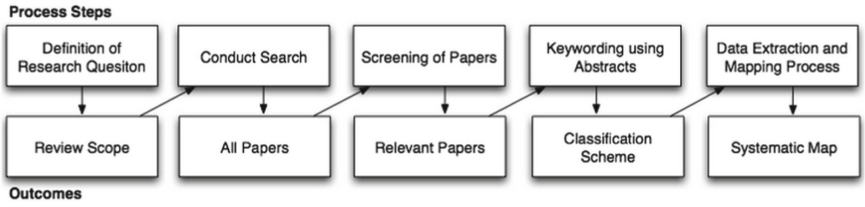

Fig. 1. Systematic mapping process. Source [9]

The systematic mapping activities are composed of (1) definition of the research question(s), (2) conduct of the search, (3) Filtering of papers, (4) analysis of the papers from abstracts and keywords, (5) data extraction and results mapping process. These activities and outcomes are enumerated in the Table 1.

Table 1. Activities and products in systematic mapping.

Activity	Description	Product	Description
Research question	Plan and execute the searchs	All papers	List of source of publication. List of papers returned from the search activity
Conduct research	Define at least one research question	Review Scope, list of filtered papers	Enumerate some characteristics of search scope and results. Sometimes defines some restrictions
Screening of papers	This activity filters some papers	Relevant papers	List of relevant papers that complaint the restrictions in the previous activity
Keywording using abstracts	Review abstracts and classify papers using some keywords defined to the research	Classification scheme	Obtain a classification scheme of papers
Data extraction and mapping process	Extract information about research's interest that will be fundamental for the graphics and summaries	Systematic mapping	All the information returned and classified that will be later graphics

The results are sought to be classified by various criteria, among the most common are authorship, geographic regions of publication, publication sources,

publication periods, among others. In the particular case of this study, emphasis is placed on time and geography, authorship and publication sources.

In addition, something unusual academically, is that it is expanded with a section of non-academic findings (Sect. 3.4) in order to locate what products, applications or components for mathematical editing, available either freely or commercially, can be made available on public (not necessarily free) access to the visually impaired population.

2.2 Scope and Detailed Research Questions

The objective of the systematic mapping is to know the amount of research and publications carried out on the subject of mathematical editing tools that support people with visual disabilities.

From the above, the initial research questions were built:

– What research papers on mathematical editors for visually impaired people have been published in the last 15 years?

These questions were addressed by using these search strings:

1. +MathML+editor
2. MathML AND editor AND accessible
3. editor +math AND (blind OR ("visually impaired"))
4. +MathML AND editor AND math AND (blind OR ("visually impaired"))

Concerning source of publications, in the first instance, the ACM, IEEE and Web of Science repositories were identified, which were submitted for consultation to those in charge of the project, who suggested looking for the categories "informatics" or "computing" in the subscribed databases of the TEC, such as part of the electronic resources of its online Library System. Due to this, the decision was made to include EBSCO, ScienceDirect and SpringerLink as repositories to complete the study. In addition, the researcher in charge suggested verifying if any relevant pre-publication was found in Cornell University's arXiv.

Inclusion Criteria. Regarding inclusion criteria, the title and abstract of each article that refers to mathematical editors for people with visual disabilities will be reviewed. This allows us to see in the first instance how the words are related and why the article has been preselected. Additionally, a sample was followed using the snowball technique, in order to identify some primary or complementary publications.

Exclusion Criteria. As exclusion criteria, the information collected in the reading and analysis of the abstract and the conclusions will be used, deepening in the cases that are deemed necessary and a more detailed reading of other parts of the document is needed. With this criterion, it is possible to appreciate with a greater level of detail what each document deals with, to relate it to

the objectives sought and decide if it is relevant for this review, moving on to the group of primary studies. All redundant papers were excluded, also papers focused on educational issues of math learning for visually impaired students, but they did not include any technological edition math tools were excluded. Finally, non English or Spanish articles were excluded.

Definition of the Types of Study. The type of studies selected were those closely related to proposals from accessible mathematical editors, whether the development techniques used are made explicit or just the results of the exposed tools are exposed, with their scope and limitations. Also, special interest was placed on those publications that referenced available end products.

2.3 Data Collection

After the application of search strings in the repositories, the results obtained are summarized in the Table 2.

The ongoing process of filtering search strings is evident, as well as the impact, on the results obtained. The table shows the changes in the results obtained according to the search string, it is important for systematic mapping studies that various search strings are analyzed and that changes in the results achieved are also identified.

Table 2. Results obtained by repository.

Repository	Search string	Number of hits
ACM Digital Library	1	7
ACM Digital Library	3	117
ACM Digital Library	4	2
IEEE Xplore Digital Library	2	62
IEEE Xplore Digital Library	4	6
Web of Science	1–4	0
EBSCOhost Web	2	7
EBSCOhost Web	3	1
EBSCOhost Web	4	19
Elsevier ScienceDirect	1	84
Elsevier ScienceDirect	2	64
Elsevier ScienceDirect	3	11
SpringerLink	1	21
SpringerLink	4	3
CoRR de Cornell University	1	2
CoRR de Cornell University	2	3

In most cases larger or more complex search strings tend to filter more information and return fewer strings, but are expected to be more accurate for search purposes.

In addition to these results, searches in Spanish were applied, which returned 2 links to short articles that did not give the study greater relevance.

Then, as a result of the expert criteria of the professors consulted, a refinement of the search strings was carried out using the following:

- intitle: "editor" intitle: "mathematical" +(blind OR ("visually impaired") or disabilities)
- intitle: "editor" "mathematical content" "accessible formats"

This returned the reference to two projects very much aimed at mathematical editing for people with visual disabilities. One of the articles was published in the year 2002 and there are no more appearances of the project. While the second is published in the year 2020 and does present a product in validation stages.

Based on the results achieved (146 articles), the inclusion and exclusion criteria are expanded. Primary sources are reviewed and the need to include some publications was determined due to their relevance to the topic. This process resulted in 90 relevant publications and the inclusion of some publication or reference sources.

2.4 Classification

The process of classifying the results was based primarily on identifying the most relevant publication repositories. The publication repositories in which the most publications were found were ACM Communications and IEEE. In both cases, the articles were not subclassified by societies or chapters, because in both publication sources there are many subclassifications.

Another criterion for classifying the results achieved in the searches was to classify the papers according to their ***year of publication***. Presenting a clear concentration of a greater number of publications between the years 2008 to 2014. However, between the years 2016 to 2018, 5 publications are located in each year, as seen in Fig. 2. This is a reflection of a need that cannot be satisfied with the results of previous years.

Finally, the relevance classification criterion is the *country of publication*. This criterion is based on identifying the country of the university that is specified in the affiliation of the authors. In the case of papers with multiple authors and from various countries, the paper is assigned to the identified countries. This criterion shows a publication trend mostly in the USA with 24 papers, France with 7 papers, as well as Canada. Japan places 5 papers, Italy with 4 papers and Germany with 3 papers.

3 Results

The primary study selection procedure involved executing the query in each selected repository, thus obtaining a set of "studies" to which the inclusion criteria were subsequently applied to obtain the "relevant" studies. Finally, the

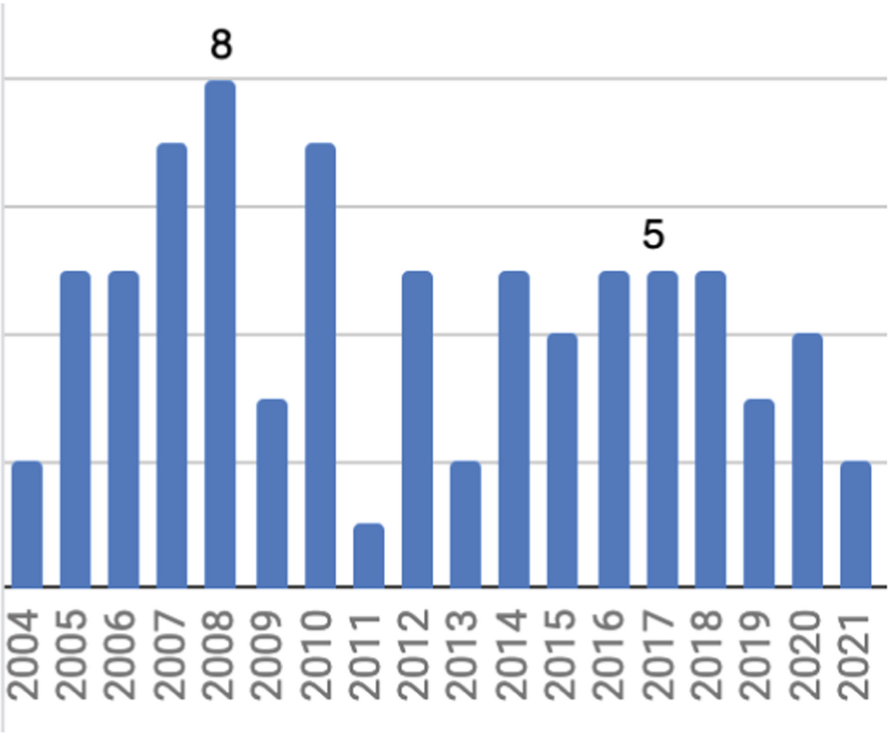

Fig. 2. Publications by year.

exclusion criteria were applied to the relevant studies and thus the "primary" studies were obtained. A refinement stage was carried out on the primary studies in which important studies related to the topic can be identified and, given their importance, were added as primary studies after refinement. In this systematic review, 417 studies have been detected, of which 55 were considered relevant and 19 primary studies have persisted after refinement (Table 3).

In Fig. 3 the topics of published literature classifications are summarized by year. This information is useful to find the years and topics with more publications based on the classifications schemes defined. So, for instance, it is evident that *Education* along with *Editor* predominate throughout the years. These topics show, respectively, a particular research interest during periods 2006–2009 and 2012–2017.

On the other hand, Fig. 4 summarizes the top 7 authors with 3 or more publications related to the main topic of this research. It is very important to mention that there are many authors with 1 or 2 publications, but for simplicity and easily reading of the graphic, they were not included. It is clear that authors Ali Awde and Dominique Archambault, working separately, have dominated the scene from 2005 to 2018.

Table 3. Summary of results obtained by repository.

Repository	Number of hits	Relevant	Primary	Primary after refinement
ACM Digital Library	129	30	11	+1
IEEE Xplore Digital Library	68	11	4	0
Web of Science	0	0	0	0
EBSCOhost Web	35	3	0	0
Elsevier ScienceDirect	159	5	0	0
SpringerLink	24	5	2	0
CoRR de Cornell University	2	1	1	0
Total	417	54	18	1

3.1 Time and Geography

As commented in the classification criteria section, knowing the country of publication or of the projects is relevant in the academy to build collaboration networks. This criterion shows a publication trend mostly in the USA with 24 papers, France with 7 papers, as well as Canada. Japan places 5 papers, Italy with 4 papers and Germany with 3 papers.

Regarding the time periods, defined in years, a considerable publication is presented between 2005 and 2020. The importance of this finding is that it reflects a degree of attention paid in the academy to the development of inclusive technologies for support. teaching mathematics to people with visual disabilities.

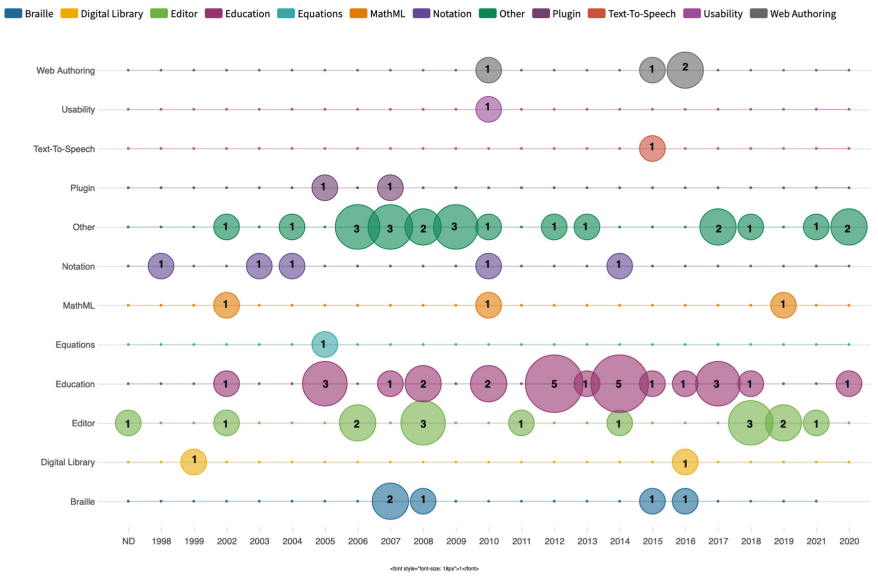

Fig. 3. Topics classification.

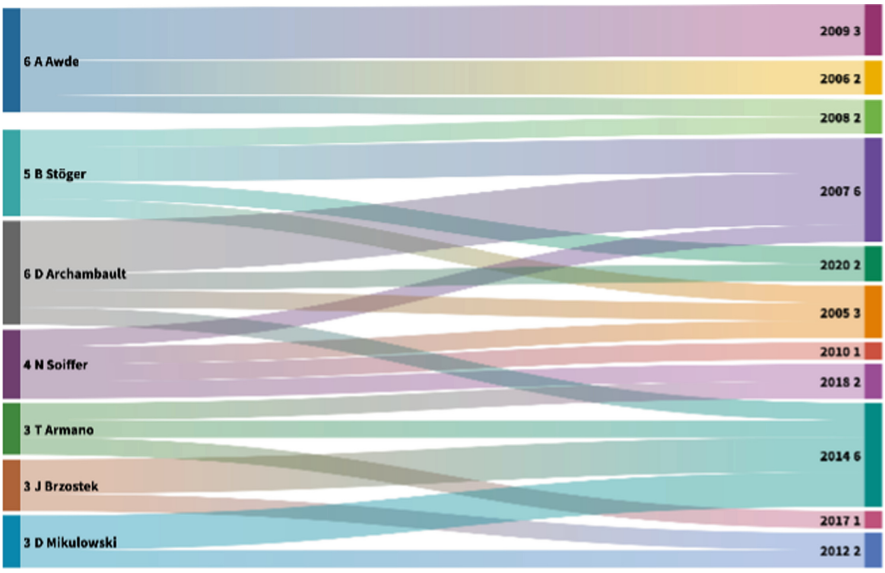

Fig. 4. Top 7 authors with 3 or more publications.

3.2 Authorship, Papers and Citations

The trends of the authors are a reflection of lines of research that are carried out from research centers or from postgraduate programs, generally in regions or countries in which research is supported more. Figure 4 shows a trend of authors and is classified by years. The authors that were most located in the search are A Awde with 6 publications, B Stöger with 5 publications and D. Archambault with 6 publications (Fig. 5).

In the classification of the works consulted, based on the type of publication, 49 works published in conferences, 28 journal articles, 7 works published as book chapters and 1 published in a workshop were found.

3.3 Publication Sources

The publication repositories in which the most publications were found were ACM Communications and IEEE. In both cases, the articles were not subclassified by societies or chapters, because in both publication sources there are many subclassifications.

Further detailing the publication sources shows that 31 publications were located in the ACM Digital Library. In IEEE library 17 publications were located. Seven publications were included that were located in ResearchGate as a result of the inclusion and exclusion processes, or also the snowball process. Then in Springer 7 publications were located and in Elsevier 6 papers were located.

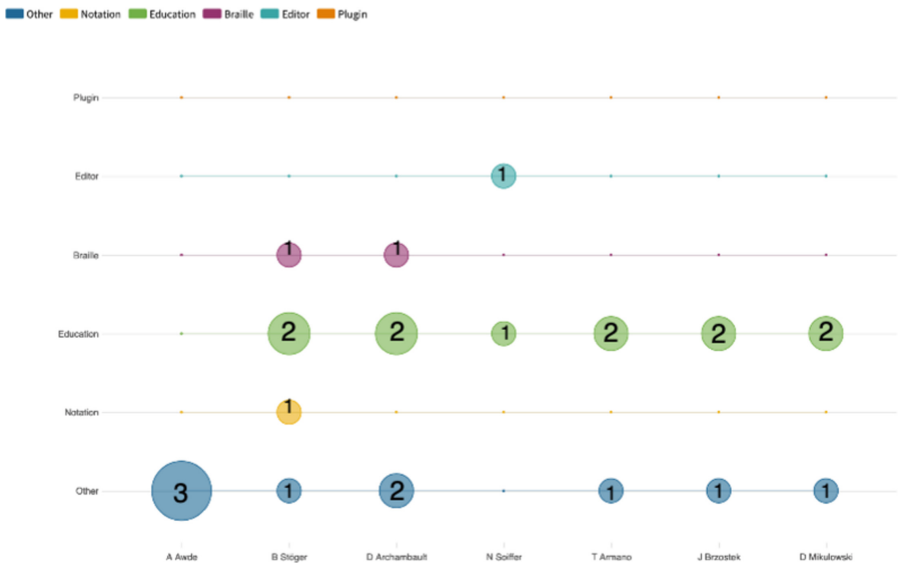

Fig. 5. Top 7 authors and topics.

3.4 Non Academic Applications

In the context of this study, the interest is not only focused on academic publications, else in current available math editor tools.

Aware that many of the investigations and publications are the product of academic projects, that once the researcher manages to finish his doctoral or master's studies, the projects are not implemented for final use by the population, is that in addition to the research and publications, an extension is made to locate what tools are currently available. Although this search cannot generally be carried out in the same publication sources as those used for the investigations.

EDICO is an accessible and inclusive scientific editor, designed to work with the JAWS [3] and braille screen reader, available for the licensed Windows operating system. This editor allows you to write linear expressions and display them in standard format and braille font. It incorporates six default user profiles. It is possible to create custom profiles from the "teacher" profile, hiding symbols or groups of symbols. Its interface is available in Spanish, Catalan, Basque, Galician and English.

Mathtype is a semantic formula editor, formerly known as WIRIS [8]. It has a desktop version for the Windows operating system and can be integrated into Microsoft Word and Google Documents under license. This tool incorporates the use of predefined profiles, based on the PARCC (Partnership for Assessment of Readiness for College and Careers) symbology. It allows you to customize the toolbar to keep the equations and symbols used frequently, it is compatible with MathML presentation and LateX and also incorporates functionalities accessible from the web. The functionalities accessible from the web that are integrated

correspond to a "text associated with a formula in the ALT attribute that most closely resembles natural language". It makes no reference to browsing or editing mathematical content in an accessible way. Its interface is available in English, German, French, Chinese and Japanese.

Lambda is a scientific-mathematical editor, available in its desktop version for the Windows operating system and JAWS screen reader under license. It includes the appropriate mathematical symbols for students with a bachelor's degree and for those who are studying for the first years in the university [4]. Lambda allows to write linear expressions, oriented to the input and output of braille. It also allows browsing, contracting or expanding expressions in an accessible way, and incorporates a scientific calculator that allows numerical calculations. It makes no reference to the use of profiles.

InftyEditor was designed to create scientific documents from scanned material; It also allows the editing of mathematical texts using the QWERTY keyboard using LateX commands. In addition, it has a WYSIWYG environment. It allows exporting resources in LateX, MathML and HTML format. It also has an English and Japanese version [13].

MathPlayer is a complement to Microsoft Internet Explorer (IE), visually renders MathML and interprets it. In addition, it has features that allow users to maintain the origin, size and color of their environment with custom settings [10].

MathJax consists of a library for the web that allows viewing mathematical content written in TeX and MathML formats in SVG (Scalable Vector Graphics) format. MathJaX works together with programs such as MathPlayer to convert mathematical expressions into that format for accessible reading with screen readers [5].

MathShare is an accessible math editor that allows high school students to navigate or cancel subexpressions and take notes on the steps he or she is taking. It allows teachers to evaluate student reasoning [10].

Accessible Equation Editor is a mathematical editor that allows the editing and navigation of mathematical text through braille using MathML as an internal format [6]. However, "the expression of mathematics is your biggest problem and we still haven't been able to solve it. Therefore, most of the time what NVDA says is not going to be very helpful. This is because NVDA tries to read MathJax's output and is confused" [1].

EULER consists of an accessible scientific-mathematical tool for people with visual disabilities, of any educational level [7]. It facilitates the reading, exploration, edition, import and export to different formats of mathematical educational resources, through the use of a computer. It supports the teaching-learning process of mathematics in people with visual disabilities, as well as their communication with other people. The tool allows to use user profiles based on the level of mathematical knowledge (primary education, basic secondary education, advanced secondary education and university education). These levels correspond to the symbology used in the PISA tests according to the OECD.

4 Discussion

The systematic mapping study showed that it is common to find research studies on inclusive technologies, but that these come to be applied in daily use is somewhat complex. The products of academic research tend to remain in publications and prototypes, in some cases following a publication culture known as "publish or perish" [11].

For its part, also bringing these prototypes to an end user requires significant efforts in time and resources, as well as platforms and support that goes beyond the scope of academic research. As discussed in [12], the industry is now focused on short-term research, while academia is focused on publishing or focused in many roles: "*teaching, supervising students, seeking research funding, publishing, and more. They are typically conducting research only on a part-time basis. Moreover, their research will depend on the quality of students they attract. And even so, many of today's Ph.D. students who plan to work in industry are not focused on long-term research but on product development and even marketing.*"

In the Latin American context, it is less common to see investment in inclusive projects with a focus on continuity, due to budget limitations and few collaborative work networks. This shows a clear opportunity for improvement for the academy and research centers.

5 Conclusions

Systematic mapping studies return quantitative information that is highly supportive of research. They are studies that are used to locate the state of the art of a specific topic or technology. However, one of the attentions that must be taken is in the construction of the search strings and, in addition, it must have the flexibility that may be necessary to refine the search processes.

Another important element in this type of study is to identify and document the information classification criteria. These criteria are the shortcuts for readers or researchers who are interested in this type of study. In our case, it was very important to locate information on the publication sources, years and main authors, since this will allow us to monitor projects.

In the case of the particular interest of the authors, our study extends to locating editing tools that are in use by the target population. This also allows you to see features and functionality beyond the research results. In our case, it is important to locate similarities and differences in the available technologies, to also identify possible improvements.

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References

1. http://accessibility.pearson.com/aee/faq.html
2. Brereton, P., Kitchenham, B., Budgen, D., Turner, M., Khalil, M.: Lessons from applying the systematic literature review process within the software engineering domain. J. Syst. Softw. **80**, 571–583 (2007). www.sciencedirect.com
3. Carenas, J.M., Cabra, A.B., García, M.G.M., Gea, P.C., Hernández, D.H.: Edico. Integración: Revista sobre ceguera y deficiencia visual (72), 100–108 (2018)
4. Carenas, J.M., del Campo, J.E.F.: El editor lambda para matemáticas. Integración: Revista sobre ceguera y deficiencia visual (59), 5 (2011)
5. Cervone, D.: Mathjax: a platform for mathematics on the web. Notices AMS **59**(2), 312–316 (2012)
6. Dooley, S.S., Park, S.H.: Generating nemeth braille output sequences from content mathml markup (2016)
7. Estrella, P., Bruno, L., Perassi, M.L., Garda, M.P., Mora-Lezcano, V., Chacon-Rivas, M.: Software localization: The case of the euler editor. In: 2019 XIV Latin American Conference on Learning Technologies (LACLO), pp. 1–7. IEEE, October 2019. https://doi.org/10.1109/LACLO49268.2019.00011, https://ieeexplore.ieee.org/document/8994990/
8. Marquès, D., Eixarch, R., Casanellas, G., Martínez, B., Smith, T.J.: Wiris om tools: a semantic formula editor (2006)
9. Petersen, K., Feldt, R., Mujtaba, S., Mattsson, M.: Systematic mapping studies in software engineering, June 2008. https://doi.org/10.14236/ewic/EASE2008.8. https://scienceopen.com/document?vid=6d552894-2cc3-4e2b-a483-41fa48a37ef8
10. Soiffer, N.: Mathplayer: web-based math accessibility. In: ACM SIGACCESS Conference on Assistive Technologies: Proceedings of the 7th International ACM SIGACCESS Conference on Computers and Accessibility, vol. 9, pp. 204–205 (2005)
11. Toh, C.: The culture of 'publish or perish' is hurting research - ieee - the institute, March 2018. http://theinstitute.ieee.org/ieee-roundup/blogs/blog/the-culture-of-publish-or-perish-is-hurting-research
12. Toh, C.: The state of research: Where are we headed? - ieee - the institute, February 2018. http://theinstitute.ieee.org/ieee-roundup/blogs/blog/the-state-of-research-where-are-we-headed
13. Yamaguchi, K., Komada, T., Kawane, F., Suzuki, M.: New features in math accessibility with infty software. In: Miesenberger, K., Klaus, J., Zagler, W., Karshmer, A. (eds.) ICCHP 2008. LNCS, vol. 5105, pp. 892–899. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-70540-6_134