The Role of Technology to Teaching and Learning Sign Languages: A Systematic Mapping

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***Abstract*—*Context:* The teaching and learning process has become essential for the evolution of the society as a whole. However, there are still major challenges for achieving the global goals of education, especially if we consider the portion of the population with some type of physical disability. In this context, according to World Federation of the Deaf (WFD), deaf children face many difficulties in education due to inappropriate learning environments. Also, this problem is compounded by the lack of consistency worldwide in the provision of sign language interpreting and translation. *Motivation:* However, the advent of technology is having a significant impact on the way that sign language interpreters and translators work. In this sense, the union between Information and Communication Technologies (ICT) and modern pedagogical practices can be the genesis for the creation of a global learning environment based on sign languages. *Objective:* In this scenario, this work aims to: (i) obtain an overview of the areas of Software Engineering and their technological solutions in the fields of teaching and learning sign languages; (ii) identify the main educational topics; and (iii) the most investigated sign languages. *Method:* Therefore, we conduct a Systematic Mapping (SM) with a focus on technologies applied in the teaching and learning of sign languages. *Results:* We selected 139 primary studies, using a search approach that includes both manual and automated searches, in addition to providing quality criteria for evaluating results. Thereby, we obtained pertinent information about the implemented solutions, in addition to the educational topics and sign languages covered. *Conclusions:* We conclude that technologies have already contributed to the teaching and learning of sign languages. In this context, different approaches were found, from solutions on traditional platforms (Web, Mobile and Desktop) to the use of Augmented Reality (AR) in smart glasses. However, no solution aims to enable communication between different sign languages, which shows a limitation that can motivate even more innovative research.**

***Index Terms*—Systematic mapping, software engineering, education, sign languages**

I. Introduction

Education and the search for knowledge increasingly represent a differential in an extremely competitive job market. This scenario, associated with the ubiquity of information technologies, has favored the emergence of new teaching modalities, providing more accessible and appropriate educational environments to the context of their learners [1], [2].

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Thus, for the development of effective educational environments, it is essential that intrinsic user characteristics are considered, such as their physical limitations. In this sense, deaf and hard of hearing (D/HH) people face struggles in education due to inappropriate learning environments, especially when there is a lack of support for sign languages [3].

Sign languages are fully fledged natural languages, structurally distinct from the spoken languages. There is also an international sign language, which is used by deaf people in international meetings and informally when travelling and socializing. It is considered a pidgin form of sign language that is not as complex as natural sign languages and has a limited lexicon [4].

According to the World Federation of the Deaf (WFD), there are approximately 72 million deaf people worldwide. More than 80% of them live in developing countries [4]. Therefore, such people, in general, do not have ideal conditions for social integration and personal development. Consequently, there are still many challenges that can be faced with the use of technology. So, this work aims to investigate the current relationship between technology and teaching based on sign languages.

According to a report by WFD [5], there is still a lack of consistency worldwide in the processes of interpreting and translating sign languages. In this sense, the advent of technology is having a significant impact on the way that sign languages are accessible today. Thus, disruptive solutions, using augmented reality glasses or automated sign language translation techniques for example, can guide the development of increasingly effective solutions for sign language users.

In a related perspective, Information and Communication Technologies (ICT) have changed not only our personal interactions but also our teaching practices. The globalization of ICT has created an unprecedented educational context: more flexible, connected and intelligent. Portable technologies, together with computer networks, become increasingly present in everyday life, promoting an ubiquitous access to information.

According to International Telecommunication Union (ITU) [6], [7], nearly the entire world population now lives within reach of a mobile cellular network. Statistically, 93% of the world's population lives within reach of a mobile broadband (or Internet) service and just over 53% actually uses the

Internet.

In 2018, for the first time in history, over half of the world's population has access to Internet, as compared to 2010 when this figure was less than 30%. This scenario suggests that, even in poorer regions, the creation of ICT-based solutions is plausible [6], [7].

A disruptive era is evident in the statistical data presented by the ITU. The spread of information technologies and global interconnectedness has great potential to accelerate human progress, to bridge the digital divide, and to develop knowledge societies [6], [7].

For these reasons, it is necessary to reflect on teaching/learning using sign languages, considering the growing use of technologies in the educational field. In fact, ICT can facilitate access to knowledge, especially in the context of people with physical disabilities. So, in this paper we discuss the conduction of a Systematic Mapping (SM) in order to highlight the state of the art considering the use of technologies in education through sign languages.

The paper is organized as follows: Section II describes how the SM methodology has been applied. Section III presents the results obtained considering the research questions defined in the SM. Finally, discussion and main conclusions are provided in sections IV and V, respectively.

II. Method

We followed the guidelines of [8]–[10] to define the research protocol and to conduct this SM study. In particular, the search approach of Zhang et al. [10] had a greater prominence in this study. Briefly, we performed the following steps:

- Definition of SM scope (Section II-A);
- Selection and quality criteria (Section II-B);
- Conduction of manual search (Section II-C);
- Conduction of automated search (Section II-D);
- Evaluation search performance (Section II-E);
- Data extraction from relevant papers (Section II-F).

A. Research questions

The Research Questions (RQ) are important for defining the scope and identifying potential keywords [8], [9]. Thereby, the goal of this SM is to determine how the technology is being applied in the teaching and learning of sign languages. This leads to the following RQ:

- **RQ1**: Which areas of Software Engineering (SE) are researching teaching and learning through sign languages?
  - Which are the types of proposed solutions (software or hardware or theoretical)?
  - What technologies have been used?
  - What evaluation methods have been applied?
- **RQ2**: What educational topics are covered?
- **RQ3**: What sign languages are covered?
  - Which studies address multiple sign languages?

Next, we present our search approach, with its selection and quality assessment criteria.

B. Search approach

According to [8], [9], systematic studies require explicit inclusion and exclusion criteria to assess each potential primary study. So, we have defined the following selection criteria:

Inclusion criteria:

- Studies present contributions (software or hardware or theoretical) for teaching and learning through sign languages.

Exclusion criteria:

- Studies were not published in the time frame 2000 to 2019 (following a similar approach to [11], [12]).
- Studies are not in the field of Software Engineering (SE).
- Studies classified as abstracts, summaries of conferences/ editorials, gray literature or book chapters.
- Studies not presented in English or Portuguese.
- Studies not accessible in full-text.
- Studies that are duplicates or superficially complementary of other studies.

Still on the exclusion criteria, we provide some clarifications next. First, we chose English and Portuguese because the former is the most indexed language by search engines and the latter is the authors' native language. Moreover, we intended to get an overview of contributions in Portuguese. Finally, as ”not accessible in full-text” we mean the papers not covered by our institutional access, i.e. paid and inaccessible studies were disregarded.

Additionally, we follow the Zhang et al.'s [10] search approach, which incorporates the concept of *Quasi-Gold Standard* (QGS). In this sense, the *Gold Standard* represents all possible primary studies of a research question, i.e., a utopia. Therefore, the QGS represents a subset of these studies, becoming a viable alternative according to [10], who propose the composition of the QGS in the manual search, in order to use it to evaluate the quality of the automated search. Thus, it is possible to calculate *quasi-sensitivity*, a formula that evaluates the performance of automated search, which should ideally include most of the QGS.

To conclude, the QGS-based systematic search approach [10] is able to improve the rigor of search process as well as it can serve as a supplement to the existing guidelines, for example [8], [9]. Following we present our manual research and their respective selected studies, which represent our QGS.

C. Manual search

For the manual search step we chose venues (journals and conferences) related to Software Engineering (SE) and Education. Both Brazilian and international venues were defined with the support of SE specialists. However, only international sources were considered in this work, because most venues in Brazil are not indexed by search engines and this would reduce the effectiveness of the QGS-based systematic search approach.

Table I presents the international conferences and journals considered during the manual search. In this step, the *title-abstract-keywords* fields are essential in evaluating the studies, but other sections can be considered for a more effective classification using selection criteria. This step resulted in the selection of 19 primary studies, which also represent our QGS.

TABLE I
SELECTED VENUES FOR MANUAL SEARCH

Venue	**Library/Publisher**	**QGS**
ACM TOCE	ACM	0
Computers & Education	Elsevier	5
FIE	IEEE	0
HCI International	Springer	5
ICALT	IEEE	5
IEEE Trans. Educ.	IEEE	1
IEEE Trans. Learn. Technol.	IEEE	0
Informatics in Education	Vilnius University	0
ITiCSE	ACM	2
Learning @ Scale	ACM	0
SIGCSE	ACM	1
Total		**19**

In terms of publishers, these venues can be grouped into four libraries with relevant results: ACM (ACM Digital Library), IEEE (IEEE Xplore), Elsevier (ScienceDirect), and Springer (Springer Link). According to [10], it is appropriate to use these same databases to perform the automated search for the benefit of QGS.

D. Automated search

Before conducting a search, it is essential to define a search string. In this sense, two strategies for identifying keywords were used together: (i) from the RQ and PICO (Population, Intervention, Comparison and Outcomes) criteria [8], [9]; (ii) from the *title-abstract-keywords* imported into the analysis software for frequency analysis [10]. The results of this process produced the following search string:

(*learn* **OR** *learning* **OR** *teach* **OR** *teaching*) **AND**
("*sign language*" **OR** "*signed language*") **AND**
(*technology* **OR** *technologies*)

Following Zhang et al.'s [10] guideline, we performed the automated search on the four databases identified as relevant in the manual search: ACM Digital Library[1], IEEE Xplore[2], ScienceDirect[3], Springer Link[4]. Therefore, the defined search string was executed in such databases.

Table II summarizes the results of the automated search, where the selection of studies followed the same rationale presented in the manual search. In addition, our automated search returned most of the studies selected by manual search (QGS), which suggests a good sensitivity of the search string. In this sense, more details are discussed in the following section.

E. Evaluation and refinement

According to [10], the quality of the automated search for scientific research can be evaluated using criteria consolidated

[1]https://dl.acm.org
[2]https://ieeexplore.ieee.org
[3]https://sciencedirect.com
[4]https://link.springer.com

TABLE II
RESULTS FROM AUTOMATED SEARCH

Database	**QGS**	Final Search		
		Retrieved	**in QGS**	**Relevant**
ACM DigitalLibrary	3	922	3	47
IEEE Xplore	6	359	5	59
ScienceDirect	5	1,961	5	20
SpringerLink	5	4,980	5	36
Overall	**19**	8,222	**18**	**162**

in the literature, such as sensitivity and precision. In this sense, the authors propose the concept of *quasi-sensitivity*, a derivation of traditional sensitivity that incorporates the QGS as a quality criterion (Equation 1).

$$\textit{quasi-sensibility} = \frac{\textit{Relevant studies retrieved (in QGS)}}{\textit{Total relevant studies (QGS)}} \quad (1)$$

Therefore, to evaluate the performance of the automated search, we calculated the *quasi-sensitivity* considering the data in Table II. According to [10], when the search performance is acceptable (*quasi-sensitivity* $\geq$ 80%), the results from the automated search can be merged with the QGS, and the search process terminates.

As a result, the *quasi-sensitivity* was calculated to be 94.74% (18/19), i.e., the search performance is acceptable [10]. Therefore, the 163 articles selected in manual and automated searches are potential primary studies, so they must be read completely. In this step, 24 studies were excluded according to the preestablished selection criteria. Figure 1 summarizes our primaries studies and the QGS-based systematic search approach.

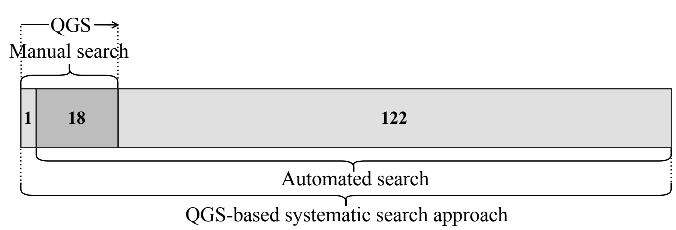

Fig. 1. Composition of the systematic search results.

F. Data extraction

To extract relevant data from the identified primary studies, we created a data extraction form. The template in Table III describes each field and presents its relationship with each RQ, when applicable.

Next we provide an analysis of the identified papers. Due to the large number of papers included in this mapping study, we are not able to include all references in the paper. A full list of papers along with the corresponding study number can be found online[5]. This list of references is grouped based on the topics described in the next section.

[5]Available at https://bit.ly/FIE20-SM-DataExtraction

TABLE III
DATA EXTRACTION FORM

Data item	Value	RQ
General		
Study ID	Integer	
Article title	Name of the article	
Author name	Set of Names of the authors	
Year	Year of the article	
Venue	Name of publication venue	
Search type	Manual or automated or both	
Language	English or Portuguese	
Country	Country of first author affiliation	
Specific		
Area in SE	Knowledge areas in SWEBOK	RQ1
Solution kind	Software or hardware or theoretical	RQ1
Empirical strategy	Which empirical strategies were found	RQ1
Educational topic	Which educational topics were found	RQ2
Sign languages	Which sign languages were found	RQ3

III. RESULTS

Considering the 139 primary studies identified in the SM, we synthesize the most relevant information for our RQ following the template defined in the data extraction form (Table III). Therefore, in this section, we highlight the findings of each research question.

Before that, interpreting some of the general data of our extraction form, we can observe some interesting scenarios that transcend our RQ.

First, considering the number of annual publications, we identified an increasing linear trend estimate (Figure 2). Therefore, it is statistically possible that our research domain is on the rise. In addition, the reduced number of publications before 2010 (less than 16%) can be considered as a cut-off point in a replication or update of this SM.

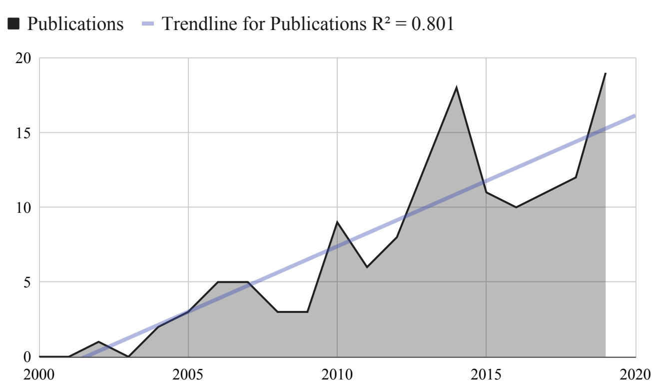

Fig. 2. Annual publications with linear trend estimation (R^2).

Another relevant data is the publications venues, because they can help to define the rationale for future manual searches. Thus, Table IV presents the main venues of this SM. In this context, the strong presence of conferences/journals defined in our manual search (*italicized* rows at the top of Table IV) suggests an efficient execution of this phase in our search protocol.

TABLE IV
DISTRIBUTION OF PUBLICATION VENUES

Venue Name	Venue Type	Studies
HCI International	*Conference*	*12*
ICALT	*Conference*	*6*
Computers & Education	*Journal*	*5*
ICCHP	Conference	8
ASSETS	Conference	6
Procedia Computer Science	Journal	5
Others		97
Total		**139**

Finally, we analyzed the distribution of primary studies by country of origin. In this context, we identified a large number of relevant studies in the USA and Brazil, which together published almost 31% of the papers. Figure 3 shows the top 10 countries, the complete distribution map can be accessed online[6].

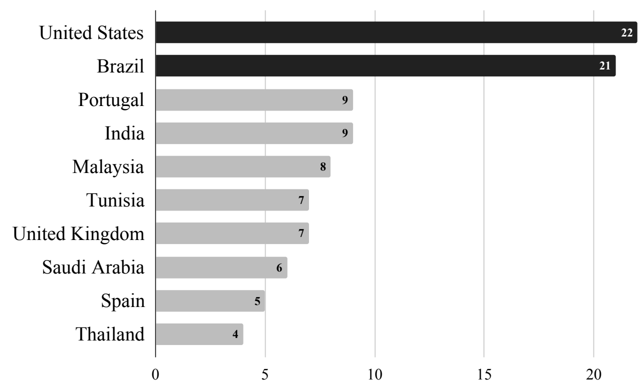

Fig. 3. Publications by country.

A. *Software Engineering Areas (RQ1)*

Our first research question aims to identify the formal topics in the SE that have been investigating education through sign languages. The areas covered were classified based on the Software Engineering Body of Knowledge (SWEBOK) structure [9], [13].

Therefore, we considered the fifteen possible areas of the SE, where four were explored by the primary studies of this SM. This concentration was already expected, because we defined the objective of identifying technological solutions. In this context, we have the following areas of higher education (Figure 4):

- *Software Construction*: studies with emphasis on the development of solutions, often with their respective implementation details. In addition, they may present secondary definitions of design and quality. Finally, the API (Application Programming Interface) design and use are also classified in this area;

[6]Available at https://bit.ly/FIE20-SM-WorldwideStudiesMap

- *Software Design*: studies that present concepts of analysis and design applied to technological solutions. Abstractions like architectures and frameworks are also classified as Software Design;
- *Engineering Foundations*: studies focusing on the empirical evaluation of their solutions. Therefore, this area is related to case studies, surveys and experiments.
- *Software Quality*: studies with non-formal evaluations and validations, related to minimally structured quality criteria. Quality assurance reviews and audits are also conducted in this area.

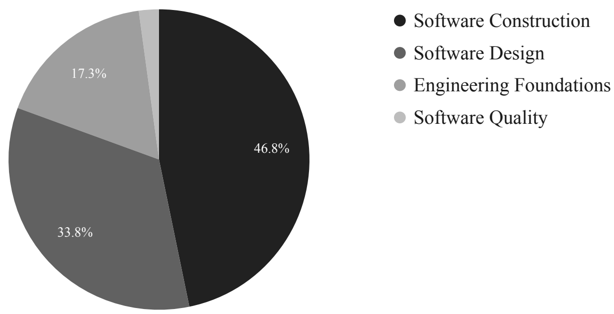

Fig. 4. Publications by SE area [13].

Considering the SE areas, it is evident that most of the primary studies present the design and construction of solutions for teaching/learning sign languages. On the other hand, we consider that there is a significant number of studies with an emphasis on empirical evaluations (S8, S9, S11, S12, S17, S22, S30, S31, S32, S33, S38, S39, S40, S43, S45, S77, S83, S84, S91, S93, S98, S113, S130, S131).

However, many other articles have an empirical evaluation, but were classified in other areas of the SE because they had a main focus more suited to them. In this scenario, the total 47.5% of primary studies present some kind of empirical evaluation (survey, case study or experiment [14]).

Additionally, we classify the contributions of the primary studies as follows: software, hardware or theoretical. Therefore, we concluded that 73.4% of the studies are based on software, 12.9% on hardware and 13.7% are theoretical contributions. In addition, we identified the type of solution for each selected study. Figure 5 shows the top 10 solution types.

These data shows the dominance of some software development platforms: Web, Mobile and Desktop. Together, these platforms are equivalent to 49% of primary studies. However, we have identified only two multiplatform solutions (S70, S116). This small fraction of studies can denote a relevant gap in terms of accessibility, as we believe that the lack of a unified experience can impair and/or limit the users' experience.

On the other hand, several design proposals were identified (S2, S26, S27, S32, S38, S39, S40, S44, S79, S80, S84, S85, S87, S95, S130, S131, S134), showing that potential projects have been evaluated by the scientific community before their effective implementation.

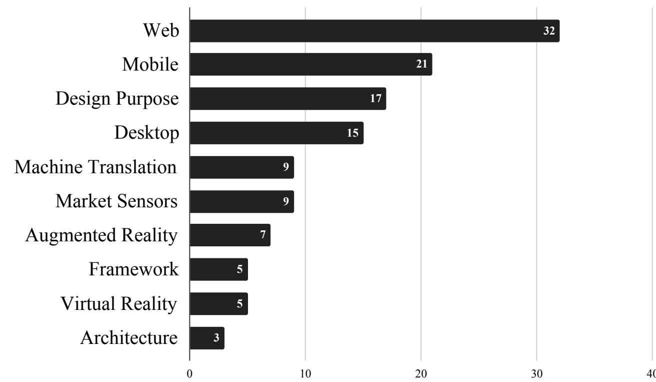

Fig. 5. Publications by solution type.

Besides that, more specific proposals related to machine translation and sign language subtitling were classified individually (S5, S10, S17, S20, S21, S47, S54, S82, S86, S121, S129). By doing so, it was possible to obtain a more technical view on the complexity and challenges identified in this type of solution.

A significant number of studies have an emphasis on market sensors (S19, S43, S58, S61, S97, S105, S108, S138, S123). In this sense, the Kinect[7], Leap Motion[8] and Myo Armband[9] sensors were the most used respectively. This shows that there are initiatives in the industry that enable the development of solutions for the recognition of sign languages with standardization of hardware.

To conclude, the primary studies show that some techniques and technologies are gaining notoriety. In this sense, we highlight the use of the concepts of Augmented Reality (AR) and Virtual Reality (VR) in several solutions (S6, S7, S8, S34, S46, S69, S77, S96, S106, S124, S135, S139). In addition, some API, frameworks and software architectures have been proposed (S49, S56, S63, S64, S66, S68, S74, S75, S78, S103), showing that there are initiatives for creating shared solutions in this domain.

Figure 6 shows a "word cloud" with all types of solutions identified in the selected primary studies. Note that it represents the frequency of each solution through a proportional scale of font size and color tone (red indicates higher frequency and black lower frequency).

B. Education (RQ2)

Our second RQ aims to identify educational topics and better understand the target audience for these solutions. Hence, we identified the teaching topics addressed in the primary studies (Figure 7).

Approximately 42.5% of the studies deal with the teaching of sign languages, showing that there are still many challenges being investigated by the scientific community. On the other

[7]https://developer.microsoft.com/pt-br/windows/kinect
[8]https://developer.leapmotion.com
[9]https://developerblog.myo.com

Fig. 6. Frequency of the types of solutions found (word cloud).

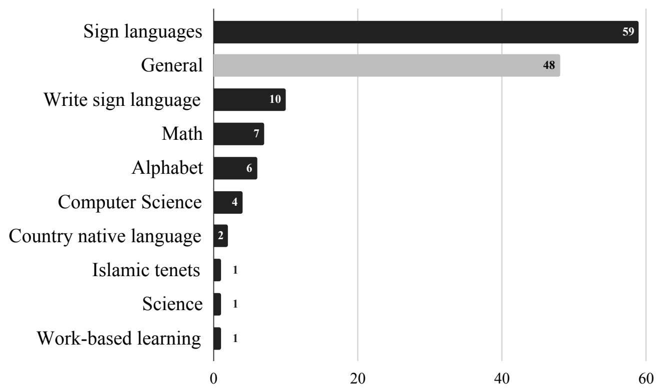

Fig. 7. Publications by educational topic.

hand, about 34.5% are studies applied to education regardless of a topic, generally they are more flexible solutions and with a greater disruptive capacity.

The other 23% are distributed among other teaching topics, among which we highlight the written sign languages, where all studies explore SignWriting[10] (S9, S25, S26, S27, S28, S29, S30, S31, S64, S68). A writing system which uses visual symbols to represent the handshapes, movements, and facial expressions of signed languages.

Through SignWriting it is possible to write any sign, regardless of the sign language, so we can consider it a universal writing system. However, it is necessary to study its worldwide reach and evaluate its practical feasibility.

In addition, we identified the target audience of the studies, with the intention of contributing to the answer to this RQ (Figure 8). In this sense, the majority (approximately 97%) are related specifically to Deaf and Hard of Hearing (D/HH) users. This shows that there are efforts for the social inclusion of the D/HH in different contexts.

In contrast, only 3% of solutions have a general target audience (S35, S56, S122, S138). These studies present solutions that cover people with additional intellectual or sensory disabilities. Because of this, such studies tend to explore sign languages in a secondary way, but as an essential teaching tool.

[10]http://signwriting.org

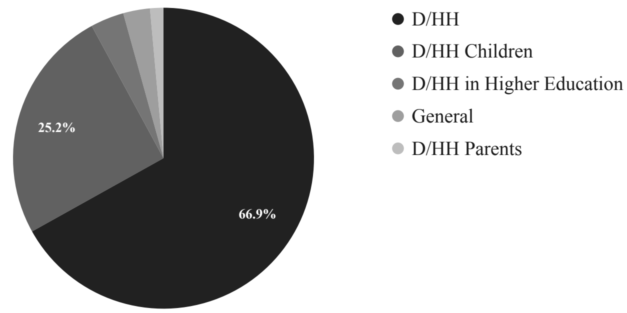

Fig. 8. Publications by educational target public.

C. Sign Languages (RQ3)

Our last RQ concerns the use of sign languages in the educational field supported by technology. Firstly, we identified the sign languages most searched by the primary studies, Figure 9 presents the top 10. Again, USA and Brazil are at the top, with American Sign Language (ASL) and Brazilian Sign Language (LIBRAS). This is an obvious conclusion, considering the distribution of studies by country previously presented.

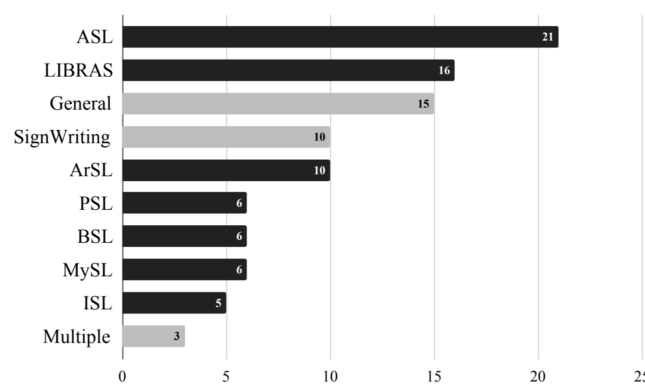

Fig. 9. Publications by Sign Language.

ASL has made relevant contributions since 2004 (S4, S5, S6, S7, S8, S32, S33, S37, S38, S40, S41, S48, S65, S67, S76, S84, S88, S126, S130, S131, S133), showing the best consistency among the sign languages identified. On the other hand, LIBRAS has only one study prior to 2013 (S127), which suggests an increase in LIBRAS in recent years (S17, S18, S20, S23, S34, S47, S80, S91, S92, S96, S101, S103, S108, S109, S117).

Other sign languages are noteworthy: Arabic Sign Language (ArSL), Portuguese Sign Language (PSL), British Sign Language (BSL), Malaysian Sign Language (MySL) e Indian Sign Language (ISL). In this context, solutions based on ArSL have been growing consistently in recent years (S1, S10, S13, S14, S15, S16, S21, S58, S66, S136).

Additionally, some studies were classified as "General" because they explore the domain in a generic/abstract way, without specifying a sign language (S19, S22, S39, S44, S46, S59, S63, S71, S79, S85, S106, S114, S122, S124, S138). However, only one study focuses on the possibility of unifying sign languages (S79).

Finally, SignWriting appears again with a significant number of contributions (S9, S25, S26, S27, S28, S29, S30, S31, S64, S68), showing that the written sign language has great scientific appeal. To conclude, another 3 studies explore multiple sign languages (S62, S74, S102). However, none of them presents a generic solution or with a high level of abstraction.

Therefore, we can conclude that there are many research relevant to the domain explored in this Systematic Mapping. However, most solutions are built without architectural patterns and styles, which makes it difficult to access information and create more intelligent and collaborative solutions. This and other discussions will be presented in the following section.

IV. Discussion

Initially, considering our search protocol, we identified some reflections related to the conduct of this SM. First, the definition of venues for manual search was conducted carefully, because the studies selected in this phase define our main quality criterion, the QGS. In this sense, the support of specialists was essential for the identification of effective venues, which had their importance measured by the representative occurrence of primary studies.

Subsequently, during the automated search, we concluded that a more detailed analysis of the QGS studies can be extremely effective in defining the search string. In this context, the identification of key words and recurring terms meant that our results included almost entirely the QGS studies, resulting in a high quasi-sensitivity.

In turn, the QGS-based systematic search approach was essential to conduct a more structured and formal SM. As a result, sensitive decisions such as the definition of search engines or the quality of the search string could be made following a formal guideline. Thus, the primary studies discussed in this work were identified following strict systematic selection criteria.

Based on the presented results, it is possible to state that sign languages, in the educational domain, have been consistently investigated by formal areas of SE. In this context, we highlight some primary studies with interesting contributions to this discussion.

Joy et al. [15] presented one of the most complete studies of this SM, focusing on a quiz-based tool for learning Indian Sign Language. Initially, the authors conduct a brief literature review, comparing the accuracy of the proposed technique with other methods/applications. Then they propose the design, with an emphasis on Automatic Sign Language Recognition (ASLR). Finally, the implementation and empirical evaluation are presented, detailing the architecture and measuring the effectiveness of the solution experimentally.

Martino et al. [16] and Mehta et al. [17] propose machine translation solutions based on 3D avatars. In this sense, but considering all primary studies, we identified that avatar-based solutions are equivalent to 27% of the selected contributions. Therefore, we can deduce that 3D avatars are of great relevance to the state of practice in the representation of sign languages.

In this context, Martino et al. [16] present a system based on corpus, this category of solutions builds computational knowledge from examples or statistical models. In this case, the corpus was built from a science textbook for children. Finally, the architectural details and results of a preliminary assessment are also presented.

Mehta et al. [17] propose a solution for the automated 3D sign language caption generation for video. However, considering the system workflow, if a set of signs is not recognized, a sign language interpreter can register it manually. The database thus evolves incrementally, which increases the solution's automatic translation capacity.

Another highlight are the wearable solutions, such as gloves, glasses, watches etc (S65, S71, S88, S102, S125). Miller et al. [18] applied the AR concept through smart glasses, so D/HH users can to gather all necessary information during a classroom lecture (e.g., instructor, slides, sign language interpreter or captioning). In addition, the authors conducted a pilot and evaluated the proposal experimentally.

Only one of the primary studies explicitly explores the concept of API [19]. This concept represents a set of routines and patterns available through an interface, so that other applications can consume the shared resources of a domain. For this reason, API can provide the integration between systems that have different languages in an agile and secure way, which is extremely necessary for the development of a more flexible and global educational solution.

Escudeiro et al. [19] propose the Blind and Deaf Communications API (BDC-API), a framework that translates digital educational content for the deaf and blind. The authors also propose an educational model based on Massive and Open Online Courses (MOOCs) and present details of the solution design.

Many of the selected studies investigate the concept of gamification, especially those aimed at children. Pontes et al. [20] present the design, construction and empirical evaluation of an educational game to teach numbers in LIBRAS. In addition, the experiment evaluates educational and game resources.

The study by Ellis et al. [21] presents a relatively simple desktop solution, embedded on DVD for teaching Australian Sign Language (Auslan). However, the application had an interesting feature that allows the user to configure the region. This is very positive and relevant because in countries with a lot of diversity, regional variations of sign languages are very common.

Concluding about regional variations of sign languages, ICT should be essential for the development of context-sensitive solutions. In this sense, smartphones, smart watches and other devices could automatically obtain the user location and provide a personalized experience proactively.

Finally, Kumar et al. [22] is our last study for discussion. In their study, the authors talk about the difficulty of users of sign languages to communicate globally. They present an initial proposal for work and methodology. However, their main contribution is theoretical, with the aim of reflecting on how current solutions have been developed (mostly focused on a specific sign language).

In general, we found a relevant diversity of solutions in this SM. Through them, we identified the massive use of ICT and Artificial Intelligence (AI) techniques, mainly in the sub-areas of Neural Networks, Computer Vision and Machine Learning. In this way, we can conclude that our hardware and software capacities have never been higher, enabling the creation of more robust and efficient applications.

On the other hand, there are not many proposals concerned with computationally structuring educational solutions aimed at sign languages. We believe that SE techniques can help in proposing educational applications that have a generic and collaborative architecture, aiming at global solutions for teaching and learning sign languages.

V. Conclusions and Future Work

In this paper we provide an overview of the research performed about the use of technology for teaching and learning sign languages. We conducted a SM study, which resulted in 139 selected papers. We classify papers according to SE areas [13], educational topics and sign languages to answer the RQ defined in Section II. We also discuss some of the main selected primary studies, addressing topics such as the level of abstraction and the global scalability of solutions.

Considering areas of SE, we have identified that most solutions are related to Software Design and Software Construction [13]. In addition, almost half of primary studies have some empirical evaluation, which highlights the importance of a formal evaluation process.

In technical aspects, the solutions are divided between the Web, Mobile and Desktop platforms, but some studies emphasize more specific approaches/technologies such as machine translation, sensors, AR/VR, frameworks, architectures, among others.

Regarding educational topics, there is a high incidence of solutions for teaching sign languages, an expected result considering the terms used in our search string. Additionally, we highlight a written sign language, called SignWriting, through which is possible to communicate independently of national sign language, since each user will interpret the sign in their native language. This characteristic makes possible a series of possibilities for the creation of global solutions.

Finally, considering sign languages, we identified a predominance of ASL and LIBRAS. In addition, many other sign languages have been mapped, including SignWriting. In addition, some studies deal with sign languages in a generic way. However, none of them presented a concrete implementation aiming at the unification or coexistence of sign languages, which could derive an interesting research topic.

This systematic mapping contains the following threats to validity. First, it is important to consider that the first author individually performed all the stages of this study, including the selection of papers (manual and automated searches), reading, classification and data extraction. For validation, the other authors provided feedback on all stages. Second, we limited the publication date of the selected works to after the year 2000, as we believe that previous works would not represent current educational approaches, especially considering the context of SE. Third, the use of the QGS-based systematic search approach [10] does not guarantee the quality of the selected studies. However, we applied some of the main SE guidelines [8]–[10] in order to minimize bias in the results of this study.

As future work, we intend to investigate in detail the structural and technical aspects to define a reference architecture for educational applications based on sign languages. In addition, we consider conducting a Systematic Review, which would refine the scope of the current SM, obtaining more specific results and directed to a particular research topic.

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