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Smart Glasses User Experience in STEM Students: A Systematic Mapping Study

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Abstract. User experience (UX) is related to the feelings and emotions that people undergo when interacting with technology. This concept also applies to wearable devices, such as smart glasses, which have been widely adopted in a myriad of contexts in recent years. This paper analyzes the literature on user experience with smart glasses, with a particular focus on STEM educational settings. Our goal is to identify gaps and opportunities within this area and contribute to inform future research. To this end, we conducted a systematic mapping study of papers published between 2014 and 2020 indexed by four scientific databases and repositories: the ACM digital library, the IEEE Xplore, Scopus, and Web of Science. Our selection and systematic classification processes considered studies conducted in educational settings or with educational purposes. A total of 485 studies were initially identified and mapped. After revising and analyzing this set of publications, 51 studies were selected and further classified according to their research and contribution, and the educational setting in which they were conducted. This mapping study offers the first systematic exploration of the state of the art on user experience with smart glasses within the context of STEM education.

Keywords: Human-computer interaction · Smart glasses · STEM education · STEM students · User experience · Systematic mapping

1 Introduction

In a broad sense, wearable computing could be defined as technology that is worn on the body, like clothing [1]. This paradigm assumes the existence of a device, with which humans somehow interact and that is able to perform diverse types of computational tasks [2]. In educational settings, wearable technologies can be

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particularly useful, as they can become active tools in the classroom, improving the students' instruction and supporting new ways of participation [3]. Smart glasses are a type of wearable devices with capabilities that augment or superimpose real-world objects [4] on top of what a person can see. Recent technological advancements, have made smart glasses increasingly more innovative and powerful. Ultimately, this has led to their use in a wider range of scenarios. A notable example of this is the Augmented Reality (AR) capabilities featured by most current smart glasses [5]. AR brings numerous advantages when smart glasses are used in educational contexts and several research efforts have exploited AR-based solutions to facilitate and enhance learning. In medicine education, for example, smart glasses enable access to virtual representations of the human body that can be used in surgery training. This allows students to get significant experience before engaging in real-world practical scenarios [6].

The widespread and increasing application of wearable technologies and, in particular, of smart glasses has led to a myriad of research efforts in this area. In turn, this has contributed to the generation of knowledge collected in a large variety of scientific publications. We present a systematic mapping of this literature. More specifically, we focus on user experience of smart glasses in STEM educational settings (science, technology, engineering, mathematics). We seek to contribute to the understanding of the current state of the art in this area, and to identify opportunities that motivate and inform future research efforts.

2 Related Work

Most of the work that has reviewed the literature on smart glasses in educational contexts has focused on areas related to medicine and medical training. Dougherty et al., for example, explored the use of Google Glass in nonsurgical medical settings in a systematic review that covered literature published between 2013 and 2017 [7]. Along the same lines, Yoo et al. focused on works that involved augmented reality and wearable head up displays in surgical use [8]. Mitrasinovic et al. [9] also review salient uses of smart glasses in healthcare with a particular focus on practical capabilities and patient confidentiality. More recently, Badiali et al. explored the adoption of AR guidance in surgical practice in oral and cranio-xaxillofacial surgery [10]. Given that these works are centered on medical settings, they review databases of publications on life sciences and biomedical topics (e.g., PubMed MEDLINE[1], Embase[2], EBSCO[3]), as well as repositories oriented to the publication of technological advancements (e.g., IEEE Xplore).

Closer to our area of interest, the work by Kumar et al. [11] investigated the typical applications of smart glasses in the education sector and identified several ways in which wearable technology supports teaching and learning processes (e.g., documentation of lectures, capturing lectures' essential points, telementoring, trainee's evaluation, on-site report preparation). A similar investigation was

[1] https://pubmed.ncbi.nlm.nih.gov.
[2] https://www.embase.com.
[3] https://www.ebsco.com.

conducted by Sapargaliyev [12] but only for scenarios that used Google Glass as a teaching and learning tool.

The body of knowledge referred above, explores specific facets of the use of smart glasses, both from a medical perspective and from an educational point of view. We share with these research efforts the goal of reviewing the literature on the use of smart glasses to identify gaps and research opportunities. We, however, are interested in how the use of smart glasses in educational contexts relates to the concept of user experience. This is a central principle of our work. Thus, our systematic mapping focuses on studies that involved the use of smart glasses with STEM students and that somehow characterized aspects related to user experience (such as gathering of usability metrics, or identifying important human factors). To this end, we follow a structured searching protocol that focuses only on the publications produced in the last five years—as most commercial smart glasses started to become available more widely since 2015 [1]. This allows us to draw conclusions in the light of the most recent research.

3 The Systematic Mapping Study

We conduct our systematic mapping following the strategies and frameworks proposed by Kitchenham [13], Brereton [14] and Petersen [15]. In the development of our literature search, we followed the PICO process [16], that defines four conceptual elements to drive the publications search: a **P**opulation (or area of interest), an **I**ntervention, a **C**omparison (also called control or comparator), and an **O**utcome. These elements are defined as follows:

Population: The scientific studies with Smart Glasses that have been conducted with a focus on user experience.
Intervention: Smart glasses and related technologies.
Comparison: Where are smart glasses used.
Outcome: Identification of UX related aspects when STEM students used smart glasses in learning environments.

3.1 Mapping Questions

We aim at conducting a systematic mapping study on the user experience with smart glasses in STEM educational settings. To this end, we consider aspects related to usability, interaction, and human factors that hint at the possible benefits and limitations of this type of technology. More specifically, our mapping questions are:

MQ1: What are the uses of smart glasses in STEM educational contexts?
MQ2: What types of smart glasses are used to evaluate UX and/or usability in these studies?

RQ1 seeks to identify the application areas of smart glasses in STEM educational contexts in STEM educational contexts. On the other hand, RQ2 inquires on the types of smart glasses that are most frequently used to explore user experience and related concepts.

3.2 Search Strategy

Our search strategy involved the definition of search strings to identify relevant primary studies, according to what Kitchenham et al. [13] suggest. On top of these initial results, we used the PICO criteria to structure and further refine our search results. The PICO criteria we used are detailed in Table 1.

Table 1. Terms included in the search

Criteria	Main terms	Alternative terms
Population	User experience	UX, student, pupil, trainee, undergraduate, undergrad, apprentice, disciple, learner, learners, scholar, teacher, lecturer, professor, tutor, instructor, trainer, educator experience
Intervention	Wearable	Smart Glasses, smart glass, smart eyewear, google glass, augmented reality glasses, ar glasses
Comparison	STEM	Stem education, stem subjects, stem majors, stem learning, learning for stem, stem teaching, knowledge in stem, stem careers, stem disciplines, stem areas, higher education, student learning, education, learning, teaching, knowledge, training, study, learnedness
Outcome	Application	Use, usage, utilization, utility, usefulness, application, implementation, manipulation

We identified our primary studies by using search strings on the selected scientific databases. These strings contained the main and alternative terms listed above joined through conjunction and disjunction logical operators.

3.3 Databases and Inclusion & Exclusion Criteria

We decided to query four digital repositories of scientific literature: the ACM Digital Library[4], the IEEE Xplore[5], Scopus[6], and Web of Science (WoS)[7].

[4] https://dl.acm.org.
[5] https://ieeexplore.ieee.org.
[6] https://www.scopus.com.
[7] https://www.webofknowledge.com.

We chose these digital libraries because they are amongst the most worldwide recognized repositories of research results in the areas of engineering, computing, and informatics. Moreover, they have excellent bibliographic indicators and metrics for journals, conference papers, book chapters, and magazines [17].

Based on our mapping questions, we defined the following inclusion and exclusion criteria:

Inclusion criteria: Papers published from 2014 to 2020 that report research with smart glasses in STEM educational settings and focus on UX aspects. This includes publications from journals and conferences that are written in English and appear indexed by any of the databases mentioned above.
Exclusion criteria: Papers whose full text was not available for download, short papers (e.g., position papers, extended abstracts), other systematic revisions or literature surveys, duplicated entries (e.g., papers that are simultaneously indexed in more than one database), papers that do not focus on smart glasses and UX or that do not involve studies with STEM Students, grey literature (e.g., reports, working papers, government documents, white papers and evaluations), and studies outside the period [2014 – 2020].

From each paper we considered, we extracted the following data:

General information: Title, author, and publication date.
Document type: Conference paper, journal, symposium, and tech report.
Application scope: Educational setting, industry.
Smart glasses type: E.g., Google Glass, Epson Moverio, Microsoft Hololens.

3.4 Studies Selection Process

The studies we selected resulted from a two-stage procedure—as done in other systematic mappings (e.g., [18]). In the first stage, a researcher reviewed the title and abstract of the papers of our initial search. In this step, irrelevant documents (e.g., those that involved wearable devices but not smart glasses) were discarded. The list of resulting papers was then revised by another researcher, who conducted a verification step. This consisted on reading the papers' title and abstract to assess their relevance. When the second researcher disagreed with the opinion of the first one, the study was discussed further until a unanimous decision was reached. In the second stage, we obtained the full text version of the documents selected in the previous step. On these, we applied the inclusion and exclusion criteria defined earlier. This process was done by two researchers and disagreements were resolved with the opinion of a third person.

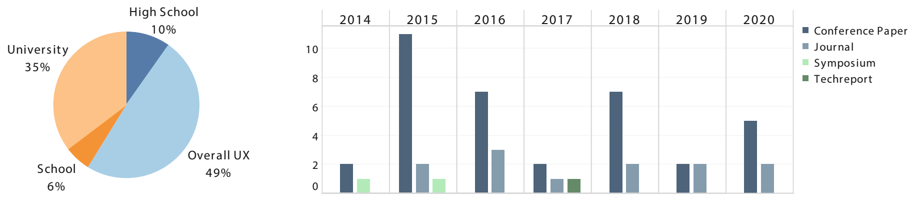
4 Results

Our initial search resulted in 485 studies (see first column of Table 2). Duplicated papers were then removed. This step reduced the publication pool to a total of 382 papers. We then applied the inclusion and exclusion criteria defined earlier. The full text of all the papers that complied with these criteria was then reviewed. Our final set of studies was composed by 51 papers. A detailed breakdown of this process (per database) is show in Table 2.

Table 2. Processing phases of the search results.

Database	Results of initial search	After removing duplicates	Records screened by abstract & other metadata	After applying inclusion & exclusion criteria	Selected papers after full-text analysis
Scopus	125	85	38	15	15
IEEE Xplore	45	24	11	8	8
ACM	214	214	58	26	26
WoS	101	59	16	2	2
Total	485	382	123	51	51

Our systematic mapping resulted in a collection of 51 relevant publications[8]. Our results show that a few studies conducted with smart glasses in STEM educational settings and that focused on user experience, were published in 2014 (n = 3). 2015 is the year with more research activity in this area (n = 14), followed by 2016 (n = 10). The following years have a more or less oscillating number of publications: 2017 (n = 4), 2018 (n = 9), 2019 (n = 4), and 2020 (n = 7). Figure 1 shows this evolution together with the distribution of papers per education level (Fig. 1a) and the publications' type of venue (Fig. 1b).



(a) Educational context (b) Publication types per year

Fig. 1. Contexts in which smart glassed are used and evolution of publications.

Our review revealed that smart glasses have been widely used and studied at different educational levels (**MQ1**). In primary schools, for example, Silva et al. used Glassist [19], an application designed to help teachers in management

[8] The full list of papers analyzed is available at http://bit.ly/2WMha83.

tasks, on Google Glass. The results of a preliminary evaluation of Glassist seemed promising. At the high school level, Kuhn et al. [20] described the development of an application to perform physical experiments. Students who evaluated this self-reported higher levels of cognitive load when working with Google Glass versus other devices.

A myriad of additional studies have explored the use of smart glasses in higher education activities (e.g., [21–24]). Among many others, this includes applications oriented to support learning in science (e.g., [25–28]), as well as technology and engineering (e.g., [29–37]). In the latter category, Cao et al. [38] used a pair of Epson Moverio BT-350 smart glasses for an AR guidance system for experimental teaching. The system supports learning of basic hardware information together with training of a programming environment.

Less conventional educational settings in which smart glasses have been used include museums (e.g., [39]), public speaking (e.g., [40]), procedural knowledge training (e.g., [41]) and fire safety (e.g., [42]). Our systematic mapping did not surface uses of smart glasses in mathematical teaching or learning activities.

Regarding the most frequent types of smart glasses used in STEM educational settings (**MQ2**), we found that the Google Glasses have been, by far, the most popular wearable device used for scientific research in this space between 2014 and 2020. 50 % ($n = 26$) of the studies we reviewed used them. The Google Glasses were followed by the Epson Moverio ones and the Microsoft Hololens—each used in 4 studies. Other types of devices were used in either one or two of the studies we reviewed. These results are summarized in Fig. 2.

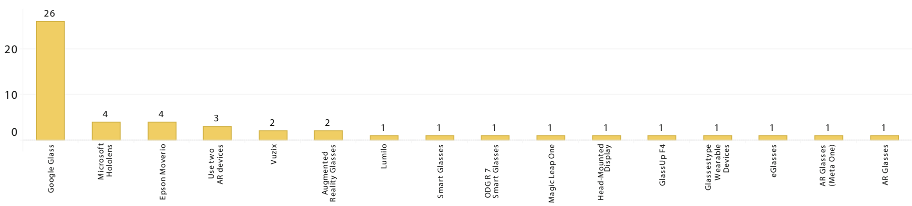


Fig. 2. Number of smart glasses used in the studies we mapped.

5 Discussion

Our mapping study shows that smart glasses have been steadily used in educational settings between 2014 and 2020. This is consistent with the increasing adoption of wearable devices promoted by communities from other academic disciplines—such as Human-Computer Interaction and Information Visualization. Our work also highlights that virtual and augmented reality are important supporting technologies in the use of smart glasses in teaching and learning environments. In fact, none of the studies we reviewed prescinded from these technologies. Thus, VR and AR play a crucial role in advancing the adoption of smart glasses in a wider range of scenarios.

Our literature exploration also confirmed that the vast majority of work with smart glasses—both within and outside educational settings—has focused on medical and clinical applications. This suggests that there is potential for exploiting smart glasses and related technologies in a larger variety of educational settings. For example, we believe these devices could be beneficial to train students on concepts that involve physical manipulation of objects (such as tools or specialized equipment). We also believe this is especially relevant for the current world context, in which face-to-face instruction has shifted greatly to remote learning due to the sanitary crisis around the COVID-19 pandemic. An interesting counterpart of the many applications of smart glasses in medical contexts is the absence of these devices in the teaching of Mathematics. This may be explained due to the abstract nature of many math concepts. Overcoming abstraction would require representing such concepts through animations or virtual models whose production can be time consuming and often requires specialized knowledge. This type of applications, however, could pave the way for new and interesting research questions in the area of wearable devices.

We also note that just a comparatively small number of the studies we reviewed focused on user experience. Most smart glasses applications are built and designed oriented to answer specific research questions. This could explain why researchers do not often investigate user experience as a main aspect of their studies. Nevertheless, there are notable exceptions (e.g., [43–56]). This body of work also includes examples in which usability and user experience have been investigated from specific perspectives: with users with different levels of computer skills [57], in gaming [58] and public spaces [59], with palm-based text entry [60], in the automotive industry [61], in manufacturing [62,63], and in farming [64]. Finally, other studies also show that there exists human factors that can also affect the acceptability and technological adoption of smart glasses [65,66]. This highlights the importance of considering the "humans in the loop" when designing and studying studies that use smart glasses and related technology.

6 Conclusions and Future Work

This paper presented a systematic mapping study on user experience with smart glasses in STEM educational settings. We focused on educational scenarios, extending previous work that explored smart glasses and UX in medicine and medical training contexts. We considered scientific publications generated between 2014 and 2020 and indexed in four digital repositories (the ACM digital library, the IEEE Xplore, Scopus, and Web of Science). From an initial set of 485 papers, we selected 51 papers that reported studies with a focus on UX. Based on these publications, we identified the most common uses of smart glasses in educational settings and the most common types of devices. We also discussed potential opportunities that lay at the intersection of the research with smart glasses and the evaluation of usability.

The main limitation of our mapping study—also evidenced by similar works (e.g., [67])—is that the studies we considered were obtained using tools integrated into the indexing systems and the digital libraries we consulted. Additionally, the results output by these tools were retrieved based on handcrafted chains of logical operators and keywords that we constructed. Moreover, our results are dependent on the keywords we used to characterize the analyzed studies, which might not have captured information reflected by synonyms or other types of semantic variations. Because of this, some sources could have been omitted and, for this reason, our mapping should not be considered comprehensive.

Our results, nevertheless, can be used to motivate research on new uses of smart glasses in educational contexts. One of the future perspectives of this work is to extend this mapping study into a systematic revision of the literature. This would allow to deepen our understanding of the results described in the papers we considered. Ultimately, this would support a more focused identification of research opportunities beyond educational contexts.

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