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Analysis of the impact of augmented reality on learning in times of pandemic

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***Abstract*– Information and communication technologies (ICT) have played an important role in society, affecting almost every aspect of our lives. In the educational field, ICT revolutionizes the teaching and learning experience, and helps one of the greatest challenges that arise in the classroom, education. Different technologies have been applied in this area, such as Video Modeling (MV), Serious Games (JS) and Gamification; but one of the most effective are emerging immersive technologies such as Augmented Reality (AR). A systematic review of the literature (RSL) of the studies of AR in student learning was carried out. The search strategy adopted identified 116,420 studies, of which 104 were selected as primary studies. The studies selected for the RSL helped answer 8 research questions posed for this study. The results of the RSL have concluded predominant trends in the research and applications of AR in learning, the areas of knowledge where AR is used and the areas that use AR.**

***Keywords*-- Systematic review, augmented reality, mobile applications, teaching-learning.**

I. Introduction

ICTs have offered great inclusion in the classroom, and have greatly improved teaching and learning. The use of ICT, in this last group of students, becomes almost indispensable, since this type of students require special treatment when teaching them a specific subject [28] [43]. One of the most widely used emerging technologies in the education of students are immersive technologies, such as Virtual Reality (VR) and Augmented Reality (AR).

It was studied that the application of immersive technologies such as AR [20] [33] [12] help to improve teaching and learning in students. The advantage granted by AR over traditional methods is interactive learning as it plays an important role for students. Visual learning through 3D graphics have a great impact on the learning environment [14]. It allows students to understand and helps to simulate situations that do not endanger the student, which otherwise would be difficult to materialize [32] [25], and in a fun and simple way, which makes education much easier and interesting, thus students' motivation, interest and attention, and thus teaching and learning improves [34]. The devices used for AR are Head Mounted Devices (HMD) [36], Smart Lenses [82], Tablets [44], Webcams [98] and Mobile Devices [14] [75] [95] through the camera included in them. The latter are the most commonly used for AR and the ones that will be used for this study.

AR is shown as an innovative and revolutionary technology in the field of education, although it has its application also in other areas such as Industry, Entertainment, Architecture, Tourism and Advertising [9], one of its most promising uses is in education, and even more in the education of students.

Therefore, in this study, the review of current research on the use of augmented reality in students will be done, a look is given on the disabilities where AR is most used for teaching-learning, as well as the areas of knowledge where they are used; and what other technologies are used for teaching-learning of students. It was also reviewed in which countries this technology is being applied in classrooms and what other areas make use of AR. Finally, it was seen which are the methodologies and tools to develop AR, the most prominent authors in the topic of study and the types of publications most used by these authors.

The structure of the study was organized as follows. Section I presents the introduction to the topic of study. Section II presents the background to previous work done on the topic. Section III presents the review method used for the study, the SLR, where all the steps followed to write this study are explained. Section IV presents the overview of the selected primary studies and presents the results and discussions to the research questions posed for this study. Section V presents the conclusions and future research on the topic.

II. Content

There are several definitions of Augmented Reality (AR), a first definition of AR refers to "Interconnecting virtual objects and integrating them into the real world" [12]; a second definition refers to AR as "An emerging technology that adds additional virtual information to the perception of the real world, in real time" [94]. Another definition about AR tells us that "It combines a live view of the physical world and digital content including images, text, audio, and video" [75], and a last definition refers to AR as a "Technique that merges virtual objects into real environments, which could be applied in some areas for students" [10]. It can be evidenced, in each of these definitions, that AR is a technology that superimposes digital objects such as images, text, audio and video; to the real world, and is performed in real time.

To date, AR is shown as a very promising technology in the area of education, and even more so in the application of student learning [64]. Therefore, it is sought to review in what type of learning the use of AR is being made and in what subject this technology is being used.

As far as it has been possible to investigate, the SLRs that focus on the use of AR for the teaching-learning of students have focused on individual study, being in smaller quantity the SLRs that evaluate learning as a whole. The following are some of the reviews found that demonstrate the identified gap.

First, Khowaja K., Banire B., Al-Thani D., Sqalli M. T., Aqle A., Shah A., and Salim S. S. [111], 2020, conclude that while the effect of using AR helps in individual learning, a summative conclusion on the effectiveness of AR for skill learning on the existing literature is not possible.

Lorenzo Lledó G., Lorenzo Lledó A., Lledó A. and Pérez-Vázquez E. [112], 2020, study the specific educational needs where augmented reality has application possibilities. Therefore, the aim of their research is to review the scientific production in Web of Science (WOS) and Scopus from 1990-2020 on the application of augmented reality in learning.

Berenguer C., Baixauli I., Gómez S., Andrés M. de E. P. and De Stasio S. [113], 2020, had the objective of the systematic review to investigate the impact of augmented reality across social, cognitive and behavioral domains in children and adolescents.

Gómez-Puerta M., Chiner E., Melero-Pérez P. and Lorenzo Lledó G. [114], 2020, offered as a result a positive view of the application of this technology for teaching, although the characteristics of the studies do not yet allow its generalization.

Finally, Blattgerste J., Renner P. and Pfeiffer T. [115], 2019, provided insights into current challenges and possibilities for assistance in AR learning and action. They discussed trends in the research field, including potential future work for researchers to focus on.

There is interest in the application of AR for student teaching and learning. AR is the term used to define a direct or indirect view of a real-world physical environment, making it a great resource in the inclusive arena. It can provoke a feeling of inclusive learning and increase motivation, both in the student who learns in a real way what for various circumstances he/she cannot or has not been able to access, and in the teacher, for seeing the progress in the transmission of content. As a consequence, it is necessary to carry out a systematic review of the literature identifying the learning and knowledge where the interest in its application has increased.

Method of review

The review method has been developed taking into account the guidelines suggested by B. Kitchenham [105] for systematic literature review (SLR) as shown in the figure. The review method includes the following seven steps: (A) formulating research problems, (B) selecting sources and search strategies, (C) establishing selection criteria, (D) study selection, (E) quality assessment, (F) data extraction strategies, and (G) data synthesis.

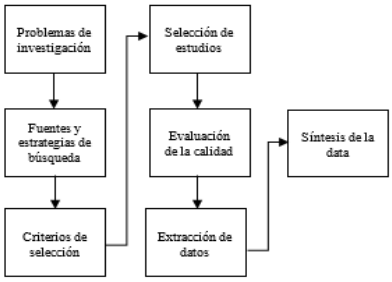

Fig. 1 Description of the steps used for the RSL.

A. *Research problems*

The main objective of this study was to develop an understanding of the use of augmented reality in student education. In addition, this study aims to provide a framework that will facilitate further research on the topic. To meet the objectives of this study, the following research problems were formulated:

RQ1. In what type of disability is the use of augmented reality most effective for the learning process?

RQ2. In what areas of knowledge is augmented reality being applied the most?

RQ3. What other technologies are used to improve the learning process of students?

RQ4. Which countries are implementing the use of augmented reality for the learning process?

RQ5. In which areas is augmented reality being applied?

RQ6. What methodologies and tools are being used for the development of augmented reality?

RQ7. Who are the most active authors in the area?

RQ8. What are the most prominent types of publications on the subject?

TABLE I
OBJECTIVES OF THE PROPOSED RQS

Id.	Objective
RQ1	Identify the disabilities in which the use of augmented reality is most effective for the learning process.
RQ2	Identify the areas of knowledge that most apply the use of augmented reality.
RQ3	Identify other technologies that are used to enhance the learning process for students.
RQ4	Identify which countries are implementing the use of augmented reality for the learning process.
RQ5	Identify what other areas make use of augmented reality.
RQ6	Identify the methodologies and tools being used for the development of augmented reality.

RQ7	Identify the most active authors in the area.
RQ8	Identify the most prominent types of publications on the subject.

B. Sources and search strategies

The search sources for the study were chosen from prominent digital libraries related to computer science, engineering, technology and related fields. The next table shows the 11 sources that were chosen for the search.

TABLE II
SELECTED SEARCH SOURCES TO PERFORM THE SEARCH

No.	Source
1	ARDI
2	ProQuest
3	ACM Digital Library
4	IEEE Xplore
5	Science Direct
6	Microsoft Academic
7	Google Scholar
8	Taylor & Francis
9	Wiley Online Library
10	ERIC
11	Scopus

For the search strategy, search terms were established based on the research problems. Search equations were created using Boolean operators (AND and OR) according to the syntax of each search source. Table 3 shows the terms of the equations, which were of the type (T1 AND T2 AND (T3) AND (T4) AND T5).

TABLE III
SEARCH TERMS

Index	Term
T1	Impact
T2	Augmented reality
T3	Method OR Methodology OR Model
T4	Learning OR Teaching
T5	Students

The result of applying the different search equations gave a total of 116 420 base studies, distributed as follows.

TABLE IV
NUMBER OF STUDIES BY SOURCE

No.	Source	No. of studies
1	ACM Digital Library	41 403
2	IEEE Xplore	22 960
3	ProQuest	21 232
4	Google Scholar	19 500
5	Taylor & Francis	9 101
6	Wiley Online Library	985
7	Science Direct	710
8	Scopus	346
9	Microsoft Academic	85
10	ARDI	75
11	ERIC	23
Total		116 420

The ACM Digital Library, IEEE Xplore, ProQuest and Google Scholar are the most prominent digital libraries on the subject under study.

C. Selection criteria

Exclusion criteria have been defined to accurately assess the quality of the available studies. Studies were reviewed and discussed by the authors for exclusion. The exclusion criteria given for review of the studies were as follows.

CE1: Articles were older than 5 years.
CE2: Articles were published in publication types other.
than conferences or peer-reviewed journals or workshops.
CE3: The articles are written in a language other
than .English.
CE4: The titles and keywords of the articles are.
inappropriate
CE5: The abstract of the articles are irrelevant.
CE6: The proposed solution applies to a process different.
from the learning process.
CE7: Incomplete access to the article.
CE8: The articles are duplicated.

D. Selection of studies

We started with 116 420 base studies, to which 4 stages were applied for study selection, each with 2 exclusion criteria as shown in the figure.

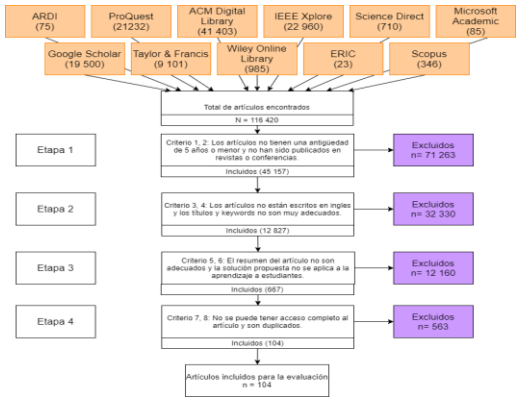

Fig. 2 Consolidated number of results when applying criteria.

In stage 1, CE1 (Articles are older than 5 years) and CE2 (Articles were published in publication types other than conferences or peer-reviewed journals or workshop) were applied using the search tool embedded in the sources. In CE1, studies since 2015 have been segmented. In CE2 the publications are segmented into: conferences, journals or workshop, however, sources such as Google Scholar not having the facility in the search tool we proceeded to a manual verification. At this stage, 71,263 studies were excluded. In stage 2, CE3 (The articles are written in a language other than English) was applied through the search tool incorporated in the sources and CE4 (The titles and keywords of the articles are inadequate) through manual review of the authors. At this stage 32 330 studies were excluded. In stage 3, CE5 (The abstract of the articles are irrelevant) and CE6 (The proposed solution applies to a process other than learning) were applied by manual review of the authors. At this stage, 12 160 studies were excluded. In stage 4, EC7 (Incomplete access to the article) was applied by verifying the download of the study in PDF format and EC8 (The articles are duplicates) by using the Excel application. At this stage, 563 studies were excluded.

E. Quality assessment

Each of the 104 studies remaining after stage 4 of the study selection were independently assessed by the authors according to 7 formulated QAs (Quality Assurance).

QA1: Are the research objectives clearly identified in the paper?
QA2: Is the experiment performed adequate and acceptable?
QA3: Does the document explain the context in which the research was performed?
QA4: Is the document well organized?
QA5: Are the methods used to analyze the results appropriate?
QA6: Is the data set used clearly identified?
QA7: Are the results of the experiments performed clearly identified and reported?

Four QA are related to the quality of the rationale, objectives, and context of the study (QA1, QA2, QA3, and QA4). Two QA were related to the rigor of the research, methods employed to establish the validity of the data collection tools and analysis methods and, therefore, the reliability of the findings (QA5 and QA6). In addition, one QA was related to the assessment of the credibility of the study results (QA7). Taken together, these 7 QAs provide a measure that provided assurance that the findings of a particular study could make a valuable contribution to the review. Each of the 7 QAs was scored on a dichotomous scale ("yes" or "no").

Of the studies evaluated for quality assurance, all 104 were retained. All disagreements were resolved by discussion among the authors.

F. Data extraction

During this stage, data were extracted from each of the 104 studies included in this SLR according to a predefined extraction form in the Excel application. The properties considered in the extraction are Title, URL, Source, Year, Country, No. Pages, Languages, Publication Type, Publication Name, Research Methodology, Authors, Affiliation, No. Citations, Abstract, Keywords, Detail 1, Detail 2 (If required), Detail 3 (If required), Sample Size.

In addition, the pages with content that answered the research questions addressed by this study have been extracted.

G. Summary of data

After extracting the information from each study, an in-depth data analysis was conducted to answer each research question. For RQ1, students who used augmented reality for the learning process were identified and classified. For RQ2, the knowledge area to which the revised study has been applied was identified or inferred. RQ3 identified the technologies used or mentioned in the study that are related to student learning. For RQ4, the countries in which the study was carried out or that are related to the study were recognized. For RQ5, in addition to the area of education, other areas mentioned or in which the use of augmented reality was carried out were considered. For RQ6, the methodologies and tools used in the studies for the application of augmented reality in learning have been identified. For RQ7 and RQ8 use was made of the authors and type of publication collected from the studies in the data extraction stage.

The information extracted for the research questions has been tabulated and presented as quantitative data that was used to develop a statistical comparison between the different findings for each research question. The statistics developed have helped to uncover certain research patterns as well as research directions that were conducted in the interval from 2015 to 2020.

H. Answers to the research questions

This section presents the synthesis of the findings obtained from this review organized according to the eight research questions.

RQ1. In which type of disability is the use of augmented reality more effective for the teaching-learning process?

According to the results of the literature review, there are ten types of disabilities in which augmented reality is used for teaching-learning. Table V shows the types of disabilities and their references.

TABLE V
TYPES OF DISABILITY

Id.	Type of disability	Articles	Cant. (%)
1	Autism	[2] [4] [7] [10] [11] [12] [14] [15] [16] [17] [18] [23] [35] [54] [56] [57] [58] [59] [60] [61] [62] [63] [71] [73] [74] [75] [77] [80] [81] [83] [84]	31 (30)
2	Intellectual disability (ID)	[1] [3] [4] [8] [32] [54] [55] [56] [63] [68] [72] [75] [76] [77]	14 (13)
3	Deafness or hearing impairment	[16] [19] [20] [21] [26] [27] [34] [53] [69] [70] [80] [83]	12 (12)
4	Physical disability	[2] [3] [12] [13] [16] [21] [25] [29] [32] [36] [54]	11 (11)
5	Attention Deficit Hyperactivity Disorder (ADHD)	[11] [22] [24] [33] [55] [70] [77] [78] [79] [80] [82]	11 (11)
6	Down Syndrome	[6] [7] [9] [16] [55] [72] [80] [28]	8 (8)
7	Specific Learning Disability (SLD)	[1] [2] [66] [67] [78] [80]	6 (6)
8	Dyslexia	[5] [14] [21] [24] [65] [80]	6 (6)
9	Communication deficit	[7] [20]	2 (2)
10	Mental retardation	[80] [83]	2 (2)
11	Dyspraxia	[48], [94]	2 (2)
12	Williams syndrome	[55]	1 (1)
13	Dyscalculia	[80]	1 (1)
14	Blindness or visual impairment	[80]	1 (1)
15	Asperger Syndrome (AS)	[98]	1 (1)
16	Dysgraphia	[99]	1 (1)

RQ2. In which areas of knowledge is augmented reality being applied the most?

The results of the review found that there are 18 areas of knowledge where mobile applications with augmented reality are being used. Table VI shows the knowledge areas and their references.

TABLE VI
KNOWLEDGE AREAS

Id.	Knowledge areas	Articles	Cant. (%)
1	Social skills	[4] [10] [11] [15] [17] [26] [35] [54] [55] [56] [57] [58] [59] [60] [61] [68] [71] [73] [74] [76] [77] [81]	22 (21)
2	Mathematics	[1] [4] [8] [14] [18] [19] [29] [32] [33] [58] [64] [66] [67] [72] [77] [78] [80] [82]	18 (17)
3	Literacy	[7] [14] [34] [53] [54] [57] [60] [64] [69] [71] [75] [79] [83]	13 (13)
4	Languages	[18] [16] [63] [66] [72] [79] [82]	7 (7)
5	Science	[4] [6] [8] [19] [29] [58] [72]	7 (7)
6	Anatomy	[2] [12] [16] [24] [61] [70]	6 (6)
7	Biology	[20] [30] [67] [82]	4 (4)
8	Chemistry	[16] [20] [24] [82]	4 (4)
9	Geography	[16] [30] [58] [61]	4 (4)
10	Physics	[2] [16] [20] [82]	4 (4)
11	Creativity	[17] [20] [22]	3 (3)
12	Language	[3] [23] [82]	3 (3)
13	Reading	[65] [82] [84]	3 (3)
14	Art	[58] [66] [72]	3 (3)
15	Astronomy	[16] [20] [82]	3 (3)
16	History	[9] [82]	2 (2)
17	Physical Education	[54]	1 (1)
18	Medicine	[82]	1 (1)

RQ3. What other technologies are used to improve the learning process of students?

Through the literature review, 17 different technologies used in teaching students with disabilities were found. Table VII shows the other technologies used in teaching students with disabilities and their references.

TABLE VII
OTHER TECHNOLOGIES USED FOR TEACHING AND LEARNING OF STUDENTS

Id.	Technology	Articles	Cant. (%)
1	Virtual Reality	[3] [4] [5] [6] [12] [13] [15] [18] [19] [20] [21] [26] [29] [33] [36] [57] [59] [67] [71] [74] [77]	21 (20)
2	Serious games	[6] [14] [18] [54] [57] [58] [59] [66] [70] [71] [74] [76] [77] [80]	14 (13)
3	Video Modelling (VM)	[1] [4] [8] [14] [16] [20] [22] [23] [26] [53] [55] [56] [58] [68] [72] [74] [77]	7 (7)
4	Gamification	[3] [18] [19] [77] [80] [81]	6 (6)
5	Smart glasses	[11] [35] [54] [60] [81] [82]	6 (6)
6	AR books	[66] [78] [80] [82]	4 (4)

7	Computer-assisted instruction (CAI)	[56] [68] [75] [80]	4 (4)
8	Robotization	[5] [15] [54]	3 (3)
9	Artificial intelligence	[27] [80] [81]	3 (3)
10	Augmented and Assisted Communication (AAC)	[5] [10]	2 (2)
11	AR Marker Card	[63] [84]	2 (2)
12	Simulation	[59] [77]	2 (2)
13	Optical Character Recognition	[65]	1 (1)
14	Virtual laboratories	[19]	1 (1)
15	Video Prompts (VP)	[72]	1 (1)
16	Smart Clock	[32]	1 (1)
17	Web applications	[80]	1 (1)

RQ4. Which countries are implementing the use of augmented reality for the learning process?

The systematic review of the 104 articles identified 27 countries where augmented reality is used for teaching students. Table VIII shows the countries with their references.

TABLE VIII
COUNTRIES IMPLEMENTING THE USE OF AUGMENTED REALITY

Id.	País	Articles	Cant. (%)
1	US	[1] [4] [5] [8] [9] [11] [23] [27] [32] [55] [56] [67] [68] [72] [75] [81] [85] [86] [89] [101]	20 (19)
2	Taiwan	[13] [22] [58] [70] [74] [77] [79] [91] [104]	9 (9)
3	Malaysia	[2] [62] [64] [69] [71] [80] [84]	7 (7)
4	Spain	[4] [6] [9] [10] [73] [78] [98]	7 (7)
5	Brazil	[3] [7] [18] [57] [92] [94]	6 (6)
6	India	[20] [24] [63] [65]	4 (4)
7	Indonesia	[28] [33] [36] [83]	4 (4)
8	Greece	[17] [29] [76]	3 (3)
9	China	[30] [35] [60]	3 (3)
10	Romania	[19] [26] [61]	3 (3)
11	Turkey	[16] [82]	2 (2)
12	Canada	[88] [93]	2 (2)
13	Czechia Republica	[12] [90]	2 (2)
14	Pakistan	[14] [99]	2 (2)
15	Saudi Arabia	[34] [53] [96]	1 (1)
16	United Kingdom	[59]	1 (1)
17	Cyprus	[66]	1 (1)
18	Russia	[87]	1 (1)
19	Italy	[95]	1 (1)
20	Argentina	[97]	1 (1)
21	Sultanate of Oman	[100]	1 (1)
22	Denmark	[102]	1 (1)
23	Egypt	[103]	1 (1)
24	Eslovaquia	[21]	1 (1)
25	Ucrania	[15]	1 (1)
26	Ecuador	[25]	1 (1)
27	Korea	[31]	1 (1)

RQ5. In which areas is augmented reality used?

According to the results obtained from the RSL, 10 areas in which augmented reality is used were identified. Table IX shows the areas and references to the studies.

Most of the studies mentioned that augmented reality is used in medicine with 19% of the total studies, followed by industry with 13%, and it is also used in entertainment with 12% of the total studies.

TABLE IX
AREAS MAKING USE OF AUGMENTED REALITY

Id.	Area	Articles	Cant. (%)
1	Medicine	[1] [3] [6] [8] [20] [9] [54] [61] [70] [79] [82] [83] [25] [13] [28] [30] [32] [43] [49] [97]	20 (19)
2	Industry	[5] [20] [9] [21] [14] [53] [61] [70] [79] [80] [28] [43] [44] [97]	14 (13)
3	Entertainment	[7] [20] [9] [61] [67] [79] [82] [30] [43] [49] [52] [97]	12 (12)
4	Tourism	[7] [9] [25] [28] [30] [37] [49]	7 (7)
5	Advertising	[20] [9] [16] [67] [82] [97]	6 (6)
6	Architecture	[20] [9] [61] [87]	4 (4)

7	Location	[68] [83] [88] [49]	4 (4)
8	Military	[61] [28] [82]	3 (3)
9	Communication	[61]	1 (1)
10	Archaeology	[97]	1 (1)

RQ6. What methodologies are being used for the development of augmented reality?

According to the results obtained from the RSL, the methodologies being used for the development of augmented reality were identified, also the tools being used for the development of augmented reality were identified. Table X shows the methodologies and their references, while Table XI shows the tools and their references.

TABLE X
METHODOLOGIES USED FOR AUGMENTED REALITY DEVELOPMENT

Id.	Methodologies	Articles	Cant. (%)
1	Evolutionary development	[3] [7] [10]	3 (3)
2	ATHYNOS	[92] [94]	2 (2)
3	ADDIE	[2]	1 (1)
4	UCD	[53]	1 (1)
5	Traditional development	[9]	1 (1)
6	TPACK	[61]	1 (1)
7	client-server model	[61]	1 (1)

TABLE XI
TOOLS USED FOR AUGMENTED REALITY DEVELOPMENT

Id.	Tools	Articles	Cant. (%)
1	Unity	[3] [14] [15] [16] [21] [24] [53] [61] [83] [92] [94] [25] [27] [26] [37] [43] [46] [47] [48] [49] [50] [51] [52] [102]	24 (23)
2	Vuforia	[2] [3] [14] [15] [16] [24] [53] [84] [92] [94] [61] [26] [43] [46] [47] [48] [49] [50] [51] [102]	20 (19)
3	Aurasma (HP Reveal)	[1] [4] [8] [12] [17] [23] [55] [56] [67] [70] [72] [75] [79] [82] [90] [42]	16 (15)
4	Blender 3D	[18] [21] [26] [50]	4 (4)
5	AR ToolKit	[9] [20] [28] [31]	4 (4)
6	HoloLens ToolKit	[25] [27] [40]	3 (3)
7	iMovie	[55] [72]	2 (2)
8	React Native	[65]	1 (1)
9	Cinema 4D	[16]	1 (1)
10	PrimeSense OpenNI	[73]	1 (1)
11	Scratch 2.0	[13]	1 (1)
12	iOS platform	[54]	1 (1)
13	Goblin XNA	[59]	1 (1)
14	easyAR	[38]	1 (1)

RQ7. Who are the most active authors in the area?

According to the primary studies selected for the SLR, the following information was obtained for the authors, as shown in Table XII.

TABLE XII
MOST PRODUCTIVE AUTHORS ON THE SUBJECT

Id.	Authors	Articles	Cant. (%)
1	Arshya Vahabzadeh	[11] [81] [85] [86] [89]	5 (5)
2	Ned T. Sahin	[11] [81] [85] [86]	4 (4)
3	Ryan O. Kellems	[1] [4] [8] [72]	4 (4)
4	Aziza Almutairi	[34] [53] [96]	3 (3)
5	Chien-hsu Chen	[51] [58] [104]	3 (3)

RQ8. What are the most prominent types of publications on the subject?

According to the selection made for the SLR of the various prominent digital libraries selected (Table I), the following publication types were obtained as shown in Table XIII.

TABLE XIII
MOST IMPORTANT TYPES OF PUBLICATION

Id.	Types of publication	Articles	Cant. (%)
1	Journal	[1] [2] [4] [5] [6] [8] [9] [10] [11] [13] [15] [16] [23] [24] [29] [30] [31] [41] [49] [51] [52] [53] [54] [55] [56] [57] [58] [59] [62] [63] [64] [66] [67] [68] [69] [70] [72] [74] [75] [76] [77] [78] [80] [81] [82] [83] [84] [85] [86] [87] [88] [89] [93] [103]	54 (56)
2	Conference	[3] [7] [12] [14] [17] [18] [19] [20] [21] [22] [25] [26] [27] [28] [32] [33] [34] [35] [36] [38] [39] [40] [42] [43] [44] [45] [46] [47] [48] [50] [60] [61] [65] [71] [73] [79] [90] [91] [92] [94] [95] [96] [97] [98] [99] [100] [101] [102] [104]	49 (43)
3	Workshop	[37]	1 (1)

III. DISCUSSION

RQ1. In what type of disability is the use of augmented reality most effective for the teaching-learning process?

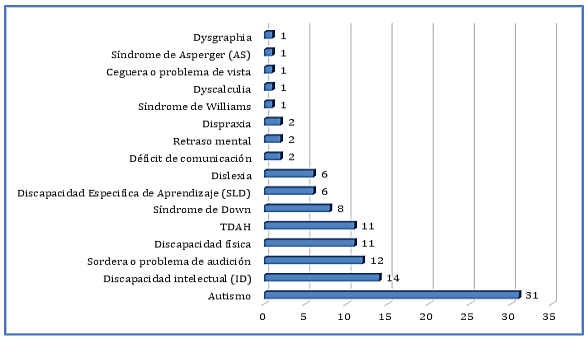

Fig. 3 Types of disabilities where augmented reality is used.

According to Figure 3, the type of disability in which augmented reality is most used for teaching-learning is autism. People with autism spectrum disorders (ASD) demonstrate qualitative impairments in social communication and social interaction in multiple contexts [56]. It is agreed with Carreon A., Smith S. J., Mosher M., Rao K., and Rowland A. (2020) that it is autism that is the main disability addressed with augmented reality according to the literature review. It is recommended that the number of articles analyzed be expanded to encompass a greater number of disabilities.

RQ2. In which areas of knowledge is augmented reality being applied the most?

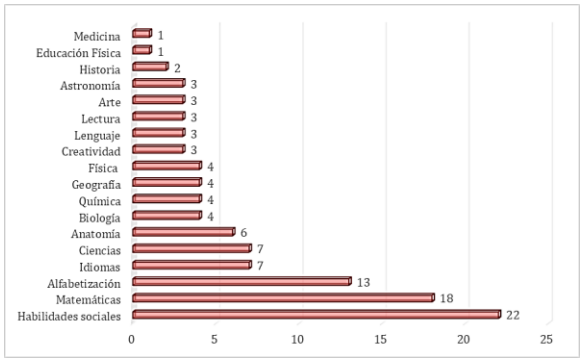

Fig. 4 Areas of knowledge where augmented reality is applied.

Figure 4 shows a clear inclination for the application of augmented reality for teaching social skills. These are a set of naturally learned behaviors (and therefore can be taught), which are manifested in interpersonal situations, socially accepted and these are fundamental to establish quality relationships and generate bonding with different types of people. Likewise, it is agreed with Carreon A., et al. (2020) that social skills are the area of knowledge with the greatest application of augmented reality. Further analysis should be taken into consideration for evaluation of effectiveness in the knowledge area.

RQ3. What other technologies are used to improve the learning process of students?

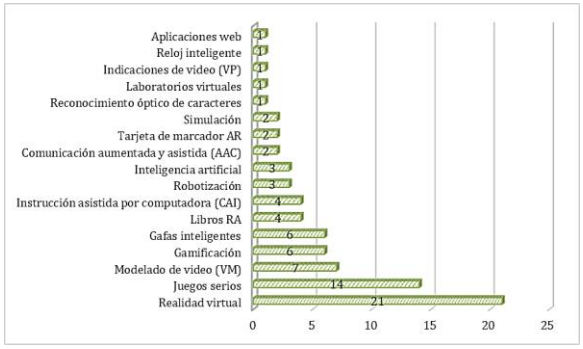

Fig. 5 Technologies that are used to improve the learning process.

In Figure 5, virtual reality was identified as the most applied technology for teaching students, ignoring augmented reality, which is analyzed in other questions. The characteristics of virtual reality provide the sensation of being present in a non-physical world by surrounding the user with images, videos, sound, movement, and other stimuli [67]. It is disagreed with Lai J. W. M. and Bower M. (2019), that serious games are the most popular technology used in teaching. Despite having the same evaluation criteria, with respect to the number of articles, the discrepancy could have been generated by the difference in time in which the study was developed, with the study under development being the most recent and evidencing the current interests of the community.

RQ4. Which countries are implementing the use of augmented reality for the learning process?

Fig. 6 Countries with application in augmented reality.

Teaching in different countries is different, and each country applies augmented reality technology in a different way. US was identified as the country that has implemented augmented reality for the learning-teaching process the most. In comparison with Chen P. et al. (2017) who concluded according to their study that Taiwan is the country where more studies were conducted with reference to augmented reality as a learning tool. It is reflected that in recent years the interest of the study in US has been increasing with respect to Taiwan.

RQ5. In what areas is augmented reality being used?

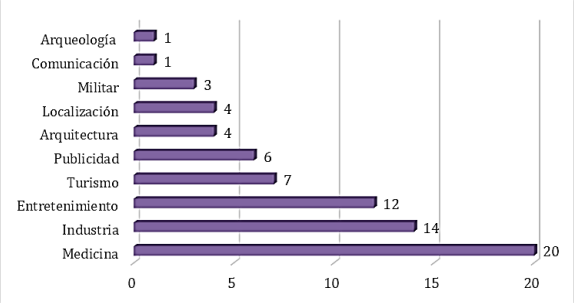

Fig. 7 Areas that make use of augmented reality.

In Figure 7, the area where augmented reality is most used is medicine, where it is used as a tool for therapy and rehabilitation, to help people recover from brain damage or in physiotherapies [28]; it is also used in this field, to a lesser extent, to help in the process of operations within hospitals, since AR helps doctors to visualize the human organ when performing any operation to minimize errors [28]. The other area where augmented reality is most used is in industry, where it is used for training in the use of machinery or aiding in the operation of machinery to enable people to work effectively in protected organizations [32]. Finally, the other area where this technology is used is in entertainment, which is mostly used in video games [61].

Compared to A. Dey (2018), it is agreed that one of the areas where augmented reality is most applied for teaching are Medicine, Education, Industry, Shipping, Entertainment and Tourism.

RQ6. What methodologies are being used for the development of augmented reality?

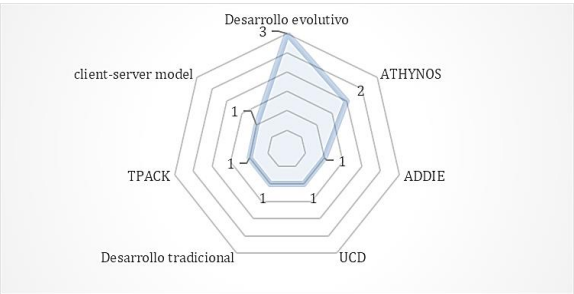

Fig. 8 Methodologies used for augmented reality development.

It was found that the most used methodology for the development of augmented reality for teaching-learning of students is the Evolutionary Development, this methodology ensures a correct development and provides the necessary steps to meet the necessary specifications for the use by students, since this type of user needs specific requirements such as proper accessibility, interface, and usability [60] [5] [5] [6].

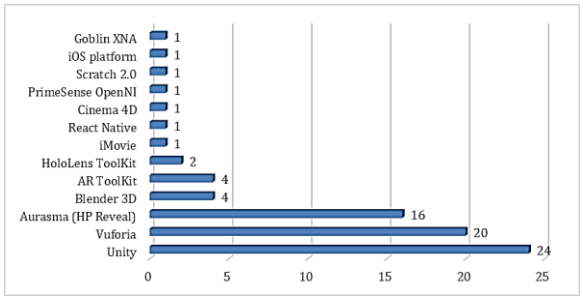

Fig. 9 Tools used for augmented reality development.

It was also found that the most used tools for the development of augmented reality with Aurasma (HP Reveal), Unity and Vuforia. Aurasma (HP Reveal) being an augmented reality app that uses the smartphone camera to superimpose 3D objects in the real environment [42] [56]. While Unity and Vuforia are the duo par excellence for the development of augmented reality. Unity enables the development of 2D and 3D applications and games, while Vuforia enables the realization of AR, VR and Mixed Reality (MR) [15]. The integration of Unity and Vuforia allows the creation of applications and games for Android and iOS [15] [24]. One of the most widely used tools for 3D modeling is Blender 3D [18].

Compared to J. Quintero (2019), it is agreed that Aurasma (HP Reveal) and Vuforia are the most used tools for augmented reality development, while Blender 3D is the most used tool for 3D modeling.

RQ7. Who are the most active authors in the area?

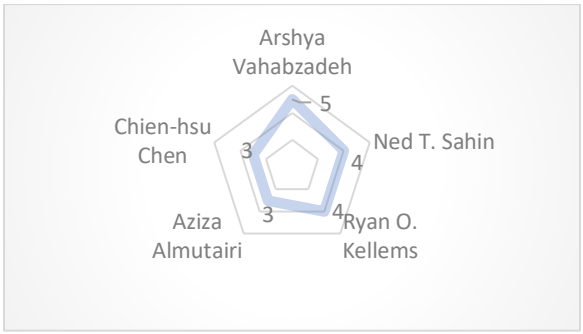

Fig. 10 Most active authors.

According to Figure 10, it was found that the author, Arshya Vahabzadeh, is the most productive author on augmented reality applied to teaching-learning in students, with 5 selected articles; followed by the author, Ned T. Sahin, who is also a prominent author on the topic under study, has made great contributions to the area, with 4 studies selected for this SLR. Other prominent authors on the topic are Ryan O. Kellems with 4 studies selected for the SLR; Aziza Almutairi and Chien-hsu Chen with 3 studies selected for the SLR.

RQ8. What are the most prominent types of publications on the subject?

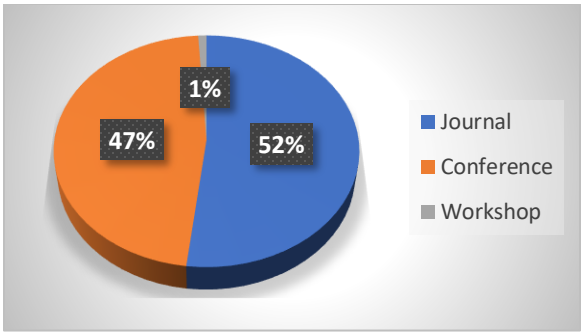

Fig. 11 Types of publication.

In Figure 11, the predominant type of publication for this study is the Journal, with a total of 56% of the total studies; the Journal has been the main source of information for this study and is the type of publication preferred by the authors referenced. The second favorite type of publication of the authors selected for the SLR is the Conference, with 43% of the total number of studies, and finally the Workshop, with only 1% of the total number of studies selected.

IV. Conclusions

In conclusion, this study has used systematic literature review (SLR), to provide a comprehensive statistical analysis of augmented reality for student teaching-learning, by extracting specific information from 104 articles and answering the research questions.

The results of the review are as follows; the disability with the greatest interest to be addressed is autism. The area of knowledge where it has been most applied is in the teaching of social skills. Virtual reality has been identified as a technology of great interest that is gaining momentum. The country that had the most relevance in the research was the US. Communications has been identified as a recent area of application in the projection of interactive images and videos to attract customers. Unity was identified as the most popular augmented reality development tool. Finally, the predominant publication type for this study is Journal, with a total of 56%.

These results were only based on the number of articles where they were mentioned, without evaluating whether they are the most recommended. It is recommended for future research to evaluate if the disability and area of knowledge are the most recommended for applying augmented reality and if Unity is the best tool for its development.

On the other hand, although the study was based on teaching-learning with augmented reality, it allowed obtaining information for a rethinking of a subsequent research with a focus on virtual reality in the field of communications.

There is a time limit for the articles that were reviewed. This is a topic where new publications will continue to emerge. Therefore, future research should consider more recent research. This will help increase awareness of the field among practitioners and researchers.

Acknowledgment

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g.” Try to avoid the stilted expression, “One of us (R. B. G.) thanks …” Instead, try “R.B.G. thanks …” Put sponsor acknowledgments in the unnumbered footnote on the first page.

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