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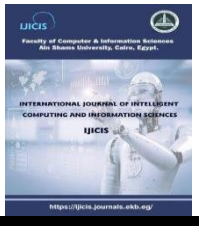

AUGMENTED REALITY IN TECHNOLOGY-ENHANCED LEARNING: SYSTEMATIC REVIEW 2011-2021

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Abstract: *With the raise of COVID-19 pandemic in 2020, the traditional teaching-learning process became inefficient. Technology-Enhanced Learning (TEL) research has increasingly focused on emergent technologies such as Augmented Reality (AR). It became one of the technologies that has received great attention and interest in the last decade. In this paper, we conducted a systematic review that describes the current state of using AR as a learning tool. Taking into consideration the needs of all students including those with a disability, in different levels of education. It is done through the analysis of the following factors: AR in learning system, AR in levels of education and categories of educational AR applications. A total of 103 studies between 2011 and 2021 were analyzed through searching in four interdisciplinary databases: Springer, IEEE Xplore, ResearchGate, and Google Scholar. This analysis helped to see in which direction AR systems for education are heading and how it will be designed to fit the students' needs and improve their learning. Further research and development will make AR a more promising learning tool.*

Keywords: *Augmented Reality, Education, TEL, AR Books, AR Applications.*

1. Introduction

Since the term "Augmented Reality" was introduced in 1990 by Tom Caudell, became one of the technologies that have received great attention and interest in recent years [89]. The augmentation is typically done in real time and in semantic context with environmental elements. Augmented Reality (AR) enhances users' perception of reality by mixing the physical environment of the real world with a computer-generated virtual object. To view these objects, users either use smartphones, tablets, or wearable devices [89].

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AR system consists of hardware, software, and application. The hardware are displays, sensors, processors, and input devices. The data is acquired from the real world through sensors. Then in Tracking, the processor analyzes the sensor inputs and chooses the appropriate virtual graphics to be displayed. At last, display devices are used to display the right virtual object in the right size and right coordinate on the real world as illustrated in Figure 1. The software allows AR applications to run on the used device but does not have the AR content. The AR content is existed in the AR application. The AR Software uses technologies, such as: Environment Understanding, Motion Tracking, and Light Estimation, to build the AR experience [102].

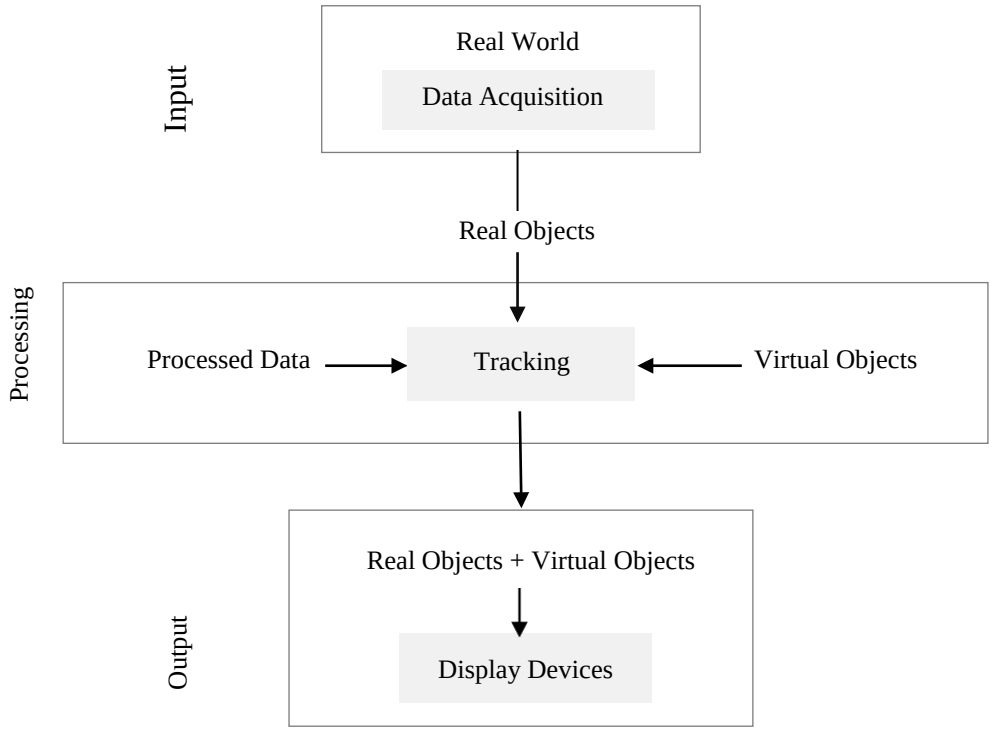

Figure 1: AR system [103].

There are four types of AR: see-through based, PC based, mobile based, and projection based [1]. See-through based AR uses Head Mounted Displays (HMD) such as Microsoft holo-lens to display the virtual objects. Where Mobile based AR uses mobile devices, such as smartphones and tablets, to blends the information from our senses with mobile devices in ways that were not possible before [2]. Mobile based AR also known as Mobile AR (MAR), is the most popular type among the four with 57% according to Nizam's [1] review.

With the raise of COVID-19 pandemic in 2020, the traditional teaching-learning process of lectures, taking notes, reading facts from books, and taking exams, without striking minds of learners, became inefficient. Ever since all the efforts have turned to integrating the latest technologies in the educational process. Technology-Enhanced Learning (TEL) research has increasingly focused on emergent technologies such as Augmented Reality (AR) [3]. A considerable amount of literature has been published in using AR in educational contexts [4-10] due to the ability of AR to provide extra digital content for any subject that has some difficulties in understanding [52, 90, 94].

For example, Zainab and Huda [9] showed that "user satisfaction" is the most frequently mentioned positive impact of using AR in education. Yuen et al. [11] summarized five directions for AR in education. Belmonte et al. [12] did a scientific mapping in Web of Science about AR in education field. Altinpulluk [13] and Fidan [14] used the content analysis technique to determine the trends and features of using AR in education. A list of benefits of using AR in education has been mentioned by Horváthová in [53].

The rest of this paper is organized as follows: Section 2, discuss the methodology of our study, followed by the results of the systematic review in section 3. Finally, we concluded our work with suggestions for future work in section 4.

2. Methodology

The methodology used in this paper is a systematic review. First, we design the research questions then we collected data related to these questions from literature reviews, conference proceedings, journals, thesis, and books. Using PRISMA checklist methodology helped us to evaluate the used papers as a basis for reporting systematic review. Figure 2 illustrates the research steps.

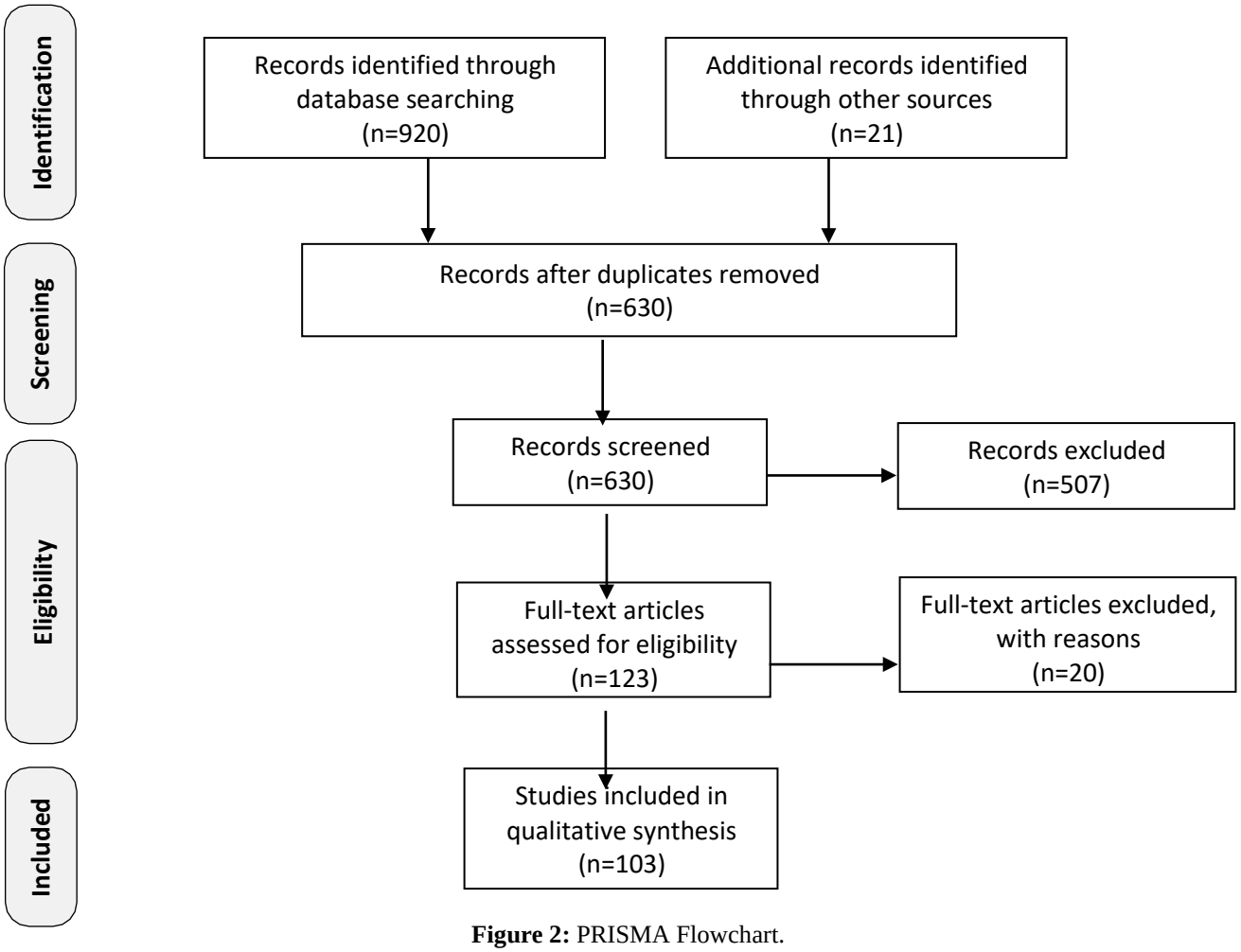

Figure 2: PRISMA Flowchart.

The aim of this systematic review is to show the current state of using AR as learning tool in the last decade and how that enhanced the learning process. It addresses the following research questions:

- **RQ1:** How AR is integrated in the learning system?
- **RQ2:** How AR is used in different levels of Education?
- **RQ3:** What is the existing AR educational applications and its categories?

To select the research papers that answer mentioned research questions, certain inclusion and exclusion criteria are used. These criteria are showed in Table 1.

Table 1: The used inclusion and exclusion criteria.

Inclusion Criteria
• English research articles published between 2011 and 2021. • Review studies that have domain in using AR in education and learning process. • Papers that describe AR applications that support the process of learning certain subject. • Articles about AR educational games. • Studies that indicate the different levels of education that support AR as a learning tool. • Books and thesis related to using AR as a learning tool.
Exclusion Criteria
• Papers that are duplicated. • Publications that didn't contain terms 'AR' and 'Education'. • Studies that refer to using virtual reality in education. • Old review studies that already covered in the latest reviews.

As research sources, four multidisciplinary databases were selected. They are Springer, IEEE Xplore, ResearchGate, and Google Scholar. The first search was made on 24 March 2021, and the last on 20 Sep of the same year. The findings are discussed in the Results section.

3. Results

In this section we describe the obtained results. Then the findings according to each research question are discussed. 920 research papers were found using the search strings shown in Table 2. After applying the inclusion and exclusion criteria, 103 papers are used for this systematic review. Considering the title and abstract of each literature and cross-checking the results of the four databases to discard repeated documents. Table 3 shows the main characteristics of the used articles.

3.1. RQ1: How AR is integrated in the learning system?

The best way to learn is by doing rather than reading or listening. The more the senses like sight, sound, touch involved while learning the powerful the learning experience is. That's why the AR is used in making educational games [15,16] and in enhancing the distance learning process [17]. Li et al. found through their literature review [16] that AR educational games enhanced the learning performance and the learning experience in terms of fun, interest, and enjoyment. Where Krüger and Bodemer [54] showed the different types of interaction with the AR learning material and how that influenced the learning process and its outcomes. Martin et al. [55] discussed using AR as a part of a modular learning system to emerge education for Industry 4.0.

Table 2: The search strings used for each database.

Databases	Search Strings
• Springer. • IEEE Xplore. • ResearchGate. • Google Scholar.	Augmented Reality **AND** in **AND** Education.
	Augmented Reality **AND** and **AND** TEL.
	Augmented Reality **AND** for **AND** STEAM **AND** Learning.
	Augmented Reality **AND** Educational **AND** Application.
	Augmented Reality **AND** in **AND** Learning System.
	Augmented Reality **AND** in **AND** Schools.
	Augmented Reality **AND** for **AND** Distance Learning
	Augmented Reality **AND** for **AND** Higher Education.
	Augmented Reality **AND** in **AND** University.
	Augmented Reality **AND** games **AND** for **AND** Learning
	Augmented Reality **AND** for **AND** Learning.
	Augmented Reality **AND** for **AND** Teachers.
	Augmented Reality **AND** for **AND** Students.

Table 3: Main characteristics of used articles.

Articles	Main Characteristics
[1-10], 16, 18, 24, 41, 52, 92	Review and survey papers that discuss using AR in Education.
[15-22], [54-57], 95	Studies that show how AR is used in the learning system.
91, [96-98]	Studies that investigated the use of AR in the learning systemin different countries.
[23-32], 55, [58-60], 92, 93, 99	Studies related to using AR in different levels of education(pre-school, primary school, secondary school, and University).
[33-36], [61-64], 100	Tools that help both teachers and students to create AR content.
35, 37, 38, 60, [65-71]	AR Books that are acquiring augmented data by floating acamera on a book's page to recognize its content.
39, [72-80], 92	Educational AR games published between 2011 and 2021.
[81, 82, 101]	Studies about using AR to help students with disabilities to learn and communicate effectively.
[40-50], 72, 82, [85-88], 101	Subject specific AR applications that present interactive contents for a specific set of knowledge.
[94-101]	Thesis about AR in Education.
[89-93]	Book chapters that discuss using AR technology in Education.

Garzón [18] and Ozdemir [19] provided Meta-analysis of the AR impact on students' learning gains. Findings indicated that AR applications increase students' academic achievement in the learning process compared to traditional methods [18]. Another analysis has been presented by Schmitz et al. in [56] to evaluate how these games impact the students' motivation and knowledge gain. The attention, satisfaction, and confidence factors of motivation were increased as found by Khan et al. in [20]. Hanid et al. [21] reveled the dominant strategies that use AR in education. These strategies are interactive learning, game-based learning, collaborative learning, and experiential learning [95]. Among the four types of learning strategies, interactive learning is the most reported in this meta-analysis review. AR also has great potentials in open and distance learning as discussed by Saykili and Altınpulluk in [22,57]. Researchers have investigated the use of AR in the learning system of different countries such as India [91], Australia [96], Bangladesh [97], USA and Kuwait [98].

3.2. RQ2: How AR is used in different Levels of Education?

AR is currently being applied across disciplines in primary, secondary, and higher education, and has been found to increase the academic success levels and motivations of students. We investigated the studies published between 2011 and 2021, that are related to using AR in the different levels of education. The number of reviewed articles for each level is illustrated in Figure 3.

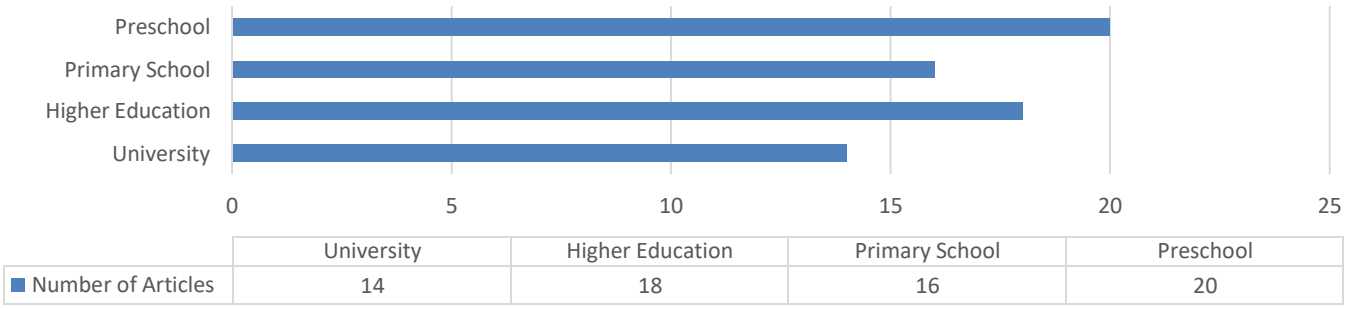

Figure 3: Number of reviewed articles for each level of education.

Mohamudally covered in his book [92] all major studies related to pre-school, primary school, and secondary school. Leighton [93] and Pedaste [23] discussed the affordances of using AR in K-12 Education. Pellas et al. [24] reported a systematic review of using ARGBL (AR with Game-Based Learning) across various primary and secondary education subjects. This review offered new insights on integrating ARGBL in learning system to increase student motivation and improve learning outcomes and the learning experience. Where Silva et al. [58] investigated why AR not used in schools.

Although some may be hesitant to adjust their curriculum to accommodate AR, higher-education professionals should at least be aware of how AR can shape teaching and learning, as current students become accustomed to use such technology in their daily life [25]. Thomas et al. [25] discussed that in their review. They also discussed pedagogical benefits and challenges of implementing AR in higher education. Jamali et al. [26] proposed an MAR (Mobile AR) framework for higher education that can enhance learners' motivation and attention especially when dealing with complex objects, like learning human anatomy. Sinha [27] discussed the role of AR application in Higher Education Learning. Huisinga [99] explored in her dissertation the effects of using AR to support reading in higher

education. Stojšić et al. [28] discussed students' attitudes toward using MAR in higher education focusing on augmented textbooks. Moreover, AR is started to be used in the University environments such as Technical University [59], King Faisal University [29], FuJen University [30], Comenius University [31], Taiwanese University [32], Massachusetts Institute of Technology (MIT) and Harvard University [60].

3.3. RQ3: Existing AR Educational Applications and its Categories.

Unlike other computer interfaces that draw users away from the real world and onto the screen, AR interfaces enhance the real-world experience [61]. The proposed AR applications for Education can be categorized into applications to create the AR content, AR books, AR games, and subject specific applications [51]. 37 studies between 2011 and 2021 were collected and summarized for each category in Tables 4, 5, 6, and 7, respectively. Each Table shows the application's name, and brief information about the application. Table 4 shows examples of the applications that helps both teachers and students to create their AR content. Chookaew et al. [62] employed the advantages of AR to motivate the pre-service teachers to construct their teaching materials. Where Silva [63] investigated how teachers use AR in their lesson. Lytridis et al. developed ARTutor, an AR platform, which enables teachers [33] and students [34] to create augmented books.

Table 4: Tools that help both teachers and students to create the AR content.

Tool's Name	Description
Vuforia Chalk [100]	It allows students to annotate live video feeds remotely.
GeoGebra [35]	Teachers use it to visualize geometry, algebra, statistics, and calculus.
MagicToon [36]	An interactive modeling system with MAR that allows children to build 3D cartoonscenes creatively from their own 2D cartoon drawings on paper.
VEDILS [64]	A visual tool based on the MIT App Inventor 2 environment for designing interactivelearning scenarios and can be deployed on Android devices.
ARTutor [33]	AR platform, which enables teachers [33] and students [34] to create augmented books.

The concept of any AR book is acquiring augmented data by floating a camera on a book's page to recognize its content. This concept is used to make the educational books more interactive [35]. It also helps the students comprehend any given point in the academic book without the need to search the internet to get the information needed [37]. In Table 5 we show examples of AR Books that have been published in studies between 2011 and 2021.

With the existence of interactive games and advanced communication tools, the traditional teaching methods find no place. To avoid the academic procrastination, game activity is embedded in the AR tool as suggested by Ibanez in [72]. Examples of published educational AR games between 2011 and 2021 are showed in Table 6.

Table 5: Examples of AR Books that published in studies between 2011 and 2021.

Name	About
Historia	AR application that reinforcement History subject for the second level of a public highschool in Ecuador [60].
Magical Playbook	It augments a 3D character and animation with audio onto the marker page of the book [38].
3D Pop-UpBook	It employs storytelling as a teaching technique in a blended learning environment for gradethree students in Bangkok to learn English language [65].
GeoAR	An interactive book which incorporates AR resources. It supports the process of teachingand learning of Geometry topics [66].
APPLearn(Heart)	It allows students to learn about the cardiac structure and its function through interactiveplaying [67].
Inpresso AR	It can download and play different AR experiences for any existing book [68].
MyVision AIR	It aims to enhance the reading experience of adult-learners by incorporating AR content tonormal books [69].
Research App	It enables the students to visualize the African continent in 3D on their smartphones. Bymodeling maps from the textbook [70].
wARna	A mobile-based app that augments a coloring book with user-manipulated 3D contents[71].

Table 6: Examples of Educational AR Games published between 2011 and 2021.

Application's Name	About
PlanetarySystemGO	It consists of a location-based game to learn about the Universe [39].
ABC3D	It enhances preschool-aged children's knowledge of print-based literacy [73].
EduPARK	MAR game that aims to promote learning in an urban park [77].
FootMath [75]	It visualizes, manipulates, and explores mathematical functions, through the simulation of a 3D football game, in which the user can change the function parameters with different values, to score a goal.
AR-Maze	It uses a designated image (Location Map) as a marker and displays a 3D scene on top of it. Players control the AR scene to provide the image, textual andaudio feedback superimposed on the real scene [76].
CodeCubes	The AR game is composed of three levels. It consists of programming a car course in a racetrack, driving from the start to the final goal [77].
Kotak Edu [78]	It enhances early childhood knowledge of animal in a relaxed and fun way with AR features.
SolarSystemGO	It provides awareness of the vastness and proportionality of the Solar System objects, such as the Sun and the planets [79].
Conserv-AR	a mobile game application that employs virtual and augmented reality concepts alongside games design to increase awareness and knowledge surrounding environmental conservation in Western Australia [80].

AR increased students' achievements in STEAM (Science, Technology, Engineering, Arts, and Mathematics) education [40,41]. It also helps students with disabilities to learn and communicate effectively [81,82,101]. Subject specific AR applications are developed and designed to present interactive contents for a specific set of knowledge [101]. Examples of these subject specific applications are collected in Table 7.

Table 7: Examples of subject specific AR applications published between 2011 and 2021.

Application's Name	Subject	About
Teach Me A Story	History	It is for secondary student. It helps them to be aware of the notions of political / economic power of civilization. [83]
PCBuildAR	Computer Science	It uses 8 cards to help computer science students learn and practiceabout the classic computer system [84].
Augmented Polyhedrons – Mirage 2.2	Math	It visualizes 3D mathematical polyhedrons [72].
Leihoa	English as a second Language	It aims to initiate reading, introduce numbers, and motivate exploration of rich vocabulary in English as a second language [42].
Geometry Learning	Geometry	It uses the magic book to enable the students see 3D shapes basedon the materials they learn. [43].
AR App	Calculus	It promotes spatial visualization in Calculus courses for engineeringstudents [44].
GeometAR	Geometry	It provides the possibility to type in mathematics information suchas equations of planes, lines, via a plus-button [85].
ARGE3D	Geometry	It is for geometric objects that is contained in the mathematicscurriculum of 6th class of primary education [45].
AR Math Learning	Geometry	It introduces digital leaning materials on 'Pillar' unit of Math for 6^{th}-grade elementary school students [46].
Mobile Programming with MIT App Inventor	Programming	It is for the higher education course "Advanced Mobile Applications" [47].
Research App	Excel	It guides the students to perform Excel operations [86].
HyperCubes	Programming	AR platform to foster computational literacy [87].
WARCSB [48]	Science	Web AR for Chemistry and Structural Biology portal.
AR-SaBEr [49]	Science	A simulation tool based on AR to discover the basic principles ofelectricity through a series of experiments.
PlanetarySystemGO	Science	It provides the experience of interacting with any planetary systemof the Universe [88].

We found that Science is the most explored field. Comes next Mathematics, History and Programing as illustrated in Figure 4. The figure shows the number of reviewed articles for each of top four fields (Science, Mathematics, History and Programming).

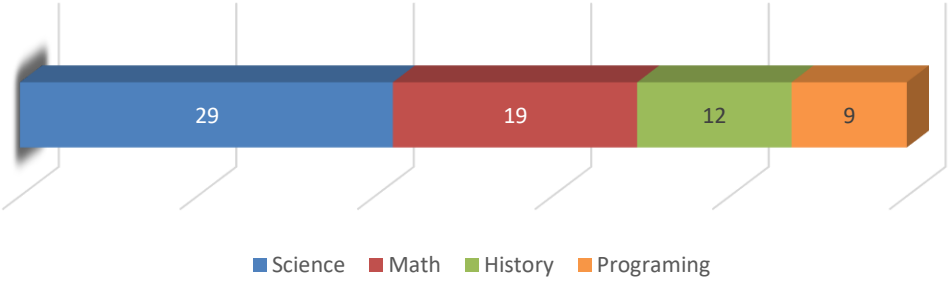

Figure 4: The number of reviewed articles for the top four fields of Education (Science, Math, History, and Programming).

4. Conclusion and Future work

As conclusion, AR showed a great potential and benefits in the education sector [9]. It can be designed to stimulate any academic scenario. It has been used mostly in science education and medical training [50]. It helped the students to be more motivated and engaged with the learning materials. It has been used and explored in all levels of education. Yet AR needs to be integrated more in university martials. Several review papers stated that the development of AR should consider the pedagogical aspect between the user and the application to provide an easy learning experience. Teachers should be able to add or update the contents easily. AR devices need to be developed in way that is easy to use and carry [10]. That is the reason behind using mobile devices in most of the reviewed articles. In other words, most of the research papers tried to solve educational problems through developing MAR systems which results in successful learning outcomes.

It is believed that the results obtained in this study will light the way for future research in other fields of education such as Art, Programming and Language Learning. Future research should look at pedagogical use of MAR in those fields. For example, MAR could be used to enhance the experience of learning programming in an interactive way not only projecting virtual informative objects. Researchers can enable these objects to show different reactions based on students' inputs. It is expected that AR will acquire greater relevance in teaching-learning process in the upcoming years [9].

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