Interactive, Collaborative and Multi-user Augmented Reality Applications in Primary and Secondary Education.
A Systematic Review

Stefano Masneri
(Vicomtech, Basque Research and Technology Alliance, San Sebastian, Spain
 https://orcid.org/0000-0003-1965-5704, smasneri001@ikasle.ehu.eus)

Ana Domínguez
(Vicomtech, Basque Research and Technology Alliance, San Sebastian, Spain
 https://orcid.org/0000-0002-9329-4225, adominguez@vicomtech.org)

Mikel Zorrilla
(Vicomtech, Basque Research and Technology Alliance, San Sebastian, Spain
 https://orcid.org/0000-0003-2589-2490, mzorrilla@vicomtech.org)

Mikel Larrañaga
(Computer Languages and Systems, University of the Basque Country (UPV/EHU), San Sebastian, Spain
 https://orcid.org/0000-0001-9727-1197, mikel.larranaga@ehu.eus)

Ana Arruarte
(Computer Languages and Systems, University of the Basque Country (UPV/EHU), San Sebastian, Spain
 https://orcid.org/0000-0001-5361-6640, a.arruarte@ehu.eus)

Abstract: Augmented reality is a technology that enhances human perception with additional, artificially generated sensory inputs. This creates new experiences enriching human vision by combining natural with digital elements. Augmented reality development dates back to the early sixties but it is only in the last decade, thanks to improvements to hardware and software, when it has begun to be rapidly incorporated in several fields, including education. This study presents a systematic review of the literature on the use of augmented reality applications in primary and secondary schools, with a specific focus on collaborative, multi-user and interactive applications. The aim of the study is to investigate the characteristics of such applications, the processes that led to their adoption, and their effectiveness in enhancing the learning experience. This study synthesises a set of 100 publications from 2015 to 2020 and performs a qualitative analysis of their content. The review describes the current state of the art in research in augmented reality for education and provides future research lines, as well as trends for the future of such applications in educational settings, analysing the relevance of the multi-user interaction challenge within the augmented reality ecosystem.

1   Introduction

Digital transformation is profoundly impacting and disrupting every facet of society, and education is no exception. In recent decades, Augmented Reality (AR) has broken into the educational area. Even though the term "Augmented Reality" was first introduced in 1992 by [Caudell and Mizell, 1992], describing a concept of glasses that enabled workers to see virtual labels and information while assembly a Boeing jet's wiring, it took many years before AR was first applied in schools as a tool to facilitate learning. Nowadays, thanks to the widespread adoption of devices that support AR applications, as well as the availability of software libraries such as ARKit[1] or ARCore[2] which greatly simplify and speed-up the development process, AR has become a technology which is being more and more used in educational settings. Given its surge in popularity, AR has become an active research topic and several systematic studies have been performed to analyse how this technology has been used in educational contexts. Some studies presented an analysis of the advantages and drawbacks of AR in generic educational settings [Akçayır and Akçayır, 2017, Radu, 2014, Diegmann et al., 2015] or have provided insights on the status of the technology as well as suggestions for future research [Cheng and Tsai, 2013, Arici et al., 2019, Bacca et al., 2014, Pellas et al., 2019]. Other reviews have focused on specific subjects, such as Science, Technology, Engineering and Maths (STEM) [Ibáñez and Delgado-kloos, 2018, Nielsen et al., 2016, Ahmad and Junaini, 2020] or language learning [Majid and Salam, 2021, Khoshnevisan and Le, 2018]; on specific topics such as AR-based serious games [Li et al., 2017, Bartolomé et al., 2011, Laine, 2018], the evaluation of the usage of AR in schools [Dasilva et al., 2019, Chen et al., 2017] or the impact of AR applications in learning effectiveness [Garzón et al., 2019]. Table 1 summarises the content of some of the most recent and comprehensive Systematic Literature Reviews (SLRs) about AR in educational settings.

Since the publication of the seminal paper on collaborative AR by [Billinghurst and Kato, 2002], which first discussed how AR could be used to enhance online and offline collaboration, much progress has been made in providing collaborative tools for AR applications. To the best of our knowledge, only the work of [Phon et al., 2014] evaluates the usage of collaborative AR applications for education, by reviewing publications on the subject from 2000 to 2013. Given the many advancements of AR technology in the last few years, we believe that a systematic review of more recent publications is required, in order to see how AR apps are used as tools to improve collaboration between students as well as between students and teachers, or how multi-user interfaces facilitate cooperation and learning.

Cooperative learning, defined as the instructional use of small groups to promote students working together to maximise their own and each other's learning [Johnson, 1991], has long been used as an educational approach to improve students' learning and performance [Johnson and Johnson, 2008, Kuh et al., 2011]. Technology can help foster collaboration among students, but their engagement depends on how much they can interact with the different tools. AR per se is not a collaborative tool: it is up to researchers and developers to provide such functionalities in an AR-based educational application. With this work, we aim to evaluate which publications described AR applications that provided the following features:

– *levels of interactivity*: the app should respond to the user input and let the student

---

[1] developers.google.com/ar/
[2] developer.apple.com/documentation/arkit/

Study	Purpose	Studies reviewed	Findings
[Garzón et al., 2019]	Identify the status and tendencies in the usage of AR in education	61	AR has a medium effect on learning effectiveness; lack of studies considering accessibility features in AR apps
[Pellas et al., 2019]	Explore the combination of AR with game-based learning (ARGBL)	21	Motivation and enrichment are pillars of ARGBL; ARGBL compares favourably to traditional learning
[Ibáñez and Delgado-kloos, 2018]	Perform qualitative analysis of the characteristics of AR apps for STEM learning	28	Most apps offer exploration or simulation activities, but usually without providing assistance in carrying out learning activities; similar design features across all studies
[Akçayır and Akçayır, 2017]	Identify advantages of AR in education and identify current gaps in AR research	68	Conflicting results regarding cognitive overload of AR; low usability is the main challenge of AR apps for education

Table 1: Summary of SLRs about usage of AR in education.

modify the app content using different interaction methods (which will be described in detail in Section 3.2;

– *multi-user functionalities*: more than one user at the same time can use the app and the actions of one user are directly reflected in the other users' devices;

– *collaboration*: besides being multi-user, a collaborative app engages its users to collaborate or compete to reach a goal or complete a task.

Furthermore, we are also interested in analysing how the usage of these applications affected the students' engagement and their academic performance.

The main contribution of this paper is to provide an SLR of the AR applications deployed in primary and secondary schools, with a particular focus on the collaborative, multi-user and interactive characteristics of such applications. We decided to consider only the articles published from 2015 to the end of 2020, since in 2015 the number of publications related to the application of AR in education has seen a huge increase (as shown in Fig. 1). We also decided to only include works with an audience comprised of primary or secondary students, since there are already several works which review the usage of AR in higher education, and because this study was conducted in the context of the ARETE[3] H2020 European project, studying multi-user AR applications for primary and secondary schools.

The Research Questions (RQ) that we addressed with this study are:

– RQ1: What collaborative, multi-user, interactive AR applications have been used in an educational environment in primary or secondary schools?
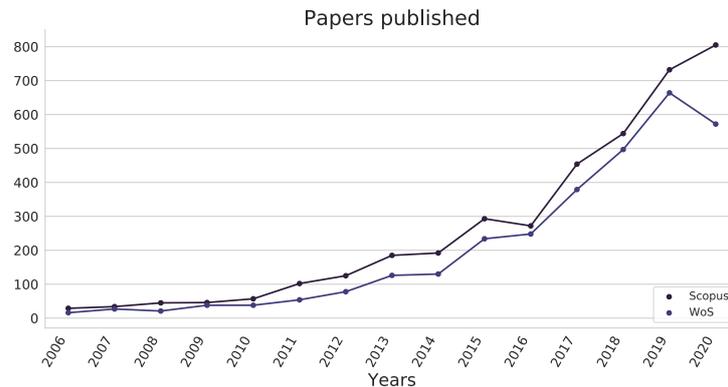
---

[3] areteproject.eu

Figure 1: Numbers of papers published per year with topic "augmented reality" and "education" from 2006 to 2020.

- RQ2: Is there a motivation for using these AR applications as an educational tool? If so, what is it?

- RQ3: How effective are these AR applications at improving the students' knowledge of a subject? How is this evaluated?

The answers to these RQs will hopefully provide researchers information about the current landscape of how AR applications are used in primary and secondary schools, what the motivation is for it and what effects AR has on the learning and retention skills. Understanding the potential of interactive and collaborative AR, as well as its limitations and the factors limiting its usage in schools, can hopefully provide information on how future applications should be designed and developed.

Besides answering these research questions, we will also discuss the different technologies used by such applications, for example, the hardware required (Head Mounted Display (HMD), tablet or smartphone), the way the system tracks information from the real world (marker-based, markerless, location-based), whether the application augments other senses beyond vision, and which design strategies (if any) have been used to make the applications accessible.

The rest of the paper is structured as follows. Section 2 describes the methodological design of the study, including an explanation of the work done to plan, conduct and report the review. Section 3 presents the findings of the systematic review and the answers to the research questions. Section 4 discusses the results obtained and suggests possible research lines as well as trends for the future of AR in education. Finally, Section 5 summarises the conclusions of the paper.

2 Method

For this review, we followed the guidelines proposed by [Kitchenham et al., 2009] and framed the search using the PICOC criteria [Petticrew and Roberts, 2008]:

- **Population**: Applications, Developers

- **Intervention**: Collaborative, multi-user and interactive AR applications

- **Comparison**: Students' results in classes using AR applications with classes that do not

- **Outcome**: Effectiveness in increasing understanding of a topic

- **Context**: Education, primary or secondary schools

Once the research questions have been defined, the literature review is split into three steps: planning, conducting and reporting. We used the online tool Parsifal[4] to conduct the first two steps of the review while the third was performed using Google Forms[5] and collecting the results in a spreadsheet. The results of the data collection, as well as the code used to generate the figures in this document, are available on Github[6].

2.1 Study selection

The aim of this phase is to select the papers which are relevant for the systematic review, define the inclusion and exclusion criteria, and to provide the categories for the analysis. We have selected publications from IEEExplore, Scopus, Springer and ISI Web of Science, as these four digital libraries collect a large amount of the research that is published in the area of technology enhanced learning. We used the search terms *Augmented Reality*, *Education* $\lor$ *Learning*, *Collaborative* $\lor$ *Interactive* $\lor$ *Multi-user*, *Application* $\lor$ *Evaluation*, as we wanted to include only papers that could help address RQ1 and RQ3. For this work, we only considered papers which appeared online from 2015 to the end of 2020. The search returned 1829 results, of which 238 were marked as duplicates. We read the abstract of the remaining 1591 articles and, applying the inclusion and exclusion criteria specified below, we were left with 260 articles. We finally proceeded to read the selected articles and excluded 160 further articles, thus selecting 100 articles for the literature review. Table 2 summarises the selection process, specifying the search string used for each digital library as well as the number of papers returned, marked as duplicated and selected for the systematic review.

As inclusion criteria, we required that the studies:

- Were published from 2015 to 2020 (both inclusive);

- Describe an AR application which has actually been implemented;

- Have a target audience of primary and/or secondary school students.

We decided to focus only on applications that were fully developed (and could then be evaluated) and that were interactive, multi-user and collaborative, because there is a broad amount of literature showing that students learn better when engaged with other children, or being involved in interactive activities compared with purely passive ones. Finally, the decision to limit the literature search to papers published after 2015 is to avoid including older publications, often using obsolete hardware with setups that cannot be reproduced easily.

The exclusion criteria are the following:

---

[4] parsif.al
[5] https://forms.gle/D7NHktgfaRmAeWTS8
[6] github.com/Stocastico/AR_SLR_Paper

    – The application described is not interactive, multi-user or collaborative;

    – The paper does not describe an AR application

    – The paper describes an unrelated application (e.g. for museums or clinical training);

    – The paper is not peer reviewed;

    – The paper is not written in English.

    Fig. 2 shows a flowchart depicting the systematic review process. The 260 papers were reviewed, evenly split, by three researchers. To compute the interrater agreement, two researchers read a set of 50 abstracts randomly selected from all the studies (excluding duplicates) and 10 papers (among the 260 eligible papers). The interrater agreement, as defined in [Cohen, 1960] was 0.88 for the abstracts and 0.73 for the papers.
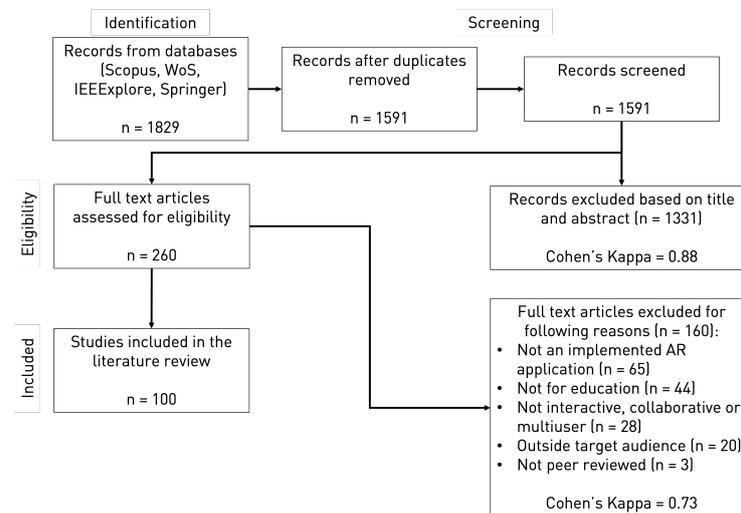

Figure 2: Prisma flowchart of the search protocol.

3   Results

In this section we present the results of the three RQs introduced in Section 1, focusing on the adoption of collaborative and multi-user tools, the advantages and disadvantages of using AR solutions in the classroom and the evaluation of the interventions. We will also briefly analyse and summarise the main characteristics of the AR applications described in the studies selected.

Digital Library	Query string	Papers	Duplicates	Selected
IEEExplore	("All Metadata": "Augmented reality" AND ("Education" OR "Learning") AND ("Collaborative" OR "Interactive" OR "multi-user" OR "multi-user") AND ("Application" OR "Evaluation")) Filters Applied: 2015 - 2020	136	48	**37**
Scopus	TITLE-ABS-KEY ("Augmented reality" AND ("Education" OR "Learning") AND ("Interactive" OR "multi-user" OR "multiuser" OR "collaborative") AND ("Application" OR "Evaluation")) AND (PUBYEAR > 2014)	521	65	**98**
Springer	(collaborative OR interactive OR multiuser OR multi-user) AND "augmented reality" AND (education OR learning) AND (primary OR secondary) AND (application OR evaluation) within Chapter - Conference Paper 2015 - 2020	904	69	**72**
Web of Science	"Augmented reality" AND ("Education" OR "Learning") AND ("Collaborative" OR "Interactive" OR "multi-user" OR "multiuser") AND ("Application" OR "Evaluation") Filters Applied: 2015 - 2020	268	56	**53**

Table 2: Query strings and number of papers returned.

3.1 Overview of reviewed studies

Of 100 studies reviewed, most of them (73 articles) were published in 2018 or afterwards. The vast majority (68 studies) of the AR apps analysed cover STEM subjects, while 18 studies cover Humanities and Foreign language subjects. The remaining articles cover specific subtopics such as sustainability, creativity and social interactions or do not specify the subject. Fig. 3 summarises the subjects covered by the AR apps analysed in this SLR.
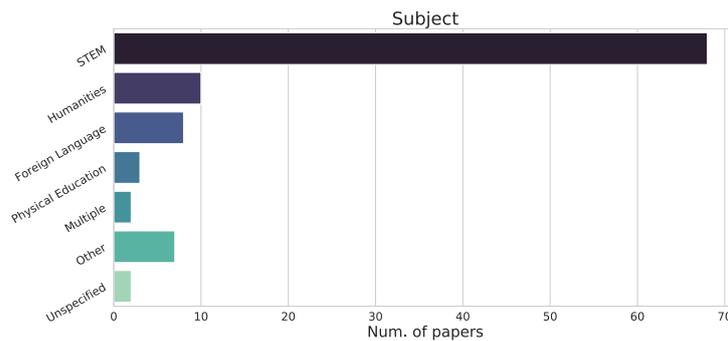

Figure 3: Subjects covered in the studies analysed.

Regarding which AR type is used in the classroom, marker-based solutions (either image or QR-code based) are the most used, as two thirds of the studies described apps using markers as the exclusive source of the augmentations. Some studies describe applications using multiple types of AR, usually a combination of markers and object detection based methods. Other types of AR such as markerless or location based are seldom implemented, as they were used only in 9 and 2 articles, respectively. Fig. 4 summarises the types of AR used by the articles analysed in this SLR.
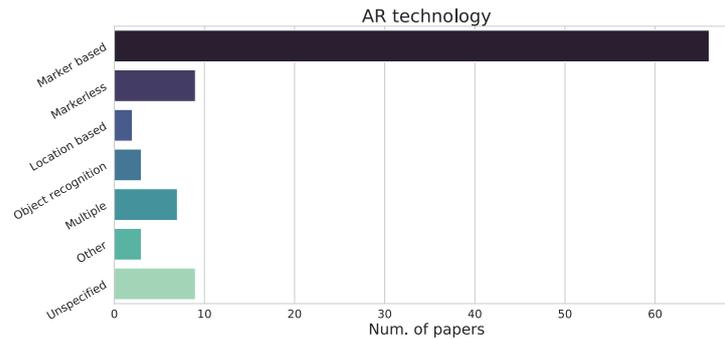

Figure 4: Different types of AR used in the studies analysed.

With reference to the hardware required to experience the AR apps and the software used to develop them we notice a similar pattern. Most of the studies describe apps which have been developed for smartphones or tablets using the Unity[7] framework, often in conjunction with the Vuforia[8] Standard Development Kit (SDK). Some studies, usually the oldest ones, describe systems using projectors or PCs with depth sensor cameras such as Microsoft Kinect[9]. Only six articles describe apps which require HMDs or smart glasses [Wei et al., 2018, Oh et al., 2016, Oh et al., 2017, Kum-biocca et al., 2019, Khan et al., 2018, Matsutomo et al., 2017]. This might be due to the higher cost of such devices and their consequent limited adoption compared to smartphones or tablets.

Using web technologies for the creation of AR application is still the exception rather than the norm: despite the availability of a javascript library such as Three.js[10] and frameworks such as A-Frame[11], only the works of [Abriata, 2020] and [Protopsaltis et al., 2016] provide augmented content that can be consumed through the browser. Somewhat surprisingly, very few studies rely on the libraries produced by Google and Apple (ARCore and ARKit), which were developed to provide advanced AR functionalities for smartphone and tablets. Usage of specialised Computer Vision (CV) libraries or Deep Learning (DL) framework is also very low, which probably means that researchers prefer to use the functionalities provided by Unity. Statistics about software usage may be skewed, though, as about one third of the studies did not provide information about it.

---

[7] unity.com/
[8] developer.vuforia.com/
[9] developer.microsoft.com/en-us/windows/kinect/
[10] threejs.org
[11] a-frame.io

Fig. 5 and 6 summarise the hardware required and the software used by the apps analysed in this SLR. The total in this case does not sum up to 100 since the same application could support more than one device and likewise it may have been developed using several software libraries.
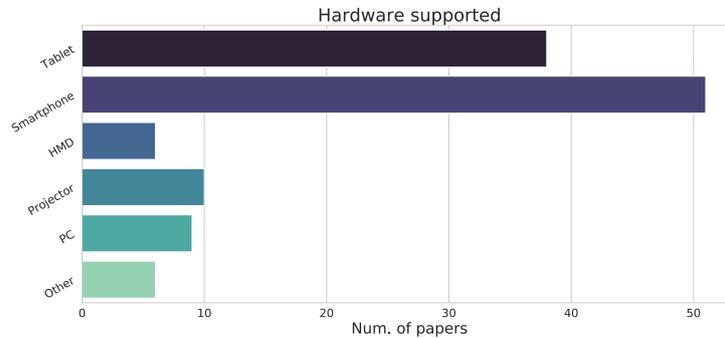

Figure 5: Device types supported by the AR applications.

Unfortunately, researchers very rarely publish their code alongside their peer reviewed publication. Of all the studies we analysed, only four [Mylonas et al., 2019, Laviole et al., 2018, Manrique-juan et al., 2017, Abriata, 2020] publicly released the source code of their application. In some cases the researchers published the application for free on Google Play or the App Store. Although in principle this allows other researchers to test the application, without releasing the source code this is impractical, as it is very rare that the application can be used without some form of adaptation (for example, translation of the content, inclusion of new multimedia elements or adjustments to the school curricula).
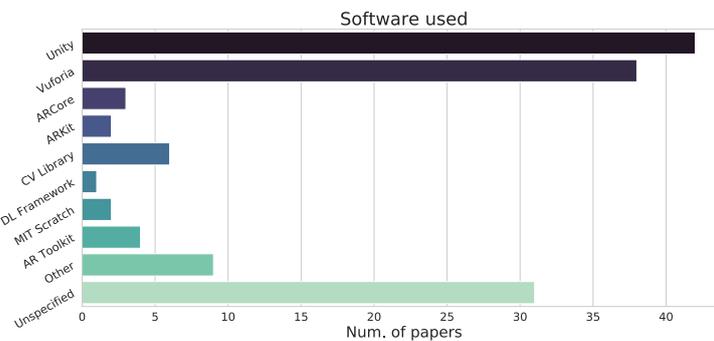

Figure 6: Software used to develop AR applications.

3.2 Interactive and collaborative capabilities of AR applications

This subsection addresses the first research question. We analysed interactive, multi-user and collaborative capabilities of the AR apps described in the selected studies. We categorised the studies into five different clusters, based on how the applications provide interactive functionalities. The categories were chosen by analysing the common traits of each study, as well as considering the characteristics of interactive applications in the context of education (assessment, feedback to the teacher, quizzes) and of user interface elements that enable the interaction. The five interactivity levels we defined are as follows:

– *Basic interactivity*: the student can interact with the app through User Interface (UI) elements such as menus and buttons directly in the augmented space.

– *Object interaction*: the student can interact directly with the augmented content, without having to use UI elements.

– *Quiz*: the application provides quizzes (or allows teachers to add new ones) to test the students' understanding of a topic directly within the app, or it includes gamification concepts.

– *Behaviour tracking*: the application keeps track of student behaviour and, using this information, the teacher can modify the content shown to the user. Both the active interactions (questions answered, buttons clicked) as well as passive usage of the app (time spent on each activity, for example) are logged and made available to the teacher so that the lecture can be modified accordingly.

– *Augmented interactions*: the augmented content shown to the user may change depending on the interactions of the user with the environment, for example when changing the relative positions of different markers, or by varying the distance of the device from the markers.

In addition to these, we also consider *multi-user* AR experiences, where multiple students are viewing the same augmented content from different devices and any change, for example caused by the interactions of one of the students, is visible to all the other students as well. Finally, we are also interested in *collaborative* AR applications, that is applications where the students share a common goal and work together (or compete against each other) to reach it.

We are particularly interested in these applications because interactive learning environments have been shown to have a positive impact on the students' education [Johnson et al., 2000]. At the same time, collaborative learning offers the students several benefits at the social, psychological, academic and assessment level [Laal and Ghodsi, 2012]. In Table 3, we classify the 100 articles we reviewed into the categories described above. Some of the studies can appear on multiple rows in the table, meaning that they may offer multiple interaction types as well as provide multi-user or collaboration functionalities. The works of [Tscholl and Lindgren, 2016] and [Manrique-juan et al., 2017] present collaborative application that were not categorised as multi-user, since only one device is shared by multiple students.

As it is impractical to provide a description of all the selected articles, here we mention the ones we deem as the most interesting. In [Khan et al., 2018], the authors implemented a mixed reality system based on HoloLens[12] smart glasses and several stretch and Inertial

---

[12] www.microsoft.com/en-us/hololens

Interaction type	Articles
Basic interactivity	[Lai et al., 2015, Tang et al., 2015, Ang and Lim, 2019, Sorrentino et al., 2015, Arcos et al., 2016, Zhao et al., 2018, Chao et al., 2018, Costa et al., 2019, Protopsaltis et al., 2016, Luna et al., 2018, Ramos and Comendador, 2019, Elkouzi et al., 2019, Huang et al., 2016, Wang, 2017, Pombo and Marques, 2017, Pombo and Marques, 2018, Chen et al., 2016, Liou et al., 2017, Hsu, 2017, Mylonas et al., 2019, Khan et al., 2018, Hrishikesh and Nair, 2016, Sarkar et al., 2018, Chang and Hwang, 2018, Chen and Wang, 2015, Huang et al., 2019, Lin et al., 2019, Cao and Hou, 2018, Pombo and Marques, 2019, Wei et al., 2019, Cerqueira et al., 2018, Klautke et al., 2018, Chang et al., 2019, Hsieh and Chen, 2019, Yilmaz and Goktas, 2017, Lee et al., 2018, Chen et al., 2019, Liu et al., 2020, Pérez-muñóz et al., 2020, Yin et al., 2020, Mikułowski and Brzostek-pawłowska, 2020, Korosidou and Bratitsis, 2019, Estudante and Dietrich, 2020, Syahidi and Mohamed, 2020, Cruzado et al., 2020, Yuhana et al., 2020, Macariu et al., 2020, Suzuki et al., 2020, Yusof et al., 2020, Theodoropoulou et al., 2020]
Object interaction	[Arcos et al., 2016, Costa et al., 2019, Iqbal et al., 2019, Cao and Liu, 2019, Kum-biocca et al., 2019, Cen et al., 2019, Ferrer et al., 2017, Oh et al., 2016, Tscholl and Lindgren, 2016, Laine and Suk, 2016, Rusiñol et al., 2018, Kurniawan and Witjaksono, 2018, Boonbrahm et al., 2016, Ibáñez et al., 2020, Manrique-juan et al., 2017, Chen, 2018, Mahmoudi et al., 2018, Antoniou et al., 2017, Hsu et al., 2018, Thamrongrat and Law, 2019, Lee et al., 2019, Amrit et al., 2015, Ortiz et al., 2018, Wei et al., 2018, Rammos and Bratitsis, 2019, Li et al., 2018, Giasiranis and Sofos, 2017, Takahashi et al., 2018, Lytridis et al., 2018, Matsutomo et al., 2017, Kenoui and Mehdi, 2020, López-faican and Jaen, 2020, Carlos-chullo et al., 2020, Syahidi and Mohamed, 2020, Thamrongrat and Lai-chonglaw, 2020, Suzuki et al., 2020, Theodoropoulou et al., 2020]
Quiz or gamification	[Lai et al., 2015, Costa et al., 2019, Protopsaltis et al., 2016, Ramos and Comendador, 2019, Laviole et al., 2018, Limsukhawat et al., 2016, Lin et al., 2016, Chang and Hwang, 2018, Daineko et al., 2018, Pombo and Marques, 2019, Lee et al., 2019, Ortiz et al., 2018, Wei et al., 2018, Li et al., 2018, Xefteris and Palaigeorgiou, 2019, Oh et al., 2017, Dave et al., 2020, Cruzado et al., 2020, Thamrongrat and Lai-chonglaw, 2020, Macariu et al., 2020]
Behaviour tracking	[Protopsaltis et al., 2016, Chen et al., 2016, Mylonas et al., 2019, Chang and Hwang, 2018, Cao and Hou, 2018, Hsu et al., 2018]
Augmented interaction	[Chao et al., 2018, Cen et al., 2019, Cai et al., 2017, Ferrer et al., 2017, Wang et al., 2018, Laviole et al., 2018, Nasongkhla et al., 2019, Gardeli and Vosinakis, 2018, Xefteris et al., 2018, Boonbrahm et al., 2015, Yilmaz and Goktas, 2017, Kalpakis et al., 2018, Lam et al., 2020, Abriata, 2020, Dave et al., 2020, Macariu et al., 2020, Theodoropoulou et al., 2020]
Multi-user	[Kum-biocca et al., 2019, Cai et al., 2017, Oh et al., 2016, Laviole et al., 2018, Boonbrahm et al., 2016, Gardeli and Vosinakis, 2018, Triantafyllidou et al., 2017, Xefteris et al., 2018, Palaigeorgiou et al., 2018, Lee et al., 2019, Ortiz et al., 2018, Xefteris and Palaigeorgiou, 2019, Takahashi et al., 2018, Lee et al., 2018, Oh et al., 2017, Dave et al., 2020, López-faican and Jaen, 2020]
Collaborative	[Cai et al., 2017, Oh et al., 2016, Tscholl and Lindgren, 2016, Laviole et al., 2018, Boonbrahm et al., 2016, Manrique-juan et al., 2017, Gardeli and Vosinakis, 2018, Lee et al., 2019, Ortiz et al., 2018, Xefteris and Palaigeorgiou, 2019, Takahashi et al., 2018, Oh et al., 2017, López-faican and Jaen, 2020]

Table 3: Articles classified according to interactivity and collaboration capabilities.

Measurement Unit (IMU) sensors, where the users can control and move augmented objects using their arms or an ad-hoc controller. The multi-user application is used to teach the students physics concepts such as force fields or velocity vectors, without needing to set up a laboratory. Some studies use multiple markers to increase interactivity. The work of [Wang et al., 2018] uses AR to teach the double-slit experiment (a physics experiment demonstrating the characteristic of light being both a wave and a particle). In the application each marker is related to one part of the experimental apparatus. By modifying the distance of each marker from the next one, the augmented animation generated by the app changes its behaviour, visually showing the dual nature of light. A similar idea is implemented by [Boonbrahm et al., 2015]. In the app, which was created to facilitate learning English as a foreign language, each marker by itself only shows a letter in 3D. When multiple markers are combined to create an English word (from a predefined set), the app will show a 3D model of the corresponding word. In [Gardeli and Vosinakis, 2018], the students learn the basics of computer science by visually implementing algorithms. Each marker, besides showing augmented content, represents an instruction in ALGO, a specially developed programming language, and sequences of different markers generate different behaviour from the augmented content. [Macariu et al., 2020], implemented an app for learning Chemistry that includes a text recognition module to provide information on specific Chemistry-related words, as well as 3D animations that show the molecule created when combining different atoms, with each atom using a specific marker.

Only a few studies experiment with other senses beyond sight. The work of [Kenoui and Mehdi, 2020] uses the IBM Watson SDK[13] to allow the user to interact by asking questions in English, while the answer is shown both as text above the augmented content and as computer-generated audio. [Mikułowski and Brzostek-pawłowska, 2020] designed a system for visually impaired students that detects mathematical formulas and generates both an audio description as well as a Braille representation on the Braille display.

In the context of multi-user applications, different studies employed different strategies to foster collaboration. [Boonbrahm et al., 2016] describe an application where the users aim to solve a jigsaw puzzle. Since students cannot move two pieces in a row but are forced to alternate their moves, the puzzle can only be solved with a joint collaboration. In the work of [Ortiz et al., 2018], the app is an ARGBL where the user learns about different regions of Colombia while competing for resources. In this case, competition with others stimulate the students to learn about the subject. Another form of collaboration is described by [Oh et al., 2016]: the authors created a smart-glasses-based AR application where the user can study properties of light such as reflection and refraction. Each user acts as a light source and sees what happens when light hits a wall or passes through different materials. At the same time, two or more users can generate multiple light rays and see how they interact with each other. Using a projector system, users without smart glasses are able to share the same experience, although not as actively as users wearing them.

3.3 Motivation for using AR as an educational tool

This subsection addresses the second research question. While the studies reviewed do not usually motivate the choice of the particular application presented in the articles, they do present however, several advantages provided by AR in the classroom. The main advantage provided by AR is that it can integrate seamlessly with the real world,

---

[13] www.ibm.com/cloud/watson-speech-to-text

especially for markerless applications that can interact with objects or printed material already available in the classroom. This encourages student engagement and minimises the time required to learn how to use the technology, allowing the students to spend more time learning the subject, as shown by [Thamrongrat and Law, 2019]. A more recent work by the same authors [Thamrongrat and Lai-chonglaw, 2020] shows that using gamification concepts in AR significantly impacts the students results.

Another advantage provided by AR is that this technology does not require the existing curriculum to be remodeled, rather it can be used as a tool to stimulate interest or to supplement existing pedagogical materials by simply adding more contextual experiences. [Pombo and Marques, 2018] mention that using an AR app improves the engagement and interest of the students visiting an urban park by providing information that would otherwise be available only on textbooks.

AR is also a powerful tool for visualisation and animation, especially for STEM subjects, as it offers several advantages for displaying *3D* or *3D+t* information (i.e., tridimensional data changing over time) in comparison to books, blackboards or videos. The work of [Cao and Liu, 2019] describes an application for learning 3D geometry where the user can interact with 3D objects with their hands. The fingers are tracked with a Leap Motion Controller[14] while a set of markers are used to generate the augmented content. In [Suzuki et al., 2020], the authors use advanced features provided by ARKit (such as joint detection) together with object tracking technologies to provide interactions and visualizations through sketches drawn on the device.

In the context of collaborative and multi-user applications, AR similarly helps to provide new opportunities for students to learn how to communicate and collaborate with one another, as well as to inspire empathy and to teach the importance of teamwork [Hill and Miller, 2013].

Some of the reviewed studies used AR applications as radically new tools that could improve skills and grades of children with mental or developmental disabilities: [Luna et al., 2018] describe an application that helps students with Attention-deficit/hyperactivity disorder (ADHD) improve their English literacy skills. Similarly, the work of [Chen et al., 2019] uses AR together with concepts maps to teach kids with Autistic Spectrum Disorder (ASD) different types of social cues designed to help them when meeting people. [Takahashi et al., 2018] designed a large scale AR and projection system, modifying the gymnasium of the school, to create a learning game for children with ASD, which intends to keep their attention focused on the content provided.

In [Beyoglu et al., 2020], the authors check the effects of using mixed reality applications and how they impact the students' motivation. They show that while such apps do not significantly impact the motivation to learn, they increase the students' motivation for collaborative working, and the results are more significant for AR than for Virtual Reality (VR) apps. More in general, AR also compares favourably with respect to VR not only because it allows users to perform tasks faster [Krichenbauer et al., 2018], but also because its requirements (namely a stable internet connection and one or more mobile devices), can be provided at a lower cost and the system does not need as much time to set up. Cost is often seen as one of the most important factors limiting the access of newer technologies, so in this sense AR is often seen as a better tool in comparison with VR or expensive hardware such as laptops and projectors.

---

[14] www.ultraleap.com/product/leap-motion-controller/
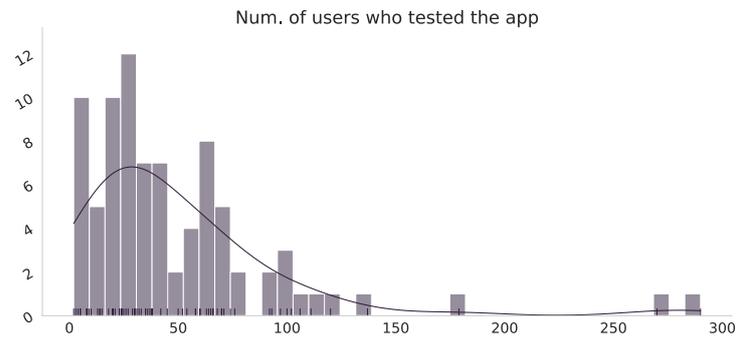
Num. of users who tested the app

Figure 7: Histogram of the participant in user tests across different studies (grey) and its smooth density estimate (black).

3.4 Effectiveness of collaborative AR applications

This subsection addresses the third research question. Of the 100 studies selected for this SLR, only 84 provided information about the number of students who tested the AR application. The number of students participating ranged from 2 to 290. Around 60% of the studies were carried out with fewer than 40 participants, and another 30% were carried out with a number of participants between 41 and 80 students. Only 8 studies employed 100 or more students for the evaluation. Fig. 7 shows the histogram representing the distribution of users who tested the AR application across the studies selected for review.

The analysis of the studies shows three main ways for evaluating how effective a AR application can be in helping students improve their understanding of a subject: performing pre and post tests, comparing with a control group, and asking the teachers to fill out surveys after the experiment.

While the first two options try to objectively measure the impact of using AR, by analysing the students' grades, the third option relies on the personal judgement of the teachers and can, in principle, be subject to bias. In Table 4, we classify the 100 reviewed articles into the categories described above. Some of the studies can appear on multiple rows in the table, meaning that they evaluate students' results in more than one way. The table does not include studies in which no evaluation was performed, or in which surveys only asked about the app usability and ease of use.

It is worth mentioning the work described in [Chang and Hwang, 2018], as here the researchers developed a system which, apart from the AR application, included a Database Management System (DBMS), a teacher interface and an e-learning platform. The evaluation of the system includes a statistical analysis of the performance of the students and their learning achievements, as well as an analysis of the ease of use of the system for teachers and students. The application described in [Thamrongrat and Law, 2019] uses AR to teach children about 3D geometry. Pre and post tests were used along with quizzes to evaluate the system. The results showed that students who used the AR applications consistently had better grades than the control group, but such results were not statistically significant. Analysing the results for different tasks, however, the data showed that the group who used AR performed worse on the easiest task, while performing much better (with statistically significant results) than the control group in

Evaluation type	Articles
Pre and post tests	[Lai et al., 2015, Chao et al., 2018, Cao and Liu, 2019, Elkouzi et al., 2019, Cen et al., 2019, Huang et al., 2016, Chang and Hwang, 2018, Limsukhawat et al., 2016, Liou et al., 2017, Laine and Suk, 2016, Lin et al., 2016, Ibáñez et al., 2020, Chen, 2018, Nasongkhla et al., 2019, Huang et al., 2019, Lin et al., 2019, Xefteris et al., 2018, Pombo and Marques, 2019, Thamrongrat and Law, 2019, Ortiz et al., 2018, Li et al., 2018, Chang et al., 2019, Xefteris and Palaigeorgiou, 2019, Lee et al., 2018, Oh et al., 2017, Chen et al., 2019, Liu et al., 2020, Carlos-chullo et al., 2020, Korosidou and Bratitsis, 2019, Syahidi and Mohamed, 2020, Cruzado et al., 2020, Thamrongrat and Lai-chonglaw, 2020, Yuhana et al., 2020, Macariu et al., 2020]
Control group	[Arcos et al., 2016, Cen et al., 2019, Huang et al., 2016, Chang and Hwang, 2018, Cai et al., 2017, Hsu, 2017, Hrishikesh and Nair, 2016, Sarkar et al., 2018, Thamrongrat and Law, 2019, Ortiz et al., 2018, Hsieh and Chen, 2019, Yilmaz and Goktas, 2017, Giasiranis and Sofos, 2017, Takahashi et al., 2018, Carlos-chullo et al., 2020, Cruzado et al., 2020, Thamrongrat and Lai-chonglaw, 2020, Yuhana et al., 2020]
Teacher survey	[Costa et al., 2019, Luna et al., 2018, Ramos and Comendador, 2019, Elkouzi et al., 2019, Cen et al., 2019, Chang and Hwang, 2018, Wang, 2017, Ferrer et al., 2017, Pombo and Marques, 2017, Pombo and Marques, 2018, Chen et al., 2016, Oh et al., 2016, Tscholl and Lindgren, 2016, Wang et al., 2018, Mylonas et al., 2019, Manrique-juan et al., 2017, Chen and Wang, 2015, Chen, 2018, Huang et al., 2019, Mahmoudi et al., 2018, Gardeli and Vosinakis, 2018, Triantafyllidou et al., 2017, Xefteris et al., 2018, Hsu et al., 2018, Palaigeorgiou et al., 2018, Pombo and Marques, 2019, Ortiz et al., 2018, Li et al., 2018, Hsieh and Chen, 2019, Kalpakis et al., 2018, Oh et al., 2017, Chen et al., 2019, Macariu et al., 2020, Suzuki et al., 2020, Yusof et al., 2020]

Table 4: Classification of studies according to the method used to evaluate effectiveness of AR in the classroom.

more complex tasks. From this, the authors conclude that AR can be a valuable tool for learning difficult geometric concepts. The same study also conducted tests about the user experience, and the results showed that the AR application could engage its users in extremely worthwhile, highly attractive and interesting learning activities with good usability.

The app described in [Cen et al., 2019] is used to teach Chemistry to 45 high school students and behaves differently depending on the distance of the device from the markers. The authors performed a quantitative evaluation of the system, analysing grades and the distribution of mistakes in the different quizzes. They conclude that there is a statistically significant improvement in the performances of the students, and that the greater the difficulty level of the question, the bigger the performance improvement is over the control group. The authors conclude that their Augmented Immersive Reality (AIR) system is most likely responsible for the bulk of learning improvements and the knowledge retention gains demonstrated in their case study, since that is the critical component differentiating their system from other applications available on the market.

Of the 59 studies presenting a quantitative evaluation of the results, none of them conclude that using AR in the classroom has a negative impact on the students' results

and their level of engagement in the classroom. Even though in many cases the improvement over traditional teaching methods is limited, only the work of [Carlos-chullo et al., 2020] does not detect any positive impact. This consensus on the effectiveness of AR applications is unexpected: besides the commonplace explication (AR is indeed a successful medium with a positive impact on students' results) two other possible explanations are the novelty effect [Pisapia et al., 1993], which explains the performance improvements introduced by a new technology such as AR as being due to an increased interest of the user, and the positive publication bias [Begg, 1994], which makes it harder for researchers to publish studies with negative results.

Only the work of [Lin et al., 2016] presents an analysis of the retention of the topics learned through AR over a time span of more than two months. As most of the students who participated in the tests had not previously used AR applications, there is a specific risk that the novelty effect introduced a recency bias, by increasing user engagement and knowledge acquisition, indirectly leading to better test scores.

4   Discussion

This study shows that the research community is very active in investigating how AR applications can improve education and facilitate students' understanding of difficult concepts. Even though collaboration and participation by students is often seen as a key towards improving knowledge retention, we still see a lack of support for cooperation mechanisms in AR applications for education: of the 100 studies analysed, only 17 described multi-user application and only 13 employ some sort of collaboration between users. ARGBL is also quite uncommon, as only 11 articles describe applications which implement gamification concepts.

By reviewing the existing literature we have also identified several issues that are preventing the widespread adoption of collaborative AR in the classroom:

– Lack of authoring tools: with the exception of the works of [Lytridis et al., 2018] and [Whitlock et al., 2020], the applications described do not make use of an authoring tool that simplify the creation of an AR experience. This means that every AR application has to be developed from scratch, requiring longer development times and multiplying the amount of work required from the developers.

– Lack of standardisation for the description of AR experiences: of all the papers we analysed, none of them mentioned using a standard for the description of how AR is used in the application. This is mainly due to a lack of specific standards, as the IEEE ARLEM standard [Wild and Perey, 2020] for AR-based learning experiences was only released in February 2020, while the ETSI Augmented Reality Framework[15] for the interoperability of AR components has not been published yet. We believe that adoption of these standards will drive and simplify the development of AR applications for education, as well as foster interoperability.

– Availability of 3D content for education: a few repositories where users can freely download 3D objects already exist, but there is a lack of 3D content specialised for education purposes. Although there are currently efforts being made to solve this issue [Masneri et al., 2020], it does severely hinders the possibility of quickly creating new AR apps for primary and secondary schools.

---

[15] www.etsi.org/committee/1420-arf

– Code publication: another issue with most of the studies we reviewed is that only a small fraction of the authors published the code of the AR application. This means that other researchers cannot build upon the results of previous researchers: even for the more interesting and highly cited articles there will be no follow up work, with the exception of that from the original authors.

We noticed that studies claiming to have a stronger positive impact on educational achievements are the ones where the AR application is part of bigger learning environments. We believe that providing automatic logging functionalities, for example through xAPI [Kevan and Ryan, 2016], a teacher dashboard where the educator can track the progress or the grades of each student and a set of tools for improving communication capabilities could go a long way to better integrate AR applications in standard schools curricula. Using xAPI could simplify the application of learning analytics techniques for the analysis and improvement of students' learning. This is especially the case for distance learning, in which the students are not in the same physical space as the teacher or other students but are following their classes remotely.

On the technical side, researchers are slowly adopting the latest advancement in technology, but the majority of the studies analysed are still focusing on more limited AR functionalities, for example marker-based systems. The implementation of AR applications that make use of Edge Artificial Intelligence (EAI) or which are based on web technologies such as WebXR[16] is currently limited because only the most recent devices have hardware capable of supporting them. Nonetheless, we believe these are key technologies that enable more immersive experiences and facilitate collaboration.

Most of the studies we reviewed, with the exception of the works described in [Chen, 2018, Kenoui and Mehdi, 2020, Mikułowski and Brzostek-pawłowska, 2020], focus on vision-based augmentations. Although it is clear that students rely predominantly on sight to collect and process information, providing other types of augmentations such as haptic or audio is worth investigating, since these could make the user experience more immersive and they could improve accessibility of AR applications for students with sight impairment.

None of the studies explored the possibility of using multi-user AR application for distance learning. The apps described by [Oh et al., 2017] and [López-faican and Jaen, 2020] use PUN[17], a network library that enables communication across different devices, but the applications require that the users share the same physical space. Especially after the prolonged lockdown due to the Covid-19 pandemic, newer technologies should provide AR apps with capabilities for the students to share the same experience even though they are not in the same room. This would be useful for teachers, who could make remote lessons more engaging, and for students, who would have the chance to work together with other schoolmates even when they are at home.

Regarding the effectiveness of AR applications in the classroom, the majority of the studies present an evaluation of the AR solution described. There are great differences between the questions for teachers and students in the user surveys, but in general users find AR a successful educational tool which is both useful and engaging. The most common critiques identified refer to the user friendliness of the application and the errors in identifying the markers. More specifically, the users complained about the difficulty of navigating through the UI, due to its lack of consistency and about the difficulty of identifying and tracking the markers in poor lighting conditions or when the camera was not close enough.

---

[16] www.w3.org/TR/webxr/
[17] www.photonengine.com/pun

Based on the review of the selected publications, we have identified a set of recommendations that should help increase the engagement of students while using AR applications as well as improving their learning and retention of new concepts. When creating the applications, developers should work closely with teachers to guarantee that the AR app can be easily integrated with existing school curricula, and that it can be used without requiring extensive training. Developers should also take particular care in simplifying the user experience for the students, as this was one of the main sources of user dissatisfaction in the studies reviewed. While using the AR application in school, the teachers should try using collaborative features both when the students learn (to maximize students' engagement) and when they are doing tests (to increase retention). After evaluating the AR applications, the teachers should also provide feedback to the developers on how to improve the application, while developers should provide educators the means to easily add new content to the app (teaching material, quizzes, 3d models, etc.), allowing them to keep using it for future lessons.

5   Conclusion

In this paper we presented a systematic review of the literature relative to applications of immersive, collaborative and multi-user AR in primary and secondary education. We analysed 100 studies and evaluated their technical characteristics and their advantages compared to traditional teaching tools as well as the impact they had on knowledge retention. We believe that the findings described in Sections 3 and 4 can be useful for researchers in driving the design of the next generation of AR applications.

With the first Research Question (RQ1) we wanted to identify which studies described interactive, multi-user and collaborative AR experiences, and we compared the main features of the AR applications described. Every paper presented AR-based interactions, but only a few applications provided multi-user and collaborative capabilities. Our analysis showed that Unity and Vuforia, the de-facto standard tools for creation of AR applications, do not provide researchers and developers the tools to easily include collaboration mechanisms in AR applications.

The second Research Question (RQ2) aimed to understand the motivation behind the usage of AR as an educational tool. In this case we analysed both the motivations presented by the researchers and the results of surveys conducted on students. Even though few papers provided information in this sense, it appears that the main motivation for using AR in schools is to facilitate understanding of abstract concepts and to increase students' engagement.

Finally, the objective of the third Research Question (RQ3) was to measure, as objectively as possible, the impact of using AR in the classroom. The studies analysed pre/post tests or comparisons with control groups to assess the usefulness of AR and, in general, they showed that making use of AR applications leads to a small but statistically significant improvement compared to the scores obtained by the test group.

References

[Abriata, 2020] Abriata, L.: "Building blocks for commodity augmented reality-based molecular visualization and modeling in web browsers"; Peerj Computer Science. 6 pp. e260 (2020)

[Ahmad and Junaini, 2020] Ahmad, N. and Junaini, S.: "Augmented Reality for Learning Mathematics: A Systematic Literature Review"; International Journal Of Emerging Technologies In Learning (ijet). 15, 106–122 (2020)

[Akçayır and Akçayır, 2017] Akçayır, M. and Akçayır, G.: "Advantages and challenges associated with augmented reality for education: A systematic review of the literature"; Educational Research Review. 20 pp. 1–11 (2017)

[Amrit et al., 2015] Amrit, M., Bansal, H. and Yammiyavar, P.: "Studies in Application of Augmented Reality in E-Learning Courses"; Icord15–research Into Design Across Boundaries Volume 2. pp. 375–384 (2015)

[Ang and Lim, 2019] Ang, I. and Lim, K.: "Enhancing STEM Education using Augmented Reality and Machine Learning"; 2019 7th International Conference On Smart Computing & Communications (icscc). pp. 1–5 (2019)

[Antoniou et al., 2017] Antoniou, P., Mpaka, M., Dratsiou, I., Aggeioplasti, K., Tsitouridou, M. and Bamidis, P.: "Scoping the Window to the Universe; Design Considerations and Expert Evaluation of an Augmented Reality Mobile Application for Astronomy Education"; Interactive Mobile Communication, Technologies And Learning. pp. 409–420 (2017)

[Arcos et al., 2016] Arcos, C., Fuertes, W., Villacís, C., Zambrano, M., Noboa, T., Tacuri, A., Aules, H. and Toulkeridis, T.: "Playful and interactive environment-based augmented reality to stimulate learning of children"; 2016 18th Mediterranean Electrotechnical Conference (melecon). pp. 1–6 (2016)

[Arici et al., 2019] Arici, F., Yildirim, P., Caliklar, Ş. and Yilmaz, R.: "Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis"; Computers & Education. 142 pp. 103647 (2019)

[Theodoropoulou et al., 2020] Theodoropoulou, H., Kiourt, C., Lalos, A., Koutsoudis, A., Paxinou, E., Kalles, D. and Pavlidis, G.: "Exploiting Extended Reality Technologies for Educational Microscopy"; "virtual Reality And Augmented Reality". pp. 149–162 (2020)

[Azuma, 1997] Azuma, R.: "A survey of augmented reality"; Presence: Teleoperators & Virtual Environments. 6, 355–385 (1997)

[Bacca et al., 2014] Bacca, J., Baldiris, S., Fabregat, R. and Graf, S.: "Augmented Reality Trends in Education: A Systematic Review of Research and Applications"; J. Educ. Technol. Soc.. 17 pp. 133-149 (2014)

[Bartolomé et al., 2011] Bartolomé, N., Zorrilla, A. and Zapirain, B.: "Can game-based therapies be trusted? Is game-based education effective? A systematic review of the Serious Games for health and education"; 2011 16th International Conference On Computer Games (cgames). pp. 275–282 (2011)

[Begg, 1994] Begg, C.: "Publication bias"; The Handbook Of Research Synthesis. 25 pp. 299–409 (1994)

[Beyoglu et al., 2020] Beyoglu, D., Hursen, C. and Nasiboglu, A.: "Use of mixed reality applications in teaching of science"; Education And Information Technologies. 25, 4271–4286 (2020)

[Billinghurst and Kato, 2002] Billinghurst, M. and Kato, H.: "Collaborative augmented reality"; Communications Of The Acm. 45, 64–70 (2002)

[Boonbrahm et al., 2015] Boonbrahm, S., Kaewrat, C. and Boonbrahm, P.: "Using augmented reality technology in assisting english learning for primary school students"; International Conference On Learning And Collaboration Technologies. pp. 24–32 (2015)

[Boonbrahm et al., 2016] Boonbrahm, P., Kaewrat, C. and Boonbrahm, S.: "Interactive Augmented Reality: A New Approach for Collaborative Learning"; International Conference On Learning And Collaboration Technologies. pp. 115–124 (2016)

[Cai et al., 2017] Cai, S., Chiang, F., Sun, Y., Lin, C. and Lee, J.: "Applications of augmented reality-based natural interactive learning in magnetic field instruction"; Interactive Learning Environments. 25, 778–791 (2017)

[Cao and Hou, 2018] Cao, R. and Hou, W.: "Research on the Interaction Design of AR Picture Books via Usability Test"; International Conference On Human Centered Computing. pp. 524–534 (2018)

[Cao and Liu, 2019] Cao, R. and Liu, Y.: "Hand ControlAR: An Augmented Reality Application for Learning 3D Geometry"; 2019 Ieee International Symposium On Mixed And Augmented Reality Adjunct (ismar-adjunct). pp. 144–149 (2019)

[Carlos-chullo et al., 2020] Carlos-chullo, J., Vilca-quispe, M. and Castro-gutierrez, E.: "Voluminis: An Augmented Reality Mobile System in Geometry Affording Competence to Evaluating Math Comprehension"; International Conference On Remote Engineering And Virtual Instrumentation. pp. 288–299 (2020)

[Caudell and Mizell, 1992] Caudell, T. and Mizell, D.: "Augmented reality: an application of heads-up display technology to manual manufacturing processes"; Proceedings Of The Twenty-fifth Hawaii International Conference On System Sciences. ii pp. 659-669 vol.2 (1992)

[Cen et al., 2019] Cen, L., Ruta, D., Alqassem, L. and Ng, J.: "Augmented Immersive Reality (AIR) for Improved Learning Performance: A Quantitative Evaluation"; Ieee Transactions On Learning Technologies. (2019)

[Cerqueira et al., 2018] Cerqueira, J., Sylla, C., Moura, J. and Ferreira, L.: "Learning Basic Mathematical Functions with Augmented Reality"; Interactivity, Game Creation, Design, Learning, And Innovation. pp. 508–513 (2018)

[Chang and Hwang, 2018] Chang, S. and Hwang, G.: "Impacts of an augmented reality-based flipped learning guiding approach on students' scientific project performance and perceptions"; Computers & Education. 125 pp. 226–239 (2018)

[Chang et al., 2019] Chang, K., Zhang, J., Huang, Y., Liu, T. and Sung, Y.: "Applying augmented reality in physical education on motor skills learning"; Interactive Learning Environments. pp. 1–13 (2019)

[Chao et al., 2018] Chao, W., Yang, C. and Chang, R.: "A Study of the Interactive Mathematics Mobile Application Development"; 2018 1st Ieee International Conference On Knowledge Innovation And Invention (ickii). pp. 248–249 (2018)

[Chen and Wang, 2015] Chen, C. and Wang, C.: "Construction of a synchronized multi-display augmented reality simulation module for learning tidal effects"; 2015 2nd International Conference On Information Science And Security (iciss). pp. 1–4 (2015)

[Chen et al., 2016] Chen, C., Chou, Y. and Huang, C.: "An augmented-reality-based concept map to support mobile learning for science"; The Asia-pacific Education Researcher. 25, 567–578 (2016)

[Chen et al., 2017] Chen, P., Liu, X., Cheng, W. and Huang, R.: "A review of using Augmented Reality in Education from 2011 to 2016"; Innovations In Smart Learning. pp. 13–18 (2017)

[Chen et al., 2019] Chen, C., Huang, C. and Chou, Y.: "Effects of augmented reality-based multidimensional concept maps on students' learning achievement, motivation and acceptance"; Universal Access In The Information Society. 18, 257–268 (2019)

[Chen, 2018] Chen, I.: "The Application of Augmented Reality in English Phonics Learning Performance of ESL Young Learners"; 2018 1st International Cognitive Cities Conference (ic3). pp. 255–259 (2018)

[Cheng and Tsai, 2013] Cheng, K. and Tsai, C.: "Affordances of augmented reality in science learning: Suggestions for future research"; Journal Of Science Education And Technology. 22, 449–462 (2013)

[Cohen, 1960] Cohen, J.: "A coefficient of agreement for nominal scales"; Educational And Psychological Measurement. 20, 37–46 (1960)

[Costa et al., 2019] Costa, M., Manso, A., Patrãcio, J., Carvalho, A., Alegria, B. and Zinatulins, V.: "An augmented reality platform targeted to promote learning about planetary systems"; 2019 International Symposium On Computers In Education (siie). pp. 1-5 (2019)

[Costa et al., 2019] Costa, M., Manso, A., Patrício, J., Carvalho, A., Alegria, B. and Zinatulins, V.: "An augmented reality platform targeted to promote learning about planetary systems"; 2019 International Symposium On Computers In Education (siie). pp. 1–5 (2019)

[Cruzado et al., 2020] Cruzado, J., Huaman, D., Capa, J. and Bellizza, M.: "IdeAR: Augmented Reality Applied to Reading Comprehension Stories"; 2020 Ieee Engineering International Research Conference (eircon). pp. 1–4 (2020)

[Daineko et al., 2018] Daineko, Y., Ipalakova, M., Tsoy, D., Shaipiten, A., Bolatov, Z. and Chinibayeva, T.: "Development of practical tasks in physics with elements of augmented reality for secondary educational institutions"; International Conference On Augmented Reality, Virtual Reality And Computer Graphics. pp. 404–412 (2018)

[Dasilva et al., 2019] Dasilva, M., Teixeira, J., Cavalcante, P. and Teichrieb, V.: "Perspectives on how to evaluate augmented reality technology tools for education: a systematic review"; Journal Of The Brazilian Computer Society. 25, 3 (2019)

[Dave et al., 2020] Dave, A., Kang, M., Hwang, J., Lorenzo, M. and Oh, P.: "Towards Smart Classroom: Affordable and Simple Approach to Dynamic Projection Mapping for Education"; 2020 10th Annual Computing And Communication Workshop And Conference (ccwc). pp. 0942–0947 (2020)

[Diegmann et al., 2015] Diegmann, P., Schmidt-kraepelin, M., Vandeneynden, S. and Basten, D.: "Benefits of Augmented Reality in Educational Environments - A Systematic Literature Review"; Wirtschaftsinformatik. (2015)

[Elkouzi et al., 2019] Elkouzi, M., Mao, A. and Zambrano, D.: "An Educational Augmented Reality Application for Elementary School Students Focusing on the Human Skeletal System"; 2019 Ieee Conference On Virtual Reality And 3d User Interfaces (vr). pp. 1594–1599 (2019)

[Estudante and Dietrich, 2020] Estudante, A. and Dietrich, N.: "Using Augmented Reality to Stimulate Students and Diffuse Escape Game Activities to Larger Audiences"; Journal Of Chemical Education. 97, 1368–1374 (2020)

[Ferrer et al., 2017] Ferrer, V., Perdomo, A., Ali, H., Fies, C. and Quarles, J.: "Virtual humans for temperature visualization in a tangible augmented reality educational game"; 2017 Ieee Virtual Reality Workshop On K-12 Embodied Learning Through Virtual & Augmented Reality (kelvar). pp. 1–6 (2017)

[Gardeli and Vosinakis, 2018] Gardeli, A. and Vosinakis, S.: "The Effect of Tangible Augmented Reality Interfaces on Teaching Computational Thinking: A Preliminary Study"; International Conference On Interactive Collaborative Learning. pp. 673–684 (2018)

[Garzón et al., 2019] Garzón, J., Pavón, J. and Baldiris, S.: "Systematic review and meta-analysis of augmented reality in educational settings"; Virtual Reality. 23, 447–459 (2019)

[Giasiranis and Sofos, 2017] Giasiranis, S. and Sofos, L.: "Flow experience and educational effectiveness of teaching informatics using AR"; Journal Of Educational Technology & Society. 20, 78–88 (2017)

[Hill and Miller, 2013] Hill, J. and Miller, K.: "Classroom instruction that works with English language learners"; (ASCD,2013)

[Hrishikesh and Nair, 2016] Hrishikesh, N. and Nair, J.: "Interactive learning system for the hearing impaired and the vocally challenged"; 2016 International Conference On Advances In Computing, Communications And Informatics (icacci). pp. 1079–1083 (2016)

[Hsieh and Chen, 2019] Hsieh, M. and Chen, S.: "Intelligence Augmented Reality Tutoring System for Mathematics Teaching and Learning"; Journal Of Internet Technology. 20, 1673–1681 (2019)

[Hsu et al., 2018] Hsu, T., Liang, H., Chiou, C. and Tseng, J.: "CoboChild: a blended mobile game-based learning service for children in museum contexts"; Data Technologies And Applications. (2018)

[Hsu, 2017] Hsu, T.: "Learning English with augmented reality: Do learning styles matter?"; Computers & Education. 106 pp. 137–149 (2017)

[Huang et al., 2016] Huang, T., Chen, C. and Chou, Y.: "Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment"; Computers & Education. 96 pp. 72–82 (2016)

[Huang et al., 2019] Huang, T., Chen, M. and Hsu, W.: "Do Learning Styles Matter? Motivating Learners in an Augmented Geopark"; Journal Of Educational Technology & Society. 22, 70–81 (2019)

[Ibáñez and Delgado-kloos, 2018] Ibáñez, M. and Delgado-kloos, C.: "Augmented reality for STEM learning: A systematic review"; Computers & Education. 123 pp. 109–123 (2018)

[Ibáñez et al., 2020] Ibáñez, M., Portillo, A., Cabada, R. and Barrón, M.: "Impact of augmented reality technology on academic achievement and motivation of students from public and private Mexican schools. A case study in a middle-school geometry course"; Computers & Education. 145 pp. 103734 (2020)

[Iqbal et al., 2019] Iqbal, M., Mangina, E. and Campbell, A.: "Exploring the use of Augmented Reality in a Kinesthetic Learning Application Integrated with an Intelligent Virtual Embodied Agent"; 2019 Ieee International Symposium On Mixed And Augmented Reality Adjunct (ismar-adjunct). pp. 12–16 (2019)

[Johnson and Johnson, 2008] Johnson, R. and Johnson, D.: "Active learning: Cooperation in the classroom"; The Annual Report Of Educational Psychology In Japan. 47 pp. 29–30 (2008)

[Johnson et al., 2000] Johnson, W., Rickel, J. and Lester, J.: "Animated pedagogical agents: Face-to-face interaction in interactive learning environments"; International Journal Of Artificial Intelligence In Education. 11, 47–78 (2000)

[Johnson, 1991] Johnson, D.: "Cooperation in the classroom"; Psyccritiques. 36, 1106–1107 (1991)

[Kalpakis et al., 2018] Kalpakis, S., Palaigeorgiou, G. and Kasvikis, K.: "Promoting historical thinking in schools through low fidelity, low-cost, easily reproduceable, tangible and embodied interactions"; International Journal Of Emerging Technologies In Learning (ijet). 13, 67–82 (2018)

[Kenoui and Mehdi, 2020] Kenoui, M. and Mehdi, M.: "Teach-Me DNA: an Interactive Course Using Voice Output in an Augmented Reality System"; 020 1st International Conference On Communications, Control Systems And Signal Processing (ccssp). pp. 260–265 (2020)

[Kevan and Ryan, 2016] Kevan, J. and Ryan, P.: "Experience API: Flexible, decentralized and activity-centric data collection"; Technology, Knowledge And Learning. 21, 143–149 (2016)

[Khan et al., 2018] Khan, M., Trujano, F. and Maes, P.: "Mathland: Constructionist Mathematical Learning in the Real World Using Immersive Mixed Reality"; International Conference On Immersive Learning. pp. 133–147 (2018)

[Khoshnevisan and Le, 2018] Khoshnevisan, B. and Le, N.: "Augmented reality in language education: A systematic literature review"; Adv. Glob. Educ. Res. 2 pp. 57–71 (2018)

[Kitchenham et al., 2009] Kitchenham, B., Brereton, O., Budgen, D., Turner, M., Bailey, J. and Linkman, S.: "Systematic literature reviews in software engineering–a systematic literature review"; Information And Software Technology. 51, 7–15 (2009)

[Klautke et al., 2018] Klautke, H., Bell, J., Freer, D., Cheng, C. and Cain, W.: "Bridging the Gulfs: Modifying an Educational Augmented Reality App to Account for Target Users' Age Differences"; International Conference Of Design, User Experience, And Usability. pp. 185–195 (2018)

[Korosidou and Bratitsis, 2019] Korosidou, E. and Bratitsis, T.: "Gamifying Early Foreign Language Learning"; Interactive Mobile Communication, Technologies And Learning. pp. 726–737 (2019)

[Krichenbauer et al., 2018] Krichenbauer, M., Yamamoto, G., Taketom, T., Or, C. and Kato, H.: "Augmented Reality versus Virtual Reality for 3D Object Manipulation"; Ieee Transactions On Visualization And Computer Graphics. 24, 1038-1048 (2018)

[Kuh et al., 2011] Kuh, G., Kinzie, J., Buckley, J., Bridges, B. and Hayek, J.: "Piecing together the student success puzzle: Research, propositions, and recommendations: ASHE higher education report"; (John Wiley & Sons,2011)

[Kum-biocca et al., 2019] Kum-biocca, H., Kim, H., Biocca, F. and Cho, Y.: "AR-VIS: Augmented Reality Interactive Visualization Environment for Exploring Dynamic Scientific Data"; International Conference On Human-computer Interaction. pp. 374–380 (2019)

[Kurniawan and Witjaksono, 2018] Kurniawan, M. and Witjaksono, G.: "Human anatomy learning systems using augmented reality on mobile application"; Procedia Computer Science. 135 pp. 80–88 (2018)

[Laal and Ghodsi, 2012] Laal, M. and Ghodsi, S.: "Benefits of collaborative learning"; Procedia-social And Behavioral Sciences. 31 pp. 486–490 (2012)

[Lai et al., 2015] Lai, A., Wong, C. and Lo, O.: "Applying augmented reality technology to book publication business"; 2015 Ieee 12th International Conference On E-business Engineering. pp. 281–286 (2015)

[Laine and Suk, 2016] Laine, T. and Suk, H.: "Designing mobile augmented reality exergames"; Games And Culture. 11, 548–580 (2016)

[Laine, 2018] Laine, T.: "Mobile educational augmented reality games: a systematic literature review and two case studies"; Computers. 7, 19 (2018)

[Lam et al., 2020] Lam, M., Tee, H., Nizam, S., Hashim, N., Suwadi, N., Tan, S., Abdmajid, N., Arshad, H. and Liew, S.: "Interactive Augmented Reality with Natural Action for Chemistry Experiment Learning"; Tem Journal. 9, 351 (2020)

[Laviole et al., 2018] Laviole, J., Thevin, L., Albouys-perrois, J. and Brock, A.: "Nectar: Multi-user Spatial Augmented Reality for everyone: Three live demonstrations of educative applications"; Proceedings Of The Virtual Reality International Conference-laval Virtual. pp. 1–6 (2018)

[Lee et al., 2018] Lee, I., Chen, C., Wang, C. and Chung, C.: "Augmented reality plus concept map technique to teach children with ASD to use social cues when meeting and greeting"; The Asia-pacific Education Researcher. 27, 227–243 (2018)

[Lee et al., 2019] Lee, L., Chau, C., Tsoi, K., Yang, N. and Wu, N.: "A Mobile Game for Learning English Vocabulary with Augmented Reality Block Builder"; International Conference On Technology In Education. pp. 116–128 (2019)

[Li et al., 2017] Li, J., Vanderspek, E., Feijs, L., Wang, F. and Hu, J.: "Augmented reality games for learning: A literature review"; International Conference On Distributed, Ambient, And Pervasive Interactions. pp. 612–626 (2017)

[Li et al., 2018] Li, J., Vanderspek, E., Hu, J. and Feijs, L.: "See me roar: On the over-positive, cross-cultural response on an AR game for math learning"; Joint International Conference On Serious Games. pp. 54–65 (2018)

[Limsukhawat et al., 2016] Limsukhawat, S., Kaewyoun, S., Wongwatkit, C. and Wongta, J.: "A Development of Augmented Reality-supported Mobile Game Application based on Jolly Phonics Approach to Enhancing English Phonics Learning Performance of ESL Learners"; The 24th International Conference On Computers In Education. pp. 483–488 (2016)

[Lin et al., 2016] Lin, C., Yu, W., Chen, W., Huang, C. and Lin, C.: "The effect of literacy learning via mobile augmented reality for the students with ADHD and reading disabilities"; International Conference On Universal Access In Human-computer Interaction. pp. 103–111 (2016)

[Lin et al., 2019] Lin, X., Wu, Q., Shen, W., Zhu, Q. and Wang, J.: "Primary School Students' Science Inquiry Learning and Behavior Patterns While Exploring Augmented Reality Science Learning"; International Conference On Technology In Education. pp. 79–90 (2019)

[Liou et al., 2017] Liou, H., Yang, S., Chen, S. and Tarng, W.: "The influences of the 2D image-based augmented reality and virtual reality on student learning"; Journal Of Educational Technology & Society. 20, 110–121 (2017)

[Liu et al., 2020] Liu, C., Wu, S., Wu, S. and Cai, S.: "An AR-Based Case Study of Using Textual and Collaborative Scaffolding for Students with Different Self-Efficacy to Learn Lever Principles"; 2020 6th International Conference Of The Immersive Learning Research Network (ilrn). pp. 9–15 (2020)

[Luna et al., 2018] Luna, J., Treacy, R., Hasegawa, T., Campbell, A. and Mangina, E.: "Words Worth Learning-Augmented Literacy Content for ADHD Students"; 2018 Ieee Games, Entertainment, Media Conference (gem). pp. 1–9 (2018)

[Lytridis et al., 2018] Lytridis, C., Tsinakos, A. and Kazanidis, I.: "ARTutor - an augmented reality platform for interactive distance learning"; Education Sciences. 8, 6 (2018)

[López-faican and Jaen, 2020] López-faican, L. and Jaen, J.: "Emofindar: Evaluation of a mobile multiplayer augmented reality game for primary school children"; Computers & Education. 149 pp. 103814 (2020)

[Macariu et al., 2020] Macariu, C., Iftene, A. and Gã®fu, D.: "Learn Chemistry with Augmented Reality"; Procedia Computer Science. 176 pp. 2133-2142 (2020)

[Mahmoudi et al., 2018] Mahmoudi, M., Zeraati, F. and Yassini, P.: "A Color Sensing AR-Based Interactive Learning System for Kids"; 2018 12th Iranian And 6th International Conference On E-learning And E-teaching (icelet). pp. 013–020 (2018)

[Majid and Salam, 2021] Majid, S. and Salam, A.: "A Systematic Review of Augmented Reality Applications in Language Learning."; International Journal Of Emerging Technologies In Learning. 16 (2021)

[Manrique-juan et al., 2017] Manrique-juan, C., Grostieta-dominguez, Z., Rojas-ruiz, R., A, M., Muñoz-gómez, L. and Silva-muñoz, C.: "A Portable Augmented-Reality Anatomy Learning System Using a Depth Camera in Real Time"; The American Biology Teacher. 79 pp. 176 - 183 (2017)

[Masneri et al., 2020] Masneri, S., Domãnguez, A., Wild, F., Pronk, J., Heintz, M., Tiede, J., Nistor, A., Chiazzese, G. and Mangina, E.: "Work-in-progress - ARETE-An Interactive Educational System using Augmented Reality"; 2020 6th International Conference Of The Immersive Learning Research Network (ilrn). pp. 283–286 (2020)

[Matsutomo et al., 2017] Matsutomo, S., Manabe, T., Cingoski, V. and Noguchi, S.: "A computer aided education system based on augmented reality by immersion to 3-D magnetic field"; Ieee Transactions On Magnetics. 53, 1–4 (2017)

[Mikułowski and Brzostek-pawłowska, 2020] Mikułowski, D. and Brzostek-pawłowska, J.: "Multi-sensual Augmented Reality in Interactive Accessible Math Tutoring System for Flipped Classroom"; International Conference On Intelligent Tutoring Systems. pp. 1–10 (2020)

[Mylonas et al., 2019] Mylonas, G., Amaxilatis, D., Pocero, L., Markelis, I., Hofstaetter, J. and Koulouris, P.: "An educational iot lab kit and tools for energy awareness in european schools"; International Journal Of Child-computer Interaction. 20 pp. 43–53 (2019)

[Nasongkhla et al., 2019] Nasongkhla, J., Chanjaradwichai, S. and Chiasiriphan, T.: "Implementing multiple AR markers in learning science content with junior high school students in Thailand"; International Journal Of Emerging Technologies In Learning (ijet). 14, 48–60 (2019)

[Nielsen et al., 2016] Nielsen, B., T, H. and Swensen, H.: "Augmented Reality in science education-affordances for student learning"; Nordic Studies In Science Education. 12 pp. 157-174 (2016)

[Oh et al., 2016] Oh, S., Park, K., Kwon, S. and So, H.: "Designing a multi-user interactive simulation using AR glasses"; Proceedings Of The Tei'16: Tenth International Conference On Tangible, Embedded, And Embodied Interaction. pp. 539–544 (2016)

[Oh et al., 2017] Oh, S., So, H. and Gaydos, M.: "Hybrid augmented reality for participatory learning: The hidden efficacy of multi-user game-based simulation"; Ieee Transactions On Learning Technologies. 11, 115–127 (2017)

[Ortiz et al., 2018] Ortiz, A., Vitery, C., González, C. and Tobar-muñoz, H.: "Evaluation of an Augmented Reality Multiplayer Learning Game"; Joint International Conference On Serious Games. pp. 91–100 (2018)

[Palaigeorgiou et al., 2018] Palaigeorgiou, G., Karakostas, A. and Skenteridou, K.: "Touching and traveling on 3D augmented tangible maps for learning geography"; Interactive Technology And Smart Education. (2018)

[Pellas et al., 2019] Pellas, N., Fotaris, P., Kazanidis, I. and Wells, D.: "Augmenting the learning experience in primary and secondary school education: A systematic review of recent trends in augmented reality game-based learning"; Virtual Reality. 23, 329–346 (2019)

[Petticrew and Roberts, 2008] Petticrew, M. and Roberts, H.: "Systematic reviews in the social sciences: A practical guide"; (John Wiley & Sons,2008)

[Phon et al., 2014] Phon, D., Ali, M. and Halim, N.: "Collaborative Augmented Reality in Education: A Review"; 2014 International Conference On Teaching And Learning In Computing And Engineering. pp. 78-83 (2014)

[Pisapia et al., 1993] Pisapia, J., Schlesinger, J. and Parks, A.: "Learning Technologies in the Classroom: Review of the Literature."; (ERIC,1993)

[Pombo and Marques, 2017] Pombo, L. and Marques, M.: "Marker-based augmented reality application for mobile learning in an urban park: Steps to make it real under the EduPARK project"; 2017 International Symposium On Computers In Education (siie). pp. 1–5 (2017)

[Pombo and Marques, 2018] Pombo, L. and Marques, M.: "THE EduPARK MOBILE AUGMENTED REALITY GAME: LEARNING VALUE AND USABILITY"; Mobile Learning 2018. pp. 23 (2018)

[Pombo and Marques, 2019] Pombo, L. and Marques, M.: "Learning with the augmented reality EduPARK game-like app: its usability and educational value for primary education"; Intelligent Computing-proceedings Of The Computing Conference. pp. 113–125 (2019)

[Protopsaltis et al., 2016] Protopsaltis, A., Mentzelopoulos, M., Ferguson, J. and Kaloyan, K.: "Quiz Cube: an AR mobile learning application"; 2016 11th International Workshop On Semantic And Social Media Adaptation And Personalization (smap). pp. 151–155 (2016)

[Pérez-muñóz et al., 2020] Pérez-muñóz, A., Castro-idrovo, D., Robles-bykbaev, Y., Robles-bykbaev, V. and Pesántez-avilés, F.: "An interactive application based on augmented reality and rules-based reasoning to support educational activities of high school students"; 2020 Ieee World Conference On Engineering Education (edunine). pp. 1–5 (2020)

[Radu, 2014] Radu, I.: "Augmented reality in education: a meta-review and cross-media analysis"; Personal And Ubiquitous Computing. 18, 1533–1543 (2014)

[Rammos and Bratitsis, 2019] Rammos, D. and Bratitsis, T.: "Alternative Teaching of History Subject in Primary School: The Case of the 3D HIT Playful Activity"; International Conference On Games And Learning Alliance. pp. 457–467 (2019)

[Ramos and Comendador, 2019] Ramos, M. and Comendador, B.: "ARTitser: A Mobile Augmented Reality in Classroom Interactive Learning Tool on Biological Science for Junior High School Students"; Proceedings Of The 2019 5th International Conference On Education And Training Technologies. pp. 135–139 (2019)

[Rusiñol et al., 2018] Rusiñol, M., Chazalon, J. and Diaz-chito, K.: "Augmented songbook: an augmented reality educational application for raising music awareness"; Multimedia Tools And Applications. 77, 13773–13798 (2018)

[Sarkar et al., 2018] Sarkar, P., Pillai, J. and Gupta, A.: "ScholAR: a collaborative learning experience for rural schools using augmented reality application"; 2018 Ieee Tenth International Conference On Technology For Education (t4e). pp. 8–15 (2018)

[Sorrentino et al., 2015] Sorrentino, F., Spano, L. and Scateni, R.: "Speaky Notes Learn languages with augmented reality"; 2015 International Conference On Interactive Mobile Communication Technologies And Learning (imcl). pp. 146–150 (2015)

[Suzuki et al., 2020] Suzuki, R., Kazi, R., Wei, L., Diverdi, S., Li, W. and Leithinger, D.: "RealitySketch: Embedding Responsive Graphics and Visualizations in AR with Dynamic Sketching"; Adjunct Publication Of The 33rd Annual Acm Symposium On User Interface Software And Technology. pp. 135-138 (2020)

[Syahidi and Mohamed, 2020] Syahidi, A. and Mohamed, A.: "Mobile Augmented Reality Application with Multi-Interaction for Learning Solutions on the Topic of Computer Network Devices (Effectiveness, Interface, and Experience Design)"; 2020 Third International Conference On Vocational Education And Electrical Engineering (icvee). pp. 1–6 (2020)

[Takahashi et al., 2018] Takahashi, I., Oki, M., Bourreau, B., Kitahara, I. and Suzuki, K.: "An Empathic Design Approach to an Augmented Gymnasium in a Special Needs School Setting."; International Journal Of Design. 12 (2018)

[Tang et al., 2015] Tang, J., Duong, T., Ng, Y. and Luk, H.: "Learning to create 3D models via an augmented reality smartphone interface"; 2015 Ieee International Conference On Teaching, Assessment, And Learning For Engineering (tale). pp. 236–241 (2015)

[Thamrongrat and Lai-chonglaw, 2020] Thamrongrat, P. and Lai-chonglaw, E.: "Analysis of The Motivational Effect of Gamified Augmented Reality Apps for Learning Geometry"; 32nd Australian Conference On Human-computer Interaction. pp. 65-77 (2020)

[Thamrongrat and Law, 2019] Thamrongrat, P. and Law, E.: "Design and Evaluation of an Augmented Reality App for Learning Geometric Shapes in 3D"; Ifip Conference On Human-computer Interaction. pp. 364–385 (2019)

[Triantafyllidou et al., 2017] Triantafyllidou, I., Chatzitsakiroglou, A., Georgiadou, S. and Palaigeorgiou, G.: "FingerTrips on tangible augmented 3D maps for learning history"; Interactive Mobile Communication, Technologies And Learning. pp. 465–476 (2017)

[Tscholl and Lindgren, 2016] Tscholl, M. and Lindgren, R.: "Designing for learning conversations: How parents support children's science Learning within an immersive simulation"; Science Education. 100, 877–902 (2016)

[Wang et al., 2018] Wang, T., Zhang, H., Xue, X. and Cai, S.: "Augmented reality-based interactive simulation application in double-slit experiment"; Online Engineering & Internet Of Things. pp. 701–707 (2018)

[Wang, 2017] Wang, Y.: "Exploring the effectiveness of integrating augmented reality-based materials to support writing activities"; Computers & Education. 113 pp. 162–176 (2017)

[Wei et al., 2018] Wei, X., Guo, D. and Weng, D.: "Improving Authentic Learning by AR-Based Simulator"; Chinese Conference On Image And Graphics Technologies. pp. 124–134 (2018)

[Wei et al., 2019] Wei, X., Yang, G. and Weng, D.: "The Influence of Mobile Augmented Reality-Based Sandbox Games on Chinese Characters Learning"; Chinese Conference On Image And Graphics Technologies. pp. 436–446 (2019)

[Whitlock et al., 2020] Whitlock, M., Mitchell, J., Pfeufer, N., Arnot, B., Craig, R., Wilson, B., Chung, B. and Szafir, D.: "MRCAT: In Situ Prototyping of Interactive AR Environments"; International Conference On Human-computer Interaction. pp. 235–255 (2020)

[Wild and Perey, 2020] Wild, F. and Perey, C.: "IEEE Standard for Augmented Reality Learning Experience Model (ARLEM)"; (IEEE Standards Association,2020)

[Xefteris and Palaigeorgiou, 2019] Xefteris, S. and Palaigeorgiou, G.: "Mixing Educational Robotics, Tangibles and Mixed Reality Environments for the Interdisciplinary Learning of Geography and History"; Int. J. Eng. Pedagog.. 9, 82–98 (2019)

[Xefteris et al., 2018] Xefteris, S., Palaigeorgiou, G. and Tsorbari, A.: "A Learning Environment for Geography and History Using Mixed Reality, Tangible Interfaces and Educational Robotics"; International Conference On Interactive Collaborative Learning. pp. 106–117 (2018)

[Yilmaz and Goktas, 2017] Yilmaz, R. and Goktas, Y.: "Using augmented reality technology in storytelling activities: examining elementary students' narrative skill and creativity"; Virtual Reality. 21, 75–89 (2017)

[Yin et al., 2020] Yin, X., Hou, S. and Hu, H.: "Research on Interactive Design of Social Interaction Training APP for Children with Autistic Spectrum Disorder (ASD) Based on Multi-modal Interaction"; E3s Web Of Conferences. 179 pp. 02044 (2020)

[Yuhana et al., 2020] Yuhana, U., Hariadi, R., Mukramin, M., Fabroyir, H. and Arifiani, S.: "AUGGO: Augmented Reality and Marker-based Application for Learning Geometry in Elementary Schools"; 2020 International Conference On Computer Engineering, Network, And Intelligent Multimedia (cenim). pp. 116-120 (2020)

[Yusof et al., 2020] Yusof, C., Ahmad, N., Ismail, A. and Sunar, M.: "Mathematics Lesson using Accelerometer Sensor Interaction in Handheld Augemented Reality Application for Kindergarten"; 2020 6th International Conference On Interactive Digital Media (icidm). pp. 1-6 (2020)

[Zhao et al., 2018] Zhao, G., Zhang, Q., Chu, J., Li, Y., Liu, S. and Lin, L.: "Augmented Reality Application for Plant Learning"; 2018 Ieee 9th International Conference On Software Engineering And Service Science (icsess). pp. 1108–1111 (2018)