A systematic review of Augmented Reality game-based applications in primary education

[1]Panagiotis Fotaris, [2]Nikolaos Pellas, [3]Ioannis Kazanidis, [4]Paul Smith

[1,4] University of East London, School of Arts and Digital Industries, U.K.

[2] University of the Aegean, Department of Product and Systems Design Engineering, Greece

[3] Information Technology Department of Eastern Macedonia and Thrace Institute of Technology, Greece

p.fotaris@uel.ac.uk
npellas@aegean.gr
kazanidis@teiemt.gr
p.t.smith@uel.ac.uk

Abstract

Augmented Reality game-based learning (ARGBL) is quickly gaining momentum in the education sector worldwide as it has the potential to enable new forms of learning and transform the learning experience. However, it remains unclear how ARGBL applications can impact students' motivation and performance in primary education. This study addresses that topic by providing a systematic review, which analyses and critically appraises the current state of knowledge and practice in the use of ARGBL applications in primary education. In total, seventeen (17) studies that used either qualitative, quantitative, or mixed-methods to collect their data were analysed and were published between 2012 and 2017. The study results indicated that ARGBL applications are mainly used to document the design and development process, as well as to share preliminary findings and student feedback. Based on a comprehensive taxonomy of application areas for AR in primary education, ARGBL can potentially influence the students' attendance, knowledge transfer, skill acquisition, hands-on digital experience, and positive attitudes in laboratory experimental exercises for different courses. This review aims to offer new insights to researchers and provide educators with effective advice and suggestions on how to improve learning outcomes, as well as increase students' motivation and learning performance by incorporating this instructional model into their teaching.

Keywords: Augmented Reality, Game-based learning, primary education, Mixed Reality, Mobile learning

Introduction

Technology has greatly affected many educational domains. Specifically, in primary education students who use modern technological tools (e.g., mobile devices or interactive environments) under the guidance of an instructor, can learn more complicated ideas now compared to previous years. Consequently, students aged between 6 and 13 are engaged more easily in problem-based and inquiry-based learning situations. On such occasions, they are required to collect or analyse data, produce models, and execute complex concepts to solve problems. Recent technological progress provides means to facilitate this type of complex learning by mobile Augmented Reality (AR) learning environments, which layer virtual information on the physical environment and require learners to solve complex problems by combining collected evidence from the real world and virtual information in real time (Chiang et al., 2014; Muñoz et al., 2017).

Although AR technologies have been around for several years, it is the recent proliferation of mobile devices that has made affordable AR systems available to the general public (Wu et al., 2013). As a result, AR is currently gaining significant momentum in education (Atwood-Blaine & Huffman, 2017), with teachers hoping that the level of active engagement seen in mobile AR games such as the overwhelmingly successful Pokémon GO can potentially translate to compelling educational media and make learning more immersive. Azuma (1997) defines AR as a system or visualisation technique that fulfils three main criteria: a combination of real and virtual worlds; real time interaction; and accurate 3D registration of virtual and real objects. It is commonly accepted as a real-time technology whereby a physical environment has been augmented by adding/embedding virtual information in it (Enyedy et al., 2012). This differs from the notion of a Virtual Environment where the user is completely immersed inside a synthetic environment. In this sense, "AR supplements reality, rather than completely replacing it" (Azuma, 1997), as it enriches the human senses with additional information beyond what is provided by the natural environment. The user experience includes the provision of a large amount of information and additional environmental stimuli, which gives users the perception of being inside a visually-rich informative environment (Squire & Jan, 2007). Therefore, AR technology can provide a more efficient understanding of abstract concepts, which can also lead to improved spatial and cognitive abilities (Laine et al., 2016; Joo-Nagata et al., 2017).

AR applications are usually available through mobile devices such as smartphones and tablets, and employ built-in cameras, GPS sensors, and Internet access to embed real-world environments with dynamic, context-aware, and interactive digital content (Chiang et al., 2014; Zhang et al., 2014). Consequently, the paradigm shift away from the lecture-style of teaching that has been experienced recently, combined with the maturity of AR technologies, have prompted educators to harness the power of AR in educational environments to create practical and highly interactive visual forms of learning (Hsiao et al., 2016; Huang et al., 2016; Furió et al., 2013). Some of the most popular fields of primary education that use AR in teaching are Science (Atwood-Blaine & Huffman, 2017; Hung et al., 2017; Hsiao et al., 2016; Furió et al., 2013), Ecology (Hwang et al., 2016; Kamarainer et al., 2013), Natural Sciences (Chen et al., 2016; Chiang et al., 2014), Physics (Cai et al., 2016; Enyedy et al., 2012), Astronomy (Zhang et al., 2014), Library instruction (Chen & Tsai, 2012), Geometry (Laine et al., 2016), Storytelling (Yilmaz & Goktas, 2016), Social Sciences (Efstathiou et al., 2017; Joo-Nagata et al., 2017), and Reading comprehension (Tobar-Muñoz et al., 2017). Additionally, recent studies have suggested that content learnt through AR technologies can benefit long-term memory, problem-solving, enthusiasm and student's collaborative abilities (Tobar-Muñoz et al., 2017; Hung et al., 2017), as well as increase academic performance (Wei et al., 2015; Zhang et al., 2014) and enhance learning satisfaction (Hsiao et al., 2016; Huang et al., 2016).

Nevertheless, there is still a lack of literature review studies presenting and sufficiently analysing the educational potential and affordances of AR technology in primary education. For example, a large body of literature has reported factors such as uses, purposes, advantages, limitations, effectiveness, and affordances of AR when they are applied in various learning domains. However, there is gap in the literature with respect to systematic literature reviews looking at these factors of AR in primary educational settings. Such potential should be studied as it can foster students' performance and positively affect learning achievements in different learning tasks. With that in mind, the present study aims at investigating the purposes of use for game-based AR applications in primary education and constructing a more pedagogical description, while using the concept of pedagogical and functional perspectives, for the mapping of learning stages to types of learning environments, thus extending their road map for further research.

This review study follows Wu et al.'s (2013) recommendations, since there are currently unexplored dimensions focusing on issues regarding the design and implementation of instructional learning methods via AR technologies. With many AR systems designed exclusively for teaching science and mathematics, it is essential to understand how instructors have used AR for the development of educational content using specific instructional methods and whether the latter assisted students in gaining knowledge. Taking this into account, this systematic literature review aims to present the current status of AR research in primary education and examine the potential of adopting this technology. This review will focus on AR game-based instructional and learning approaches (henceforth, ARGBL), the study environment and AR technologies used, the learning topics covered, the research methods used, and finally the educational potential and benefits of these technologies.

Research questions
There is already a large volume of published studies that report advantages, limitations, and challenges of AR in education. Since AR is an emerging technology, it is important to provide an overview of the advances and real impact of its use in educational settings, as well as to describe how AR has been used to develop student-centred learning scenarios. Within this context, the research questions addressed by this study are:
(1) What are the potential benefits and limitations regarding the learning effectiveness of AR game-based applications in primary education?
(2) What are the mainstream game-based instructional and learning approaches that students participate in with the purpose of improving their learning outcomes?
(3) What AR-enabled devices have been used to enhance the game-based learning experience, and where has this experience taken place?

Method
The guidelines proposed by Kitchenham (2007) were adapted for the purposes of this systematic review using the following steps:
Step 1: Planning: (a) Selection of journals, *(b)* Definition of inclusion and exclusion criteria for studies,
(c) Definition categories for the analysis.
Step 2: Conducting the review: (a) Study selection*, (b)* Data extraction (Content analysis methods were applied)*,
(c)* Data synthesis*, (d)* Data coding.

Step 3: Reporting the review: Analysis of the results and the discussion of findings, trends and conclusions regarding the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement recommendation (Moher et al., 2009).

Step 1(a): Selection of journals
The aim of this initial step was to choose the most relevant journals for the systematic review in a consistent way. To keep the process methodologically strong and scientifically consistent, a specific method has been defined for the journal selection. The Google Scholar h5-index for the category *"Educational technology"* was used as a starting point, since this category is more precise than the "Education and educational research" category from the Journal Citation Report Social Science Citation Index (JCR SSCI). In the latter, most of the journals relating to educational technology are indexed together with journals about educational research in general. For the purpose of this study, the top 5 journals from the *"Educational Technology"* category chosen from the Google Scholar h5-index were named *"GS list."* To initially validate our *"GS list,"* an iterative double check process was performed using the JCR SSCI tool to consider the impact factor of each journal and its *"relatedness"* to others. This feature of most related journals is defined in the JCR by considering the citation relationship of the journals and is based on the number of citations from one journal to the other and the total number of articles. According to the Thomson Reuters Journal Citation Reports (2012–2017) all journals that accepted these reviewed articles have impact factors from 0.532 to 2.676. This indicates that AR technology is a relatively new field for researchers and educators who want to utilise it as a modern approach to implementing practical hands-on experiments in various subjects across primary education. Several AR technologies and research methods (case or empirical studies) are provided in this review.

For quality purposes, preference was given to the selection of reviewed papers which used qualitative and/or quantitative analysis of results, as these are considered the most accurate forms of experimental research to prove or disprove a hypothesis through statistical analysis. For an experiment to be classified as a valid experimental design, the following criteria must be fulfilled (Russell & Gregory, 2003): (a) The research question should be clearly defined and adequately substantiated; (b) The method of sampling should be appropriate for the research questions and instructional design methods; (c) The data must be analysed appropriately; (d) The analytical description of findings should be provided either with qualitative or quantitative data; (e) The meaning or relevance of the study should have some practical implications for knowledge acquisition.

Table 1. Number of studies analysed in this review published in international journals

		Journal (Publishers)	Analysed studies (2012-2017)
	JCR-SSCI Journals		Total: 16
1.		Computers & Education (Elsevier)	5
2.		Interactive Learning Environments (Taylor & Francis)	3
3.		Journal of Computer Assisted Learning (Wiley)	1
4.		Journal of Educational Computing Research (SAGE)	1
5.		International Journal of Computer-Supported Collaborative Learning (Springer)	1
6.		Educational Technology Research and Development (Springer)	1
7.		Journal of Science Education and Technology (Springer)	1
8.		The Asia-Pacific Education Researcher	1
9.		International Journal of Science and Mathematics Education (Springer)	1
10.		Educational Technology & Society (Online)	1
	JCR-SCI Journals		Total: 1
1.		Virtual Reality (Springer)	1

Table 1 above presents 10 journals associated with the JCR-SSCI list that are among the journals selected for this review. It must be pointed out that this method allowed the identification of the most important journals in educational technology for this study by following a double-checking process of considering both impact factor and "relatedness" in the JCR-SSCI and JCR-SCI (Journal Citation Report - Science Citation Index). In total 17 studies were analysed from the 10 selected journals using the JCR-SSCI and 1 study from the selected journal using the JCR-SCI. To additionally include the JCR-SCI, an iterative double check process was repeated with the journals indexed in the JCR-SCI and another list of journals was obtained, which is referred to as the "JCR-SCI list". Table 1 also shows one journal from this list that has been selected for review. It was decided to include studies discussing AR technology and its impact on primary education which were published in journals off each of these lists. By analysing the year of publication of each of the considered studies, it was found that the number

of published studies relating to AR in education has progressively increased year by year, particularly during the last two years. These results make clear that AR in education is an emerging topic, corroborating the opinions of Wu et al. (2013) and Chen & Tsai (2012), who pointed out that research into AR in education is still in its early stages.

Step 1(b): Inclusion and exclusion criteria

Considering the research questions, general criteria defining the time frame for the studies and the type of studies that are relevant were devised. The following criteria were agreed upon:

General Criteria: (a) Studies published between 2012 and 2017; (b) studies describing applications or frameworks for AR in primary education; (c) conceptual articles or studies that do not provide evidence of educational potential based on a research method; (d) articles whose abstract is written in English but the rest of the paper is in another language.

Specific Criteria: (a) Studies reporting the advantages, disadvantages, instructional affordances and/or the effectiveness of AR across various primary education subjects; (b) studies describing applications considering user models and/or adaptive processes combined with AR; (c) studies describing applications of AR in primary education for students in the context of diversity; (d) studies presenting evaluation methods for AR applications in various educational scenarios.

Exclusion Criteria: (a) Studies not identified as *"articles"* in the selected journals (e.g., books, book reviews/chapters, editorial publication information, etc.); (b) studies that briefly mention the term "AR" but are on an unrelated topic.

Step 1(c): Categories for analysis and data coding: In this stage, a group of analysis categories and sub-categories are defined for each research question. This categorisation will assist grouping of all relevant studies based on their shared characteristics. During the systematic review process, some sub-categories emerged and others were refined to cover all relevant information. The list of categories for the analysis informed by the research questions is as follows:

(1) What are the potential benefits and limitations regarding the learning effectiveness of AR game-based applications in primary education?

Both target group and subjects of primary education are based on the International Standard Classification of Education (UNESCO, 2012). In addition, this review also places importance on the reported purposes, learning topics, advantages or limitations on student performance and learning gain, and the negative perceptions of using AR across different devices.

(2): What are the mainstream game-based instructional and learning approaches that students participate in with the purpose of improving their learning outcomes?

(a) types of game-based/game-like processes; (b) types of user modelling; (c) tablets or smartphones used according to learning contents or the instructional methods that have been previously utilised.

(3): What research methods and data collection tools have been chosen to measure learning gains using AR technology?

Content analysis allows research trends of a topic to be identified by analysing the articles' content and grouping papers according to their shared characteristics. This method was applied to extract the information from each paper. The studies were manually coded separately according to their key characteristics and were classified according to the categories and sub-categories defined above.

Results and Conducting the Review

In this section, the results of conducting the review are described and discussed. In step 2(a) a manual search was conducted in the selected journals and the inclusion and exclusion criteria were applied to select the studies for the review, leading to a selection of 17 journal studies. Steps 2(b) and 2(c) were carried out by reading the papers thoroughly; the data coding process was performed according to the categories defined in step 1(c). The results were presented in line with the research questions. As the research methods used for samples, instructional design methods, research and data collection differed so greatly, it was not possible to undertake an accurate meta-analysis. The overall results were synthesised to extract the main themes under which the findings of the review are identified and presented. In the analysed studies, the age groups of primary school students ranged from 6-13 years. As the process was inductive, there were no initial themes assigned to the data. Each paper was read several times and codes were assigned to individual findings. The latter appear in Table 2 below, which presents the most crucial observations and aims to illustrate the answers for the raised questions.

Table 2. General overview of primary education studies

Research studies	Game-based instructional and learning approaches	Environment and used AR devices	Learning topics	Research methods	Study results and observations
Atwood-Blaine & Huffman (2017)	Location-based ARGBL during a field trip to a hands-on science centre.	iPad-based mobile game using the open-source location-based game platform ARIS. The game took place during a field trip to a hands-on science centre. It used QR scan codes and a challenge-based game structure to encourage engagement in science. Participants wore head-mounted GoPro cameras to record interactions within the physical and social environment.	Study the impact of a mobile game on student interactions in a Science centre.	Quasi-experimental design with two groups: one that played the iPad mobile game during their science centre visit, and another that explored the science centre in a traditional free exploration manner. Video data from GoPro cameras provided examination of the student interaction with the science centre, and the gender differences in gameplay behaviours and perceptions.	The female students outperformed the male students on every measure of the iPad game achievement. The females tended to be more goal-oriented, persistent in the face of difficulty, and appreciative of hard and collaborative people fun, while males enjoyed easy fun and competitive people fun.
Efstathiou et al. (2017)	Location-based AR game during a field trip to an archaeological site.	Location-based AR IBL environment. Groups of 2-3 students had a tablet with location-based AR capabilities	Development of historical empathy and conceptual understanding.	Mixed Methods Approach. Comparative study based on students' learning performance and qualitative analysis through interviews.	Students who employed the AR application outperformed the students of the traditional field trip.
Hung et al. (2017)	ARGBL using a graphic book in combination with 3D physical objects and 3D virtual objects.	The study took place in a lab and used an Animated AR graphics book displaying 3D images of bacteria. It utilised a virtual reality head mounted display with a small video camera attached at the level of the students' eyes.	Lesson about six bacteria.	Mixed Methods Approach. Comparative study between three groups based on students' errors, retention and satisfaction. Quantitative analysis through post-test and qualitative analysis through interviews.	AR improved students' learning performances to a similar extent as conventional teaching materials, such as picture books and physical interactions do. However, AR aroused more interest / motivation in students than more conventional teaching materials, such as picture books and physical interactions.
Joo-Nagata et al. (2017)	Mobile-learning using an AR application during fieldwork.	AR and Mobile Pedestrian Navigation app used with iPads. Software used was Apple Maps and Junaio for developing AR resources using geo-location.	Territorial Heritage elements of the city of Santiago de Chile.	Mixed Methods Approach. Comparative study based on students' learning performance and satisfaction. Qualitative and quantitative data collection with pre/post-tests, satisfaction questionnaire and interviews.	Concludes that AR app combined with fieldwork increases the effectiveness of teaching-learning processes, promotes the interaction of students with contents for learning, and improves students' performance in the educational process.
Tobar-Muñoz et al. (2017)	ARGBL to promote reading comprehension in a naturalistic environment.	AR game for Android tablets and smartphones inspired by traditional "pop up" books, which is played in a naturalistic environment. Each page is an ARGBL game based on a reading comprehension question that uses the illustrations from the book as AR markers.	Reading comprehension	Design-Based Research / Mixed Methods approach. Quasi-experimental study. Intrinsic Motivation Inventory used to obtain a self-report on interest and motivation during the experience; Reading Comprehension Performance Questionnaire; Video observation.	While results in reading comprehension using the game showed no difference to results from the more traditional approaches, children did display greater motivation and interest in the activity, and the activity was enriched as it promoted problem solving, exploration, and socialisation behaviour.
Cai et al. (2016)	AR motion-sensing learning technology that teaches magnetic fields.	Students wave their hands in an AR motion sensing environment set in a lab that uses a Microsoft Kinect and magnets to trigger the virtual magnet model and the simulated magnetic field.	Physics; Rule of the magnetic field and the magnetic lines.	Mixed-methods; Quasi-experimental study (Interview and statistical analysis; qualitative and quantitative data collection).	Students using AR seemed to understand magnetic fields and lines more intuitively, and memorise the content for a longer period. The AR software was insignificant in helping students move from concepts to laws, but it triggered students' motivation and interest, encouraging them to learn more actively and extensively.
Chen et al. (2016)	Comparison of AR instructional methods: a Concept Mapped AR Learning system (using a concept map as its learning structure) vs. a standard AR Learning system (which used a book as its learning structure).	A tablet PC was used for both AR instructional method tests. The built-in camera was used for AR recognition of image targets during the activities. The tests were carried out indoors in a classroom.	Natural Science topics relating to animal food chains.	Quasi-experimental and mixed methods. (pre/post-test questionnaires and post-test interviews). An Instructional Materials Motivation Survey was used to assess the impact of the learning approaches on the students' learning motivation.	Students who used the concept map as a knowledge structure in CMAR learning achieved better learning outcomes than those who used only the AR learning method. The CMAR method helped students organise and construct course content, increased their learning motivation, and improved their learning attitudes. It was also found to simplify and clarify instructional materials used in the activity and increase learning confidence.

Hsiao et al. (2016)	Manipulative AR (MAR) system with 3D interactive models and manipulative aids.	A manipulative AR system for Weather Simulation, which included 3D interactive models and manipulative aids. The environment where the study took place was outdoors.	Understanding Weather during a Natural Science course.	Comparative study based on students' learning performance and satisfaction. Qualitative and quantitative data collection methods were used with pre/post-tests.	Results show that integrating AR applications into inquiry-based field studies make a greater positive impact on the academic achievement, satisfaction and motivation compared to the use of multimedia teaching resources installed on a tablet PC.
Hwang et al. (2016)	Location-based ARGBL during a field trip to a butterfly garden.	The entire field trip was gamified in the style of a dice-based board game. Students used Wi-Fi-enabled mobile devices running an AR location-based Competitive Learning Game in a butterfly garden. They were presented with challenges and information when a QR code tag was scanned.	Ecology of the butterflies (growing cycle, visual features, natural enemies, host plants of different species of butterfly).	Mixed experimental methods (pre/post-test questionnaire).	The AR-based gaming approach improved both the students' learning attitudes and their learning performance on the field trip.
Laine et al. (2016)	Context-aware storytelling and science learning games.	Science Spots AR learning platform is a combination of 2D AR games and 3D models that users can interact with. Played by using smartphones. Authors developed an authoring platform for creating such games.	Scientific topics such as geometry and kinetics. A proof of concept game was developed to teach geometric shapes.	Formative evaluation. Quantitative data was gathered through a questionnaire and qualitative through open questions and interviews.	Students appreciated Geometry after the test. Despite its minor shortcomings, the platform's concept is feasible. Authors conclude that the game has potential for affecting the players' attitudes towards mathematics.
Yilmaz & Goktas (2016)	Storytelling using AR and 3D models.	Marker-based AR application using a webcam and laptop setup. The study took place in the classroom.	Narrative skill, story length and creativity in storytelling.	Comparative study based on students' stories using either cards or AR with cards. Students' stories were recorded and transcribed for analysis in place of post-test.	Students who created stories with AR were found to write better, longer and more creative stories.
Chiang et al. (2014)	Mobile learning using an AR application during fieldwork.	The AR-based mobile learning system used iPad mini devices which had inbuilt GPS and were Wi-Fi enabled.	Natural Science topics relating to aquatic animals and plants.	A pre-test questionnaire was used to ensure that the two groups of students had equivalent prior knowledge before the learning activity. A post-test questionnaire was used to assess the students' learning achievements after the learning activity.	The proposed approach was shown to improve learning achievements. Students who learned with the AR-based mobile learning approach showed significantly higher motivations relating to attention, confidence, and relevance than those who learned with the conventional inquiry-based mobile learning approach.
Zhang et al. (2014)	Interactive learning in an outdoor/indoor location using a mobile AR astronomy simulation software.	A mobile digital armillary sphere (MDAS) using AR combined a digital compass with a G-sensor on a mobile device and connected the target content with the users' physical movements to provide the experience of human-computer field interaction. The study took place both indoors and outdoors.	Astronomical observation content (constellation identification, constellation proportion, constellation deformation).	Instructor interview survey; Quasi-experimental study. Students completed a learning achievement test (pre/post-test), a stargazing targets test, and a flow experience questionnaire.	Using the MDAS system during outdoor observation activities effectively enhanced both the students' learning of astronomical observation content and their performance of astronomical observation skills. It also increased students' interest in astronomical observations and learning, which had a substantial effect on retention. Students using the MDAS were significantly more active and engaged in interactions with the teacher compared to those students using traditional tools.
Furio et al. (2013)	Mobile game included multiple interaction forms (touch-screen interaction and accelerometer) and combined AR with non-AR mini-games.	In two mirror rooms, two students at a time played a mobile learning game using AR and VR technology. Children used a smartphone and a tablet PC with external casing.	Understanding water cycle concepts and process.	Comparative study based on device size and weight. (quantitative and qualitative data collection with pre/post-tests)	Students showed significant learning gains after intervention. Weight and size of device did not have an impact on learning outcomes, satisfaction, engagement, interaction, and AR experience.
Kamarainer (2013)	Location-based AR use during a field trip to a local pond environment.	During a field trip to a local pond environment, students used mobile wireless devices with FreshAiR, an AR app, in conjunction with water quality measurement tools that used graphic calculators with	Relationship between biotic and abiotic factors, data collection and interpretation skills, and the functional roles (producer,	Mixed-method (quantitative and qualitative data collection). Students were given pre/post-tests and surveys that included questions on affective measures and content understanding. Teachers were interviewed and	Positive effect on students' motivation and engagement during the AR learning experience. Students engaged well with both the AR and Probe technology. Teacher feedback suggests that AR can provide a powerful pedagogical tool that supports student-centred learning and helps students draw

		environmental probeware at designated AR hotspots.	consumer, decomposer) of organisms in an ecosystem.	participated in post-surveys about the AR learning experience.	connections between what they are learning and new situations. The technology promoted more interaction with the pond environment and with classmates compared to field trips in previous years.
Chen & Tsai (2012)	ARGBL using an educational AR system (ARLIS) based on situated learning theory to enhance library instruction.	ARLIS used a camera to recognise printed markers situated in various positions of a physical library that triggered the game's various learning missions.	Library instruction	Comparative study based on students' learning performance (Quantitative data collection with pre/post-tests)	ARLIS resulted in the same learning performance as conventional librarian instruction, but provided more benefits in terms of library skills of application and comprehension. Learning performance was not affected by students' gender or gaming skills.
Enyedy et al. (2012)	Learning Physics through Play Project (LPP) in participatory modelling to support inquiry and progressive symbolisation within rich semiotic ecologies	The study took place in a classroom and the hardware used for AR included 2 ceiling mounted cameras connected to a desktop PC.	Physics (Newtonian force and motion)	Case studies (Interview and statistical analysis/qualitative and quantitative data collection with pre/post-tests).	Students developed a better conceptual understanding of force, net force, friction and two-dimensional motion after participating in the LPP curriculum.

Table 3 displays the study results with respect to the category *"Effectiveness of AR"*. Since a single study can report more than one sub-category of effectiveness, each study can also fulfil more than one sub-category. The majority of the studies reported that AR applications lead to *"better learning performance and/or learning gains"* (58%) in educational settings. Increases in *"improved perceived enjoyment"* (10%) and *"student motivation and engagement"* (10%) were also reported. The results show that AR is a promising technology for improving student's learning performance and motivation relating to the methods of interaction and graphical content that can be utilised. *"Students' positive attitudes"* (6%) and *"Pervasiveness of learning content"* (6%) were less common, but they are also important in educational settings.

Table 3. Effectiveness of AR use in educational settings

Sub-category	Number of studies	Percentage (%)
Better learning performance and/or learning gains	9	58
Student motivation and engagement	2	10
Improved perceived enjoyment	2	10
Minimized financial cost	2	10
Students' positive attitudes	1	6
Pervasiveness of learning content	1	6

This review considered three types of AR according to the classification of Chen and Tsai (2012): marker-based, marker-less, and location-based. The former requires the use of markers (i.e., labels containing a coloured or black and white pattern that is easily recognised or registered by the AR application with input from device cameras) in order to trigger an event, such as displaying a 3D image spatially aligned with the marker's position. Marker-less AR is based on the recognition of object shapes, while location-based AR displays information according to the user's geographical location.

Results in Table 4 reveal that the majority of the reviewed studies used marker-based AR (52%), thus indicating that most AR educational applications are likely to use markers. A possible explanation might be that the tracking process of markers is more effective and more stable compared to the marker-less tracking techniques currently available. The use of static markers decreases the tracking work required and reduces the number of objects that need to be detected (Chen & Tsai, 2012). Therefore, using markers for educational purposes is recommended for providing students with a better learning experience until superior and more reliable techniques for tracking are developed for marker-less AR. Although the latter hasn't been widely used in educational settings (15%), Microsoft Kinect sensors and similar technologies have been used for AR educational applications (Cai et al., 2016; Squire & Jan, 2007), as they appear to provide some advantages in tracking and registering objects with marker-less AR. Location-based AR (21%) applications are gaining momentum, possibly due to the availability of sensors in mobile devices (e.g., accelerometer, compass, and integrated GPS) that allow users' location and geographical position to inform the AR experience.

Table 4. Types of AR applied in education

Sub-category	Number of studies	Percentage (%)
Marker-based AR	9	53%
Marker-less AR	3	17%
Location-based AR	4	24%
Not specified in the study	1	6%

Table 5 presents the data collected on the limitations of AR in educational settings. According to these, the most observed limitation in the reviewed studies is the fact that *"teachers cannot manipulate the same system for different educational subjects (lack of interdisciplinary programs)"* (35%). Students may feel frustrated if the application doesn't track or display data properly, or if they struggle to use the markers or the device to view the augmented information. To overcome this limitation, improvements to the algorithms and/or hardware used for image tracking and processing must be made. In addition to this, guidelines for designing AR-based educational experiences should be developed and further research is required to improve their usability. Another reported limitation was that *"students paid too much attention to virtual information"* (24%) due to the novelty of this technology, which may cause loss of interest when the novelty factor wears off. Equally, this can occur because *"complex AR systems may have a modest learning curve"* (12%). Other reported limitations include "too short periods of assessment to measure student learning performance" (12%) and the fact that *"teachers need to develop additional learning material exclusive to the AR needs"* (17%). It is recommended that further research be undertaken in developing intuitive AR authoring tools that do not rely heavily on programming, so that teachers can create their AR content more easily.

Table 5. Limitations of AR in educational settings

Sub-category	Number of studies	Percentage (%)
Teachers cannot manipulate the same system for different educational subjects (lack of interdisciplinary programs)	6	35
Students paid too much attention to virtual information (novelty factor)	4	24
Teachers need to develop additional learning material exclusive to the AR needs	3	17
Complex AR systems may have a modest learning curve	2	12
Too short periods of assessment to measure student learning performance	2	12

Discussion and Conclusion

ARGBL in primary education has great potential, as it can lead to students' cognitive acceleration, increased self-management, and enhancement to their engagement in practice-based activities. This review aspires to assist instructional technologists and educators, as it will allow them to recognise the educational potential and affordances of AR technologies across different disciplines and guide them towards adopting these technologies in their practice. The ever-increasing advancement in hardware and software along with the widespread use of mobile devices can provide the opportunity to rapidly increase students' learning participation through practical hands-on experiments. Before major progress in this area can be achieved, appropriate instructional design methods using different AR technologies for a variety of educational subjects must be developed along with AR authoring tools capable of facilitating the teaching and learning process. Additionally, as both ease of use and intuitive user interfaces (UI) are instrumental for a rewarding AR experience, it is imperative that UI specially tailored for young audiences are developed. Furthermore, case studies focusing on instructional design catering to the needs of specific teaching topics would help identify the most suitable elements to focus on. Finally, since course quality significantly affects student retention, the learning material should be clear, understandable, comprehensive, and relevant to the course learning objectives.

To summarise, these are the main findings of this review: (a) Science is the educational field where AR has been applied the most in primary education, with Social Sciences running a close second. ARGBL is suitable for teaching Science, as it offers the ability to bring to life invisible, abstract, and complex concepts in 3D or to visualise scientific phenomena that could not be seen without a specialised device. Social science courses, such as History, Tourism, Archaeology, and Geography can become more engaging if AR is combined with geolocation to provide location-triggered contextual information to students. Additionally, language learning can be more fun through the use of AR flashcards, while a smart AR globe could teach children about countries and cultures from around the world in an interactive and playful way; (b) Marker-based AR is the most commonly used type of AR in primary education, followed closely by location-based AR, owing to the availability of sensors in mobile devices such as gyroscopes, accelerometers, and GPS (Chen & Tsai, 2012; Hung et al., 2016). Marker-less AR still

requires some improvement in terms of algorithms for object tracking, but the use of current motion tracking hardware such as the Microsoft Kinect is becoming increasingly popular for these AR systems (Cai et al., 2016); (c) Educational AR mainly focuses on explaining and/or providing additional information about topics of interest, with AR games and AR lab experiments being growing fields. The main advantages of AR game-based learning experiences are knowledge gain, increased motivation, augmented interaction, and enhanced collaboration. With the use of AR technology, students can improve their learning performance, partly due to improved positive attitudes towards the learning process; (d) most studies in this review have used medium-sized research samples (between 30 and 200 participants) and have employed mixed evaluation methods. The most prevalent data collection methods were questionnaires, interviews, and surveys. Lastly, most of the studies were cross-sectional and quasi-experimental.

From an instructional perspective, this study suggests that interactive activities using AR technology can be designed and supported by adjusting the nature and complexity of different learning tasks through interdisciplinary instructional contexts. Motivation and enrichment of the learning experience are the two pillars of ARGBL. Target users who may find the AR integration more efficient are those who are not very experienced in the use of mobile devices in educational settings or those who prefer hands-on and practice-based learning, as AR would help them acquire technology-based and immersive experiences by combining the real and virtual worlds. When designed in a targeted manner, such technologies should involve relevant tools and functionalities that support collaborative knowledge-based work and follow up and track the co-constructed knowledge in a consistent manner. Recent studies (Efstathiou et al., 2017; Wu et al., 2013; Chen & Tsai, 2012) have reported new research directions and there is also a need for the connection of instructional methods underpinned by learning theories, such as Constructionism or Activity Theory for the creation, manipulation, and presentation of interactive 3D apps in AR game-based learning. To consider such an effort, instructional technologists and designers need to understand how to design AR learning experiences tailored to the topic to be taught and taking into consideration the skills of learners. In the creation of multisensory experiences with AR technology for interdisciplinary school programs, researchers must explore their impact on learning outcomes. There are also many possibilities offered by AR to reduce the financial cost of running many learning activities which require expensive learning materials. For example, combining virtual objects with real objects, such as students' hands or interactive world globes, could be an appropriate option to increase students' motivation and participation that can have a direct impact on learning outcomes. Longitudinal studies with long term analysis of the learning experiences could also provide important insights into the suitability of this technology for specific learning subjects.

In conclusion, the present review intends to contribute to instructional education design by providing evidence of AR game-based applications' potential to support teaching and learning in different areas of primary education. The results may offer new insights to researchers and provide educators with effective advice and guidelines on how to incorporate this instructional model into their teaching practice. Further research is still required, examining different facets of game-based AR applications for primary education. These should be based around additional theoretical frameworks and/or proposals for evaluation methods to further establish the pedagogy of AR game-based applications among different courses.

References

Atwood-Blaine, D., & Huffman, D. (2017). Mobile Gaming and Student Interactions in a Science Center: The Future of Gaming in Science Education. *International Journal for Science and Mathematics Education*. DOI 10.1007/s10763-017-9801-y

Azuma, R.T. (1997). A survey of augmented reality. Presence, 6(4), 355-385.

Cai, S., Chiang, F., Sun, Y., Lin, C., & Lee, J. (2016). Applications of augmented reality-based natural interactive learning in magnetic field instruction. *Interactive Learning Environments*, DOI: 10.1080/10494820.2016.1181094

Chen, C.-H., Chou, Y.-Y. & Huang, C.-Y. (2016). An Augmented-Reality-Based Concept Map to Support Mobile Learning for Science. *Asia-Pacific Edu Res*, 25(4), 567-578.

Chen, C.-M., & Tsai, Y.-N. (2012). Interactive augmented reality system for enhancing library instruction in elementary schools. *Computers & Education*, 59(2), 638–652.

Chiang, T.-H.-C., Yang, S.-J.-H., & Hwang, G.-J. (2014). An Augmented Reality-based Mobile Learning System to Improve Students' Learning Achievements and Motivations in Natural Science Inquiry Activities. *Educational Technology & Society*, 17(4), 352–365.

Efstathiou, I., Kyza, E., & Georgiou, Y. (2017). An inquiry-based augmented reality mobile learning approach to fostering primary school students' historical reasoning in nonformal settings. *Interactive Learning Environments*, DOI: 10.1080/10494820.2016.1276076

Enyedy, N., Danish, J.A., Delacruz, G., & Kumar, M. (2012). Learning physics through play in an augmented reality environment. *International Journal of Computer-Supported Collaborative Learning, 7*(3), 347–378.

Furió, D., González-Gancedo, S., Juan, M.-C., Seguí, I., & Rando, N. (2013). Evaluation of learning outcomes using an educational iPhone game vs. traditional game. *Computers & Education*, *64*, 1–23.

Hsiao H., Chang, C., Lin, C., & Wang, Y. (2016). Weather observers: a manipulative augmented reality system for weather simulations at home, in the classroom, and at a museum. *Interactive Learning Environments*, DOI: 10.1080/10494820.2013.834829

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

Hung, Y.-H., Chen, C.-H., & Huang, S.-W. (2017). Applying augmented reality to enhance learning: a study of different teaching materials. *Journal of Computer Assisted Learning*, 33(3), 252-266.

Hwang, G.-J., Wu, P.-H., Chen, C.-C., & Tu, N.-T. (2016). Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations, *Interactive Learning Environments*, 24(8), 1895-1906.

Joo-Nagata, J, Abad, M., Giner, G., & Garcia-Penalvo, F. (2017). Augmented reality and pedestrian navigation through its implementation in m-learning and e-learning: Evaluation of an educational program in Chile. *Computers & Education*, 11(1), 1-17.

Kamarainen, A.M., Metcalf, S., Grotzer, T., Browne, A. Mazzuca, D., Tutwiler, M.S, & Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers & Education*, 68, 545-556.

Kitchenham, B.A. (2007). Guidelines for performing Systematic Literature Reviews in Software Engineering Version 2.3, *EBSE Technical Report*, Keele University and University of Durham.

Laine, T., Nygren, E., Dirin, A., & Suk, H. (2016). Science Spots AR: a platform for science learning games with augmented reality. *Education Technology & Research Development*, 64(2), 507–531.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7), e1000097.

Russell, C. K., & Gregory, D. M. (2003). Evaluation of qualitative research studies. *Evidence Based Nursing*, 6(2), 36-40. DOI: 10.1136/ebn.6.2.36

Squire K.D., & Jan, M. (2007). Mad city mystery: developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of Science Education and Technology*, 16(1), 5–29.

Tobar-Muñoz, H., Baldiris, S., & Fabregat, R. (2017). Augmented Reality Game-Based Learning: Enriching Students' Experience During Reading Comprehension Activities. *Journal of Educational Computing Research*, 1-36.

UNESCO (2012). International Standard Classification of Education - ISCED. Montreal, Quebec: UNESCO Institute for Statistics.

Wei, X., Weng, D., Liu, Y. & Wang, Y. (2015). Teaching based on augmented reality for a technical creative design course. *Computers & Education*, 81, 221-234.

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y. & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41–49.

Yilmaz, R.M. & Goktas, Y. (2016). Using augmented reality technology in storytelling activities: Examining elementary students' narrative skill and creativity. *Virtual Reality*, 1-15.

Zhang, J., Sung, Y.-T., Hou, H.-T. & Chang, K.-E. (2014). The development and evaluation of an augmented reality-based armillary sphere for astronomical observation instruction. *Computers & Education*, 73, 178-188.