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Augmenting the learning experience in primary and secondary school education: a systematic review of recent trends in augmented reality game-based learning

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Abstract

There is a significant body of research relating to augmented reality (AR) uses for learning in the primary and the secondary education sectors across the globe. However, there is not such a substantial amount of work exploring the combination of AR with game-based learning (ARGBL). Although ARGBL has the potential to enable new forms of teaching and transform the learning experience, it remains unclear how ARGBL applications can impact students' motivation, achievements, and learning performance. This study reports a systematic review of the literature on ARGBL approaches in compulsory education considering the advantages, disadvantages, instructional affordances, and/or effectiveness of ARGBL across various primary and secondary education subjects. In total, 21 studies published between 2012 and 2017 in 11 indexed journals were analysed, with 14 studies focusing on primary education and 7 on secondary. The main findings from this review provide the current state of the art research in ARGBL in compulsory education. Trends and the vision towards the future are also discussed, as ARGBL can potentially influence the students' attendance, knowledge transfer, skill acquisition, hands-on digital experience, and positive attitude towards their learning. This review aims to lay the groundwork for educators, technology developers, and other stakeholders involved in the development of literacy programmes for young children by offering new insights with effective advice and suggestions on how to increase student motivation and improve learning outcomes and the learning experience by incorporating ARGBL into their teaching.

Keywords Augmented reality · Game-based learning · Systematic review · Primary education · Secondary education

1 Introduction

1.1 Game-based learning

Technology and its associated media exert a continuously increasing influence on peoples' lives and existence. With this in mind, many children are benefiting from the use of digital tools on a daily basis. Video games are a clear example of a medium that young people are regularly engrossed in, e.g., almost 6 million 8–15-year-old play video games in the United Kingdom (IAB 2014). Maintaining motivation and student engagement in the classroom is a challenge for teachers whose students may view their pedagogical choices and methods as dull and uninspiring (Hamari et al. 2016). Game-based learning (GBL) can help to alleviate this disinterest and support motivational gain and engagement in the child's learning (Papastergiou 2009). "Play" is a significant facet of GBL, because through it, people learn how to connect with and interpret their physical and social worlds (Gee 2008). In addition, games can be used as "bait" for learning, vehicles for content, architectures for engagement, and as "tools" to evaluate the users' strategies for gaining knowledge (Steinkuehler and Squire 2014). People who played games growing up obtain a better educational qualification than those that did not. In addition, they are greater

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consumers of culture (e.g., reading, painting, attending performing arts, and visiting heritage sites and libraries) and have a stronger tendency to engage in more active forms of cultural activity (Borowiecki and Bakhshi 2017).

Based on the above, researchers and game developers are trying to integrate educational content within game-based contexts, with the goal to transform the educational process into a fun and engaging activity for learning. Various studies have considered the use of digital games as very important in supporting education, as students who were subjects to learning with video games reported significant improvements in subject understanding, diligence, and motivation (e.g., Fotaris et al. 2016; Prensky 2006). Consequently, students in primary and secondary school education could be participating in lessons which reflect an emergent landscape that enables higher order thinking skills (e.g., creativity, problem-solving, critical thinking, collaboration, information, and technology literacy) to be taught and secured from the beginning of a child's formal education (Pellas and Vosinakis 2018). This opportunity will help students to understand and develop new knowledge, as well as build upon prior knowledge, which in turn will enable them to connect with the twenty-first century's demands and needs.

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 experiences (Fotaris et al. 2017). Consequently, the paradigm could shift away from lecture-style and more traditional teaching pedagogy towards active learning. Besides giving players the opportunity to learn through game play activities with clear goals, games also provide immediate feedback to the players' actions, which can have a positive effect on their performance (Pellas et al. 2016).

Thence, the challenge is how games can be used in the classroom to produce deeper disciplinary learning and also support and guide the learner towards richer understanding and concept mastery (Papastergiou 2009). Educators and scholars understand the importance of creativity and interaction in the learning process, so the use of interactive and innovative technologies can have a positive impact on the learning experience by allowing students to engage with topics in a personal and immersive way (Phipps et al. 2016).

1.2 Augmented reality in education

As technology continues to advance at an extraordinary rate, augmented reality (AR) attracts a lot of attention (Fotaris et al. 2017). Azuma (1997) defines AR as a system or visualization technique that fulfills three main criteria: (a) a combination of real and virtual world; (b) real-time interaction; and (c) accurate 3D registration of virtual and real objects. AR layers simulate information on the physical environment, thus enabling the user to interact with virtual objects in the real world (Chen et al. 2016). AR applications are available through wireless and mobile devices such as smartphones, tablets, and smart glasses. They employ built-in cameras, Global Positioning System (GPS) sensors, accelerometers, solid-state compasses, and Internet access to utilise either position data (location-aware AR) or real-world images and/or objects as visual markers that launch a digital information overlay (vision-based AR), thus embedding real-world environments with dynamic, context-aware, and interactive digital content (Chiang et al. 2014; Dunleavy and Dede 2014; Zhang et al. 2014).

By linking the physical world to the information browsing and delivery, AR can offer an intuitive way of giving contextual and location-specific information to the user (Alakärppä et al. 2017). It can also provide a landscape that enables children to engage with concepts that are not easily accessible in real life. In addition, AR allows these difficult conceptions to be taught and learners to solve complex problems, by combining real-time evidence from the natural world with virtual information (Tobar-Muñoz et al. 2017; Chiang et al. 2014). AR is considered a real-time technology, as the physical environment is augmented by adding/embedding virtual information within it (Enyedy et al. 2012). This differs significantly from the notion of a Virtual Environment (or world), where the user is completely immersed in a synthetic environment (Bacca et al. 2014). In this sense, "AR supplements reality, rather than completely replacing it" (Azuma 1997: 356) as it enriches the human senses with additional information beyond what is provided by the natural environment. Therefore, AR technology can provide an efficient understanding of abstract concepts, which can also lead to improved cognition and learning (Cai et al. 2016; Laine et al. 2016).

Mobile AR is regarded as one of the most promising technologies in the next 10 years and it is easily accessible due to the high penetration of mobile phones (Alakärppä et al. 2017). International Data Corp (IDC) projects that total spending on AR/VR products and services will soar from $9.1 billion in 2017 to nearly $160 billion in 2021, representing an annual growth rate of 113.2% (IDC 2017). Affordable AR systems are now available to the general public (Wu et al. 2013), while free mobile apps such as Blippar and HP Reveal allow users to create and share an overlaying digital content anchored to real-world objects (Blippar 2018; HP Reveal 2018). In addition, the mainstream success of AR applications such as Pokémon *GO*, which has been reported to succeed in shifting human mobility patterns (Colley et al. 2017), has provided a means to explore this media within educational contexts (Atwood-Blaine and Huffman 2017). Furthermore, research evidence suggests that AR can increase student motivation in the learning process (Liu and Chu 2010; Bujak et al. 2013; Di Serio et al. 2013), promote

"flow" (i.e., a user's state of "optimal experience") (Chang et al. 2014a, b, c), and positively contribute to the overall learning experience (e.g., Chen et al. 2016; Tobar-Muñoz et al. 2017). Finally, the 2016 Horizon Report named AR a "soon-to-be adopted technology" for learning (Adams et al. 2016).

In addition to the above, the combination of AR with game-based learning (ARGBL) is quickly gaining momentum by enabling new approaches to teaching and learning experience in different Primary and Secondary school education scientific disciplines. The maturity and accessibility of AR technologies have prompted educators to harness the power of ARGBL in educational environments to create practical and highly interactive visual forms of learning (Huang et al. 2016; Furió et al. 2013; Hsiao et al. 2013). Applications capable of providing information on a specific object or location using visual markers are used in museums, art exhibitions, field studies (e.g., identification of plant species), and educational settings (Alakärppä et al. 2017; Sommerauer and Müller 2014). Some of the most popular topics in primary education that use AR for teaching are formal science (Atwood-Blaine and Huffman 2017; Hung et al. 2017; Hsiao et al. 2013; Laine et al. 2016), natural science (Chen et al. 2016; Chiang et al. 2014; Hwang et al. 2016; Furió et al. 2013;), physical science (Cai et al. 2016; Enyedy et al. 2012; Zhang et al. 2014), and social science (Chen and Tsai 2012; Efstathiou et al. 2017; Tobar-Muñoz et al. 2017). Likewise, in secondary education AR is also used to teach formal science (Echeverría et al. 2012), natural science (Hsiao et al. 2012; Kamarainen et al. 2013; Ruiz-Ariza et al. 2017), physical science (Bressler and Bodzin 2013; Cai et al. 2014), and social science (Di Serio et al. 2013).

2 Research rationale

According to recent studies, content learnt through AR technologies can benefit students' long-term memory, problem-solving skills, enthusiasm, motivation, and collaborative abilities (Tobar-Muñoz et al. 2017; Hung et al. 2017; Alakärppä et al. 2017), as well as increase learning performance (Wei et al. 2015; Zhang et al. 2014), interaction, and learning satisfaction (Huang et al. 2016; Hsiao et al. 2013). Still, there are researchers who suggest that using AR for educational purposes is still in its scarcity (Akçayir and Akçayir 2017; Koutromanos et al. 2016; Wu et al. 2013). In scoping selected literature for this investigation, many AR studies appeared limited. Recent literature reviews, such as those by Chen et al. (2017) and Akçayır and Akçayır (2017), only considered studies addressing the use of AR technology from K-12 to tertiary education which were published within Social Science Citation Index (SSCI) journals. Both these reviews suggest

that the most reported advantage of AR is that it promotes enhanced learning achievement. Due to the limitations of these reviews, though additional research articles debating the educational impact of AR technologies can be identified through other databases, such as ERIC and ProQuest, or by analysing JCR-SCI journals. When considering articles located in these supplementary databases, some researchers have noted challenges imposed by AR, including usability issues and frequent technical problems. In their study findings, Radu (2014) pointed out that the positive impact of AR included increased content understanding, enhanced learning, improved language association, long-term memory retention, and enriched collaboration and motivation. However, they also claimed a need for further work to determine what types of content can be effectively taught using AR. Santos et al. (2014) based their review on the previous studies published only in the IEEE Xplore and applied a meta- and qualitative analysis in the dimensions of display metaphors, content creation, and evaluation techniques. In another review, Koutromanos et al. (2016) considered literature from 2000 to 2014 using the web databases of ScienceDirect and ERIC to identify the educational use of AR. The outcomes of their review illustrated a set of studies that give evidence of positive outcomes regarding student learning. The same authors provided some notable recommendations, including the need to exemplify the theoretical aspects and characteristics of design frameworks associated with learning through AR, as well as the pedagogical practice within which AR technology can be used.

However, what is clearly missing from the international literature are studies presenting and sufficiently analysing the educational potential and affordances of AR technology combined with GBL in educational settings (Tobar-Muñoz et al. 2017). AR and GBL are a natural assimilation, as AR offers the opportunity to participate in games using real-world learning objects (e.g., maps, books, and tools), thus adding a layer of play to the AR application (Tobar-Muñoz et al. 2017). AR games are also perceived to be more fun and engaging than basic mobile phone games, while they may also have a positive influence on the players' intentions to change behaviours (Juan et al. 2011). There is, therefore, a clear synergy here with AR which supports the notion that the combination of AR and GBL is worth exploring as an approach to learning.

Drawing upon the aforementioned assertions, this systematic review aims to investigate the potential use of ARGBL environments in primary and secondary education by summarising selected studies available in the relevant literature published from 2012 to 2017. The present study follows Wu et al.'s (2013) classifications of instructional approach usage. This decision was based on the fact that there are currently unexplored dimensions which focus on issues regarding the

design and implementation of teaching and learning methods using AR technologies. In addition, the review by Palmarini et al. (2018) points out the need for correlation between AR technologies and their applications in a more systematic way. Furthermore, the exploration will also consider pedagogy suitable for the classroom and extended school learning environments, thus extending the roadmap for further research. Specifically, the goals of this study are as follows:

(a) To provide an overview of the educational use of ARGBL in primary and secondary education, including the kinds of devices used, the digital resources and employed software, what subjects are making use of AR technology, where courses using AR take place, and how the devices are used for teaching and learning.
(b) To present the overall effect on students' learning achievements when ARGBL is integrated into primary and secondary education.
(c) To synthesise the potential teaching and learning advantages and disadvantages of implementing ARGBL within different instructional contexts, based on the analysis of relevant articles.

The current systematic review serves as a useful and timely addition to the existing literature examining the combination of AR technology and game-based learning within compulsory education. The results of this investigation may offer new insights to researchers, and provide educators with inspiration, effective advice, and suggestions on how to incorporate an ARGBL model into their teaching. The reviewed articles suggested that ARGBL applications have clear potential to positively influence students' attendance, engagement, knowledge transfer, skill acquisition, hands-on digital experience, and attitude towards their learning.

Since AR is an emerging technology, it is important to provide an overview of the advances and impact of its use in playful and game-orientated educational settings. Within this context, the research questions addressed by this study are as follows:

RQ1 What are the main game-based learning approaches that students have participated in, with the purpose of improving their learning outcomes?
RQ2 What AR-enabled devices have been used to enhance the game-based learning experience, and in what instructional conditions has this experience taken place?
RQ3 What are the potential benefits and limitations regarding the learning effectiveness of combining AR with game-based applications in primary and secondary education?

3 Methodology

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, and (c) definition of categories for the analysis.
Step 2   *Conducting the review* (a) study selection, (b) data extraction (content analysis methods were applied), (c) data synthesis, and (d) data coding.
Step 3   *Reporting the review* analysis of the results and discussion of the findings, trends, and conclusions regarding the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)" statement (Moher et al. 2009).

To further understand the adopted method choices, the following can be considered:

Step 1(a)   Selection of journals

In this initial step, it was imperative to choose the most relevant journals, i.e., journals that are methodologically strong and scientifically relevant. 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, offering too broad a foundation from which to start the literature search. To review studies of potentially more consistent quality, a list produced from the top journals from the "Educational Technology" category according to the Google Scholar h5-index was initially validated through an iterative double-check process. This feature 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.

The present review also considered the Journal Citation Reports Science Citation Index Expanded (JCR-SCI), and the same process with the iterative double check for the JCR-SSCI journal was repeated. All international journals, whose articles were accepted in this review, have impact factors ranging from 0.576 to 3.819 according to 2016 data metrics as defined by Thomson Reuters Journal Citation Reports (2017). The fact that important journals within their field publish articles on ARGBL is an indication that this emerging approach to learning is of great interest to

researchers and educators who aspire to enrich their students' experience.

To study the educational potential of the reviewed studies, the following categories should be identified:

(a) Instructional design methods or models based on theoretical foundations, and research methodologies that measured the successful implementation of learning objectives using AR applications.
(b) The purpose of these studies and their scientific construction and understanding of knowledge.
(c) The effect and/or effectiveness the AR technology had on student engagement following different teaching approaches.
(d) The learning gain in different educational subjects.
(e) The students' performance and the impact of using AR with game-based conditions on their learning outcomes.

For quality purposes, preference was given to 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 (Punch 1998). For an experiment to be classified as a valid experimental design, the following criteria must be fulfilled (Russell and 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.

The selected reviewed papers for qualitative analysis were chosen as having purposeful sampling based on a conscious selection of a small number of data sources. They also evidenced the logical reasoning and power of purposeful sampling in selecting information-rich cases (participants or settings) leading to an in-depth study that illuminates the questions of interest, covering a wide range of potentially relevant social phenomena and perspectives. Finally, they provided a descriptive analysis of methods exploring new cases or perspectives, which may lead to future-driven uses of ARGBL.

4 Data analysis

4.1 Coding of papers

The twenty-one ($n = 21$) articles meeting the inclusion criteria of this review were coded after considering the previous studies (Akçayir and Akçayir 2017; Koutromanos et al. 2016), which categorised games and their outcomes and impacts in relation to several dimensions.

4.2 Categorisation of games

Games were categorised according to the following:

(a) the aim of the game and whether it was originally designed to combine entertainment with learning;
(b) the learning subject/topic that each game addressed, e.g., science, maths, language, etc;
(c) the platform/computing devices that users played the game on, e.g., video consoles, personal computers, smartphones, tablets, etc.

4.3 The categorisation of the ARGBL effect

The current study focused on the positive impact of ARGBL on the learning experience. The categories used to analyse this impact were as follows:

(a) Learning outcomes relating to ARGBL, which resulted in knowledge acquisition or content understanding of specific learning subjects, skill gaining, and achievements.
(b) Assessment processes for specific subjects or other measurements of psychological issues, which affected students' outcomes, performance, and achievements in specific learning objectives.
(c) The effect of ARGBL is examined regarding the learning subjects' scope in playing and using a specific game.

4.4 Coding of methods

The articles that have been included in the present systematic review were coded based on the following methodological dimensions:

(a) Study design and type of used methodology (quantitative, qualitative, or mixed). The design of each study was further coded according to whether it used a true experimental design, a quasi-experimental design, a comparative study, or a qualitative research design;

(b) Data collection and analysis: studies were coded according to the methods used to collect data and the reliability and validity of these data collection tools;

(c) Results and conclusions presented a summary of the most significant findings from each study.

4.5 Quality of the studies

Every reviewed paper was read and was selected for inclusion in the study based on the following criteria:

1. the appropriateness of the research design for addressing the question/sub-questions of this review (with a higher weighting for the inclusion of a control group);
2. the appropriateness of both the research methods and the analysis of the study results;
3. the adequacy of each one of the study's research questions;
4. the alignment of the study findings with the research question(s).

The total weight of evidence for each paper was calculated by adding the scores on each of the aforementioned criteria.

4.6 Inter-rater reliability

To assess inter-rater reliability with respect to the quality coding of the papers, a sub-sample of 7 of the 21 papers (33.3%) was coded independently by two of the review's authors. The inter-rater reliability (r) for the total scores was 0.89, showing good agreement between the two authors for the quality of the selected papers.

4.7 Search strategy and development of a search protocol

The electronic databases which were searched in this review included those identified as relevant to education, information technology, and social science. These searched databases were from SCOPUS, ScienceDirect, ESCBO, JSTOR, ERIC, Web of Science, and Wiley (see "Appendix"). Web searches were conducted using Google Scholar as a search engine. Branching searches were performed using forward and backward search procedures from the reference lists of the previous literature reviews that were consulted at earlier stages of this study (e.g., Akçayir and Akçayir 2017; Chen et al. 2017; Koutromanos et al. 2016).

4.8 Search terms

The search terms (keywords) that were used for the purposes of this study included terms for games in conjunction with terms for possible outcomes, impacts, or effects of playing games for learning. Several search terms helped the authors to determine the scope of the definition of digital games, since many of the terms include the word "game" such as "computer game", "video game", "simulation game", and "game-based learning". More specific terms were also included such as "augmented reality game-based", "augmented reality games", and "AR", along with terms about learning, e.g., "learning" and "education". The table in the "Appendix" shows the search protocol that was followed for each database.

Step 1(b)   Inclusion and exclusion criteria

In regard to the research questions, the following general criteria, which defined the time frame and the type of relevant studies, were agreed upon:

General criteria

(a) Studies published between 2012 and 2017.
(b) Studies describing applications or frameworks for ARGBL in primary and secondary education.
(c) Conceptual articles or studies that provided evidence of educational potential based upon a research method.
(d) Articles whose abstract and full paper were written in English.

Specific criteria

(a) Studies reporting the advantages, disadvantages, instructional affordances, and/or effectiveness of ARGBL across various primary and secondary education subjects.
(b) Studies describing applications that considered user models and/or adaptive processes combined with ARGBL.
(c) Studies describing applications of ARGBL in primary and secondary education for students in the context of diversity.
(d) Studies presenting evaluation methods for ARGBL in various educational scenarios.

Exclusion criteria

(a) Studies not identified as "articles" in the selected journals (e.g., books, book reviews/chapters, colloquiums, editorial publication information, etc.).
(b) Studies that either mentioned the term "AR" but were on an unrelated topic to game-based learning or men-

tioned the term "game-based learning" but were on an unrelated topic to AR.

(c) Studies that did not provide sufficient data for effect size calculation or did not have clear summarisation or aggregative findings from their qualitative data.

(d) Articles that did not present data from evaluations or did not follow well-structured research methods (case studies, empirical etc.).

(e) Articles that were not written in English.

(f) Articles published before 2007 or after the third quarter of 2017.

(g) Studies that focused on the use of mixed or virtual reality instead of AR.

Step 1(c) Categories for analysis and data coding

In this stage, a group of analysis categories were defined for each research question. This categorisation assisted the 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:

RQ1 What are the main game-based learning approaches that students participated with the purpose of improving their learning outcomes?

This review considers the type of game-based approaches, instructional methods, forms of assessment, and types of user modelling that were used in each study.

RQ2 What AR-enabled devices have been used to enhance the game-based learning experience, and in what instructional conditions have this experience taken place?

This review considers the type of devices used (e.g., tablets, smartphones, PCs, and wearable devices) and the environments where each study took place (e.g., in-class, during field trips, outdoors, etc.)

RQ3 What are the potential benefits and limitations regarding the learning effectiveness of AR with game-based applications in primary and secondary education?

This review 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.

The content analysis allowed research trends of a topic to be identified by grouping papers together according to their shared characteristics. The studies were manually coded separately according to their key characteristics, and were

Table 1 Number of ARGBL studies for primary education published in international journals (2012–2017)

	JCR-SSCI journal (publishers)	Analysed studies (2012–2017)	Impact factor (2016)
1	Computers & Education (Elsevier)	3	3.819
2	Interactive Learning Environments (Taylor & Francis)	3	1.674
3	Journal of Computer-Assisted Learning (Wiley)	1	1.253
4	Journal of Educational Computing Research (SAGE)	1	1.179
5	International Journal of Computer-Supported Collaborative Learning (Springer)	1	3.469
6	Educational Technology Research and Development (Springer)	1	0.725
7	Journal of Science Education and Technology (Springer)	1	1.080
8	The Asia-Pacific Education Researcher (Springer)	1	0.576
9	International Journal of Science and Mathematics Education (Springer)	1	1.474
10	Journal of Educational Technology & Society (Online)	1	1.584

Table 2 Number of ARGBL studies for secondary education published in international journals (2012–2017)

	JCR-SSCI journal (publishers)	Analysed studies (2012–2017)	Impact factor (2016)
1	Computers & Education (Elsevier)	3	3.819
2	Computers in Human Behaviour (Elsevier)	2	3.435
3	Interactive Learning Environments (Taylor & Francis)	1	1.674
4	Journal of Computer-Assisted Learning (Wiley)	1	1.253

classified according to the categories and sub-categories defined above.

5 Analysis of relevant literature

Table 1 presents ten journals associated with the JCR-SSCI list that contained a total of 14 articles selected for this study, which discussed game-based learning with AR technologies in primary education. Similarly, Table 2 presents four journals which contained a total of seven articles discussing ARGBL in secondary education. While the number of articles may appear limited, an analysis of the publication year of each article shows that the number of published studies relating to ARGBL in primary and secondary education has progressively increased year-by-year, particularly during the last 2 years. These results make clear that ARGBL in education is an emerging topic, corroborating the opinions of the previous studies (Chen and Tsai 2012; Wu et al. 2013), who pointed out that research into ARGBL in education is still in its early stages.

The coding scheme of the reviewed papers

A coding scheme with the main criteria for each article is provided. The latter are as follows:

(a) the instructional design method that was implemented;
(b) the characteristics of the AR technologies that were used;
(c) the theoretical underpinnings (based on contemporary learning theories) that were followed;
(d) the instructional design format that was used to improve the learning experience.

Figure 1 presents a flowchart of the article selection process that was followed using guidelines from Liberati et al. (2009).

The first author of this study conducted all the content analysis results. The data were validated by the other three authors who are experienced researchers in informatics and education. They conducted the screening tasks and discussed with the first author the overall decisions based on the prescribed selection rules. All authors read the full text of each article, following the coding scheme of Fig. 2, to decide if it could be included in this review.

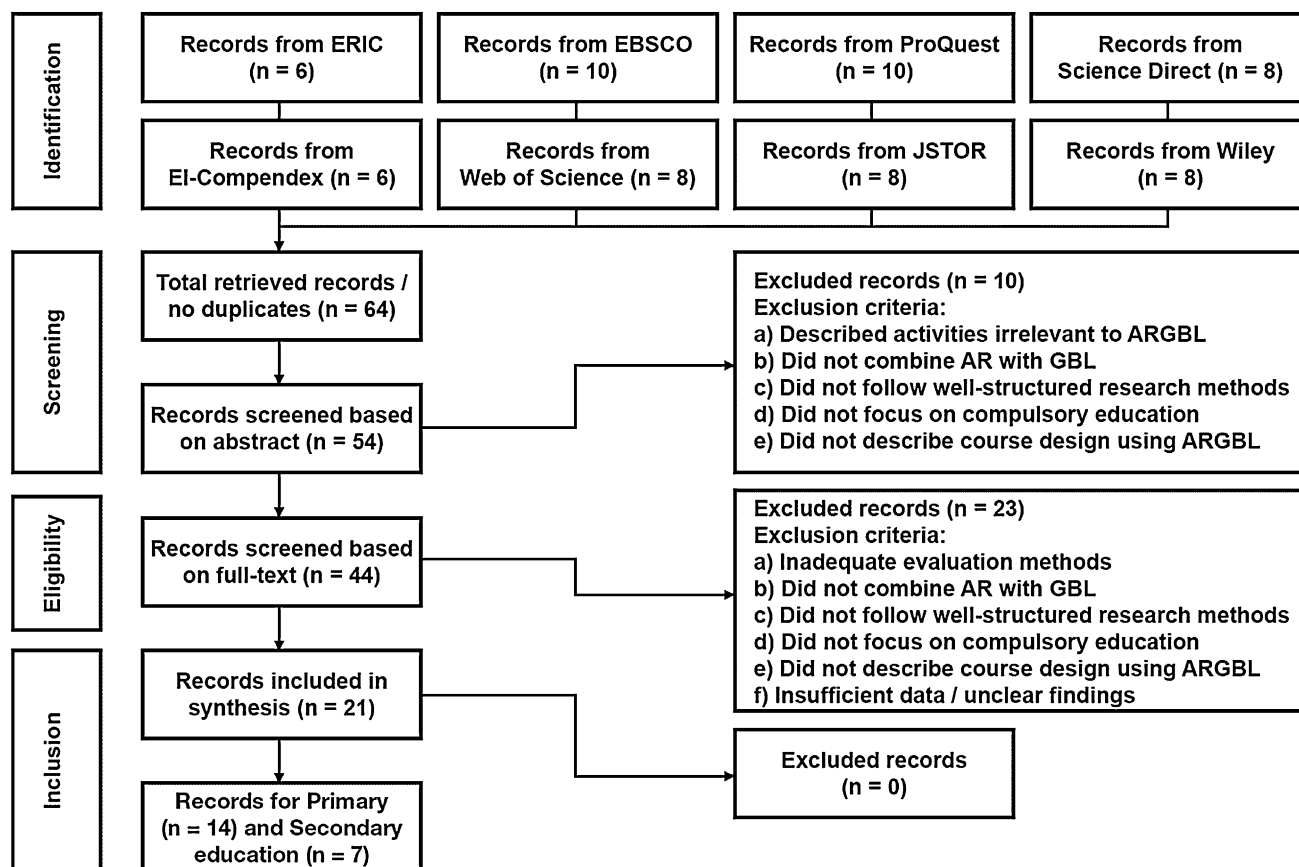Data collection and content analysis tool

Fig. 1 Flowchart for article selection process associated with publications of ARGBL in primary and secondary education
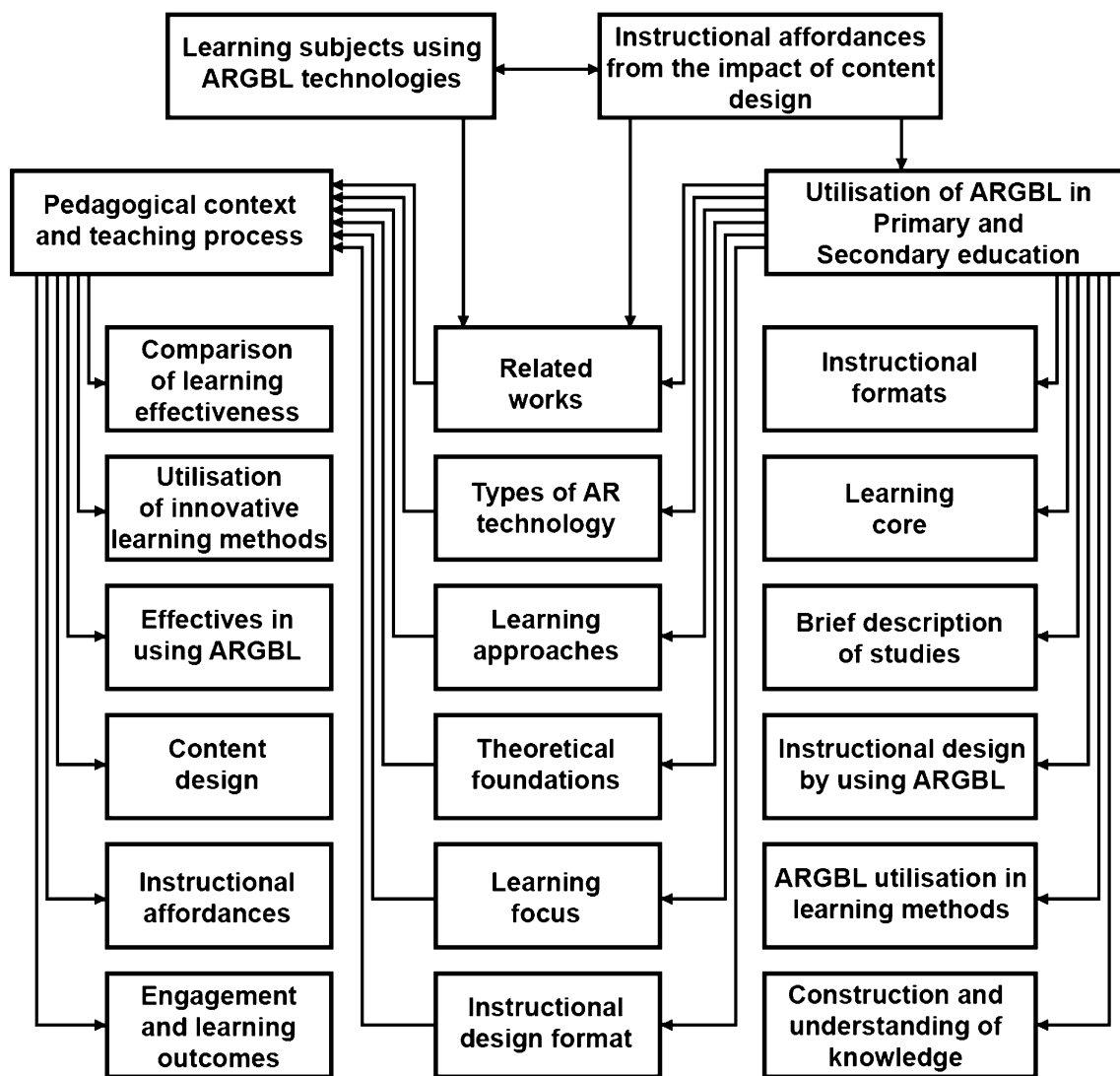
Fig. 2 Coding scheme of the reviewed papers

Nvivo (ver. 10) software was used to perform a content analysis of the reviewed studies to process and analyse the data and assess the reliability of the results.

6 Results

This section describes and discusses the results of the conducted review. In *Step* 2(a), as described in the Sect. 3, a manual search was conducted in the selected journals. The inclusion and exclusion criteria were applied to select the studies for the review, leading to a selection of 21 journal studies in total. *Step* 2(b) and *Step* 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 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. As the process was inductive, there were no initial themes assigned to the data. A synopsis of the game-based instructional and learning approaches, as well as the results and most crucial observations for each reviewed study, appear in Tables 3 (primary education) and 4 (secondary education), respectively.

As shown in Table 5, an interesting result that emerged from the data is that the majority of the studies were applied to Science, Technology, Engineering, and Mathematics (STEM) subjects. More specifically, 28.6% of ARGBL experiences in primary education covered formal science topics (Atwood-Blaine and Huffman 2017; Hung et al. 2017;

Table 3 General overview of ARGBL studies in primary education

Research studies	Game-based instructional and learning approaches	Study results and observations
Atwood-Blaine and Huffman (2017)	Location-based ARGBL during a field trip to a science centre	Female students outperformed male on every measure of the iPad game achievement
		Females were more goal-oriented, persistent in the face of difficulty, and appreciative of the collaborative challenge, while males enjoyed the fun and competitive aspect
Efstathiou et al. (2017)	Inquiry-based learning using a location-based AR game during a field trip to an archaeological site	Students who employed the AR application outperformed the students of the traditional field trip
Hung et al. (2017)	Digital game-based learning and an AR educational book	AR improved students' learning performances to a similar extent as conventional teaching material, such as picture books and physical interactions
Tobar-Muñoz et al. (2017)	ARGBL in a naturalistic environment using AR to promote reading comprehension	Increased motivation and interest in problem-solving, exploration, and socialisation behaviour
Cai et al. (2016)	Team-based inquiry-based learning in a problem-based explorative mode with AR motion-sensing learning technology	A better understanding of magnetic fields
		Increased motivation and interest which encouraged students to learn more actively and extensively
Chen et al. (2016)	A Concept Mapped AR Learning system (which used a concept map as its learning structure); Standard AR Learning system (which used a book as its learning structure)	Students achieved better learning outcomes, increased their learning motivation, and improved their learning attitudes
Hwang et al. (2016)	Location-based ARGBL during a field trip to a butterfly garden	The ARGBL approach improved both the students' learning attitudes and their learning performance at the field trip
Laine et al. (2016)	Context-aware storytelling and science learning games	Students appreciated geometry following ARGBL input
		The game has the potential for affecting the players' attitudes towards mathematics
Chiang et al. (2014)	Inquiry-based mobile learning approach compared to AR-based mobile learning approach	Better learning achievements and significantly higher motivations relating to attention, confidence, and relevance for students who followed the AR-based mobile learning approach
Zhang et al. (2014)	Interactive learning in an outdoor/indoor location using a mobile AR astronomy simulation software	MDAS system enhanced students' learning of astronomical observation content and their performance of astronomical observation skills
		Increased student interest in astronomical observations and learning, which had a substantial effect on retention
Furió et al. (2013)	Mobile game using multiple interaction forms (touch-screen interaction, and accelerometer) and a combination of AR with non-AR mini-games	Students showed significant learning gains after the intervention
		Weight and size of the device do not have an impact on learning outcomes, satisfaction, engagement, interaction, and AR experience
Hsiao et al. (2013)	Inquiry-based learning through a manipulative AR system	Greater positive impact on the students' academic achievement, satisfaction and motivation compared to the use of multimedia teaching resources installed on a tablet
Chen and Tsai (2012)	Digital game-based learning using an educational AR system based on situated learning theory to enhance library instruction	Learning performance of students provided more benefits in terms of library skills of application and comprehension
		Students' gender or gaming skills do not affect learning performance
Enyedy et al. (2012)	Computer-supported collaborative learning for physics through Play Project (LPP)	Students developed a better conceptual understanding of force, net force, friction and two-dimensional motion after participating in the LPP curriculum

Table 4 General overview of ARGBL studies in secondary education

Research studies	Game-based instructional and learning approaches	Study results and observations
Ruiz-Ariza et al. (2017)	Location-based ARGBL (Pokémon *GO*) using Smartphone GPS	Pokémon *GO* significantly increased players' selective attention, concentration levels, and sociability levels Pokémon *GO* could be used from schools and families to raise daily physical activity
Cai et al. (2014)	Inquiry-based experiments using marker-based AR to control combine and interact with a 3D model of micro-particles	AR tools can be used as supplemental learning material AR tools are more effective for low-achieving students Students' learning attitudes are positively correlated with their evaluation of the software
Bressler and Bodzin (2013)	Forensic science mystery game played on mobile devices	Students' flow experience features included a flash of intensity, a sense of discovery and the desire for higher performance Potential for mobile AR science games to increase science interest and improve collaboration skills
Kamarainen et al. (2013)	Location-based AR inquiry-based learning during a field trip to a local pond environment	Positive effect on students' motivation and engagement during the AR learning experience Students achieved a better learning gain
Di Serio et al. (2013)	Study of Renaissance art masterpieces through the presentation of their images and explanation of their relevant details with AR using Popcode or slides	Motivational factors of attention and satisfaction in ARGBL were better rated than those of a slide-based environment Attention and confidence factors were best rated when the impact of the AR system was analysed in isolation
Echeverría et al. (2012)	Co-located collaborative games in the classroom using AR and multiple-mice technology to teach electrostatics	Students significantly increased their conceptual understanding of electrostatics with both platforms AR version of the game was considerably costlier to deploy Boys performed significantly better than girls
Hsiao et al. (2012)	Ecosystems AR Learning System (EARLS) with "Learning" (AR-enhanced text-books) and "Games" (stimulates interaction through learners' body movements to increase physical exercise) sections	Learning while exercising is equally effective with EARLS, keyboard/mouse-based computer-assisted instruction and traditional learning EARLS users earned extra exercise without diminishing the quality of learning achievement, were more interested and motivated, and showed less anxiety

Table 5 ARGBL uses according to academic discipline

	Number of studies	Percentage (%)
Primary education		
Formal science	4	28.6
Natural science	4	28.6
Physical science	3	21.4
Social science	3	21.4
Secondary education		
Formal science	1	14.3
Natural science	3	42.8
Physical science	2	28.6
Social science	1	14.3

Table 6 Research methods applied

	Number of studies	Percentage (%)
Primary education		
Experimental-comparative method	2	14.3
Quasi-experimental	4	28.6
Mixed methods	8	57.1
Secondary education		
Experimental-comparative method	4	57.1
Quasi-experimental	0	0.0
Mixed methods	3	42.9

Laine et al. 2016; Hsiao et al. 2013), 28.6% were about natural science (Chen et al. 2016; Hwang et al. 2016; Chiang et al. 2014; Furió et al. 2013), 21.4% about physical science (Cai et al. 2016; Zhang et al. 2014; Enyedy et al. 2012), and 21.4% covered social science topics (Chen and Tsai 2012; Efstathiou et al. 2017; Tobar-Muñoz et al. 2017).

Likewise, 42.8% of ARGBL approaches in secondary education employed ARGBL to enhance instructional settings of natural science topics (Hsiao et al. 2012; Kamarainen et al. 2013; Ruiz-Ariza et al. 2017), 28.6%

covered physical science (Cai et al. 2014; Bressler and Bodzin 2013), 14.3% were about formal science (Echeverría et al. 2012), and 14.3% addressed social science topics (Di Serio et al. 2013).

A possible explanation to why ARGBL seems more suitable for teaching Science and other STEM subjects might be the fact that it offers the ability to bring to life invisible, abstract, and complex concepts. Students do not have to rely only on their imagination to envision what is happening (Bacca et al. 2014), because AR can augment the physical world by computer-generated perceptual information and integrate immersive sensations that are perceived as natural parts of the real-world environment.

Table 6 shows the research methods that were applied to the reviewed studies. A crucial observation is that several studies used medium-sized research samples (between 30 and 200 participants) and employed mixed methods to collect quantitative and qualitative data. The most prevalent data collection methods were questionnaires, interviews, and surveys. More specifically, in primary education, eight studies (57.1%) followed mixed research methods and presented results from quantitative and qualitative data (Efstathiou et al. 2017; Hung et al. 2017; Cai et al. 2016; Hsiao et al. 2013; Hwang et al. 2016; Laine et al. 2016; Furió et al. 2013; Enyedy et al. 2012;); 4 used quasi-experimental studies (Atwood-Blaine and Huffman 2017; Chen et al. 2016; Tobar-Muñoz et al. 2017; Zhang et al. 2014), and two (14.3%) presented quantitative data based on experimental-comparative methods (Chiang et al. 2014; Chen and Tsai 2012).

Likewise, four studies (Cai et al. 2014; Di Serio et al. 2013; Echeverría et al. 2012; Ruiz-Ariza et al. 2017) in secondary education presented quantitative data from an experimental-comparative study (57.1%). In addition, three studies (Bressler and Bodzin 2013; Hsiao et al. 2012; Kamarainen et al. 2013) used mixed methods research designs (42.9%), while no study followed a quasi-experimental approach.

Table 7 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

Table 7 Effectiveness of using ARGBL in compulsory educational settings

	Number of studies	Percentage (%)
Primary education		
Better learning performance and/or learning gains	7	50.0
Student motivation and engagement	3	21.4
Students' positive perceptions and attitudes	2	14.3
Student interaction/socialisation/collaboration	2	14.3
Secondary education		
Better learning performance and/or learning gains	4	57.1
Student motivation and engagement	2	28.6
Students' positive perceptions and attitudes	1	14.3
Student interaction/socialisation/collaboration	1	14.3

also fulfill more than one sub-category. The majority of primary education studies (50%) reported that AR applications combined with game-based learning led to "better learning performance and/or learning gains" in educational settings. In addition, 21.4% of studies suggest increases in "student motivation and engagement", and 14.3% articulate improvements in both "students' positive perception and attitudes" and "student interaction/socialisation/collaboration". Similar findings came from secondary education, with 57.1% of studies reporting "better learning performance and/or learning gains". 28.6% identify an increase in "student motivation and engagement", 14.3% an increase in "students' positive attitudes", and 14.3% an increase in "student interaction/socialisation/collaboration".

This review considered three types of AR according to the classification from Chen and Tsai (2012): marker-based, markerless, and location-based. Marker-based AR (also called image recognition) uses a camera and some type of visual marker that triggers an event when sensed by a reader (e.g., display a 3D image spatially aligned with the marker's position). Typical markers include a QR/2D code or labels containing a coloured or black and white pattern that is easily recognised or registered by the AR application. Markerless AR uses sensors in devices to accurately

detect the real-world environment, such as the locations of walls and points of intersections, allowing users to place virtual objects into a real context without needing to read an image. Finally, location-based AR uses a GPS, digital compass, velocity meter, or accelerometer which is embedded in the device to provide data based on the user's geographical location.

Results in Table 8 reveal that the majority of the reviewed studies used marker-based AR (50% in primary and 75% in secondary education), 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 markerless tracking techniques currently available. Implementation of marker-based AR is also relatively easier due to the availability of several libraries which support the development process (Bacca et al. 2014). The use of static markers decreases the required tracking work and reduces the number of objects that need to be detected (Chen and Tsai 2012). Therefore, using markers for educational purposes is recommended for providing students with a better learning experience until superior, cost-effective, and more reliable techniques for tracking are developed for markerless AR. Although the latter has not been widely used in educational settings (21.4% in primary and 14.3% in secondary education), Microsoft Kinect sensors and similar technologies have been used for AR educational applications (Cai et al. 2016; Squire and Jan 2007). This is of great importance, because they appear to provide some advantages in tracking and registering objects with markerless AR. Finally, location-based AR applications are gaining momentum, possibly due to the availability of sensors in mainstream mobile devices that allow users' location and geographical position to inform the AR experience.

Results in Table 9 unveil that the devices used for ARGBL activities are primarily smartphones, tablets, and computers with video cameras. Mobility seems to be a key point, as 64.2% of studies in primary education utilised either tablets (Atwood-Blaine and Huffman 2017; Efstathiou et al. 2017;

Table 8 Types of AR applied in compulsory education

	Number of studies	Percentage (%)
Primary education		
Marker-based AR	7	50.0
Markerless AR	3	21.4
Location-based AR	3	21.4
Not specified in the study	1	7.2
Secondary education		
Marker-based AR	5	71.4
Markerless AR	1	14.3
Location-based AR	1	14.3

Table 9 Instructional settings and devices used in ARGBL

	Number of studies	Percentage (%)
Primary education		
Tablets	5	35.7
Smartphones	4	28.5
Computer (laptop/desktop) combined with a video camera	4	28.5
Motion-sensing input devices (e.g., Microsoft Kinect)	1	7.3
Secondary education		
Tablets	0	0.0
Smartphones	3	42.9
Computer (laptop/desktop) combined with a video camera	4	57.1
Motion-sensing input devices (e.g., Microsoft Kinect)	0	0.0

Tobar-Muñoz et al. 2017; Chen et al. 2016; Chiang et al. 2014) or smartphones (Hwang et al. 2016; Laine et al. 2016; Zhang et al. 2014; Furió et al. 2013) instead of computers with cameras. A possible explanation for this might be that the majority of the reviewed studies covered Natural Science and took place outside of the conventional classroom or during a field trip, where mobile devices are more convenient. On the other hand, computers with cameras are more extensively used in secondary education (57.1%). This could be attributed to the fact that field trips are less frequent in secondary education, which could possibly explain why most of the reviewed studies took place in the classroom, where mobility is less of an issue. It remains to be seen whether new sophisticated technologies such as smart glasses, which have yet to reach the mainstream, are going to change the field of ARGBL and become the dominant technologies in the future.

Table 10 presents the data collected on the limitations of ARGBL 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)" (35.7% in primary and 42.9% in secondary education). Students may feel frustrated if the application does not 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. As both easy-to-use and intuitive user interfaces (UI) are also instrumental for a rewarding AR experience, it is imperative that usable UI specifically tailored for young audiences are developed.

Another reported limitation was that "students paid too much attention to virtual information" (21.4% in primary and 28.5% in secondary education) due to the novelty of this technology, which may cause loss of interest when the novelty factor wears off. This can occur, because "complex AR systems may have a modest learning curve" (14.3% in both primary and secondary education). Other reported limitations include "too short periods of assessment to measure student learning performance" (14.3% in primary education) and the fact that "teachers need to develop additional learning material exclusive to the AR needs" (14.3% in both primary and secondary education). Therefore, before major progress in the ARGBL area can be achieved, guidelines for designing usable AR-based educational experiences for a variety of subjects must be developed. Since teaching quality significantly affects student attention, the learning material should be clear, understandable, comprehensive, and relevant to the learning objectives. Case studies focusing on learning and teaching catering to the needs of specific teaching topics/themes would help to identify the most suitable elements to focus on. These should be accompanied by further research in the development of intuitive and user-friendly AR authoring tools that do not rely heavily on programming so that teachers can create their AR content more easily.

7 Conclusions and discussion

The educational potential of AR technology is significant, because of the benefits that influence the students' cognitive acceleration, the increase to their self-management, and the enhancement to their engagement in practice-based activities. Specifically, ARGBL can be useful for educators to recognise the educational potential and affordances in their different disciplines. Researchers seem to have taken notice, as the published studies about ARGBL in primary education particularly have been significantly increased in the

Table 10 Limitations of ARGBL in educational settings

	Number of studies	Percentage (%)
Primary education		
Teachers cannot manipulate the same system for different educational subjects (lack of interdisciplinary programs)	5	35.7
Students paid too much attention to virtual information (novelty factor)	3	21.4
Teachers need to develop additional learning material exclusive to the AR needs	2	14.3
Complex AR systems may have a modest learning curve	2	14.3
Too short periods of assessment to measure student learning performance	2	14.3
Secondary education		
Teachers cannot manipulate the same system for different educational subjects (lack of interdisciplinary programs)	3	42.9
Students paid too much attention to virtual information (novelty factor)	2	28.5
Teachers need to develop additional learning material exclusive to the AR needs	1	14.3
Complex AR systems may have a modest learning curve	1	14.3

last couple of years, with almost 65% (9 out of 14) of the reviewed studies having been published after 2016. Therefore, this systematic literature review intends to contribute to an educational design by providing evidence of ARGBL applications' potential to support teaching and learning across different disciplines in primary and secondary education. It also aspires to assist and inspire researchers and educators towards adopting AR technologies in their practice. To summarise, the main findings of this review are as follows.

GBL approaches in the reviewed studies varied, but often included location-based ARGBL (e.g., Atwood-Blaine and Huffman 2017; Kamarainen et al. 2013). Other cases encompassed the narrative aspect of the game and the way AR could support this (e.g., Laine et al. 2016; Bressler and Bodzin 2013). In regard to the disciplines where ARGBL was applied the most in primary and secondary education, STEM led the way. ARGBL is suitable for teaching Science and other STEM subjects, as it offers the ability to bring to life invisible, abstract, and complex concepts. This can be seen through 3D or other visual scientific phenomena that could not be observed without a specialised approach such as AR. Social science fields, including history, archaeology, linguistics, and geography, as well as arts and tourism can become more engaging if AR is combined with geolocation to provide location-triggered contextual information to students. For example, an interactive scavenger hunt or a guided historic tour is activity that can facilitate problem-solving, inquiry/discovery learning, and "augmented" interaction with the real world, thus impacting greatly the learning experience of students. In addition, 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. Nevertheless, more cases studies are required to understand how to design ARGBL experiences for different topics according to the skills of learners.

Marker-based AR is the most commonly used type of AR in primary and secondary education, followed closely by location-based AR, owing to the availability of sensors in mobile devices such as gyroscopes, accelerometers, and GPS (Chen and Tsai 2012; Huang et al. 2016). This might change in the near future though, as in 2017 companies such as Apple and Google launched their own smartphone-driven AR platforms, ARKit and ARCore, which will potentially make for easier and better implementation of markerless applications. In addition, Microsoft, Google, Intel, Vuzix, Magic Leap, and others have been working to bring AR to the consumer in eyeglass form (Rauschnabel 2018). Consequently, it is safe to conclude that, over the next years, markerless AR will be the mainstream of this technology along with location-based applications.

The technologies used in the reviewed studies include tablets (e.g., Efstathiou et al. 2017; Atwood-Blaine and Huffman 2017; Echeverría et al. 2012), mobile phones (Hwang et al. 2016; Zhang et al. 2014; Bressler and Bodzin 2013; Kamarainen et al. 2013), computers with webcams (Di Serio et al. 2013; Hsiao et al. 2012), ceiling-mounted cameras, AR-enhanced books, and AR-manipulated weather stations. All these different technologies suggest a broad and diverse consideration of AR within GBL pedagogy, but if smart glasses become a success in the near future, the potential for education is mind-blowing. Experimentation and simulation tools can potentially become the next big thing for ARGBL applications, since they provide a more realistic and interactive environment for students.

From an instructional design perspective, this study suggests that interactive learning challenges using AR technology can be designed to support different activity and pedagogy in various places and learning spaces such as the classroom, field trips, and the wider school environment (both indoor and outdoor). Motivation and enrichment of the learning experience appear to be the two pillars of ARGBL, which can lead to clear enjoyment, knowledge gain, augmented interaction, increased engagement, and enhanced collaboration (e.g., Atwood-Blaine and Huffman 2017; Ruiz-Ariza et al. 2017; Echeverría et al. 2012). With the use of AR technology, students can improve their learning performance (Efstathiou et al. 2017; Hung et al. 2017; Hwang et al. 2016; Chen and Tsai 2012; Enyedy et al. 2012), show increased motivation (Tobar-Muñoz et al. 2017; Di Serio et al. 2013), or achieve both (Cai et al. 2016; Chen et al. 2016; Hsiao et al. 2013; Chiang et al. 2014, Kamarainen et al. 2013), partly due to improved positive attitudes towards the learning process. However, the majority of the reviewed studies came to these positive findings after comparing their ARGBL approach to the traditional learning (Atwood-Blaine and Huffman 2017; Ruiz-Ariza et al. 2017; Chen and Tsai 2012; Hsiao et al. 2012); only a few studies compared it to mobile GBL (Furió et al. 2013; Hsiao et al. 2013), inquiry-based mobile learning (Chiang et al. 2014), or VR-based applications (Furió et al. 2013). This lack of data creates difficulty in identifying whether the benefits of the learning experience were due to specific GBL approaches, the use of AR technologies, or the combination of both.

Teachers who may find ARGBL integration within their lessons more challenging are those who may not be very experienced in the use of mobile devices in educational settings. When designed with the pedagogies of learning in mind, such technological approaches should support collaborative knowledge-based engagement and enable co-constructed knowledge to occur in the class environment. In addition, a substantial body of contemporary research (Efstathiou et al. 2017; Chen and Tsai 2012; Wu et al. 2013) has reported that there is also a need for learning theories to inform the teaching

methods. Suggested theories to consider while creating interactive ARGBL experiences include Constructionism and Activity Theory. This research also highlights important practical implications, especially for developers and teachers who want to use ARGBL applications in their classes. There is a need for new methods for creating interactive 3D content for AR learning environments (Bacca et al. 2014; Chang et al. 2014a, b, c). The development of AR authoring tools that require a limited amount of coding could potentially allow teachers with limited technical skills to create content capable of facilitating and enhancing the learning process. Further research is also required on improving the user experience and knowledge construction processes in ARGBL applications to drive the students' learning forward. This means that educators and AR game designers need to understand how to create AR learning

experiences tailored to the topic being taught, while also taking into consideration the skill set of the learners. Arguably, AR has the potential to reduce the financial cost of implementing learning activities which involve technological tools to support student engagement. Nevertheless, unless there is a shift in the quality culture of educational institutions which will value or reward teaching innovation, teachers will probably remain reluctant to adopt ARGBL, as this will add to the already heavy workload which they have to endure.

The present systematic review underlines specific educational areas in primary and secondary education where the application of AR game-based approaches has not yet been investigated. Further research is still required into different facets of game-based AR applications, including the development of theoretical frameworks and evaluation methods to

Table 11 Specific protocol executed in each database

Database	Protocol	Note
JSTOR	(((((learn or learning or engagement or learning outcomes) < in > ab) < and > ((Augmented reality or Augmented reality games or Augmented reality game-based learning) < in > ab)) < in > ab) < and > ((qualitative or quantitative)) < and > ((school or K-12) < in > ab)) < and > (pyr > O 2000 < and > pyr < O 2012)	Search on the field "Abstract"
SCOPUS	ab: ((teaching or learning or education or educational) and (Augmented reality games or Augmented reality game-based learning) and (middle school or primary or secondary)) Content type > journal articles Publication date > between Saturday, January 01, 2012 and Thursday, September 30, 2017	Search on the fields "Abstract", "Title" and "Keywords"
ScienceDirect	(learning OR teach OR learn OR education OR educational) < in > Smart Search AND (Augmented reality game-based learning or Augmented reality game-based learning) < in > Smart Search AND (primary OR secondary OR K-12) < in > Smart Search AND Date: between 2012 and 2017 AND Limited to: PEER_REVIEWED In education full text	Search on the field "Abstract" Term K-12 replaced by high school or middle school by restriction of the database Terms "teach" and "learn" suppressed limiting quantity of terms used to search the database. Variations to the terms removed were used and can be identified that did not compromise the result
ESCBO	Publication type: "Journal Articles" and full-text available	Search on the field "Keywords (all fields)"
ERIC	(Publication date: 2012–2017) ((Keywords: teaching OR Keywords: teach OR Keywords: learn OR Keywords: learning OR Keywords: education OR Keywords: educational) and (Keywords: Augmented reality OR Keywords: Augmented reality OR Keywords: 3 Augmented reality games OR Keywords: games and Augmented reality OR Keywords: qualitative and quantitative research method OR Keywords: K-12)	Search on the field "Keywords (all fields)"
Wiley	((learning or engagement or educational) < in > ab) < and > ((augmented reality or AR environments) < in > ab)) < and > ((primary or secondary or Higher education) < in > ab)) < and > (pyr > O 2000 < and > pyr < O 2013)	Search on the field "Abstract"
Web of Science	((learning or K-12 education) < in > ab) < and > ((augmented reality game-based learning) < in > ab)) < and > ((primary or secondary) < in > ab)) < and > (pyr > O 2000 < and > pyr < O 2013)	Search on the field "Abstract"

help establish the pedagogy of AR game-based applications within primary and secondary school-based classrooms. 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. Finally, there was not identified any system regarding the potential use of AR for GBL to be considered for students with special needs and there is need to be conducted a study about this topic in the future.

Appendix

See Table 11.

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