Augmented Reality (AR) in Biology and Environmental Sciences Education: the State of the Art

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ABSTRACT
Hardware miniaturization and increased computing capacity of great data volumes have made possible for Augmented Reality (AR) to become widespread. In education, AR is establishing new ways of visualizing information, communicating ideas and interacting with peers and subjects. This is particularly important in biology and environmental sciences education to represent *phenomena* not easily observable with the naked eye for its small size or abstract nature and, in some cases, to reduce complexity avoiding cognitive overload. Being an emergent technology, development of educational applications with AR relies greatly on reflection and investigation of ongoing experiences in the frontiers of knowledge. This necessity guided the present study. Our objective was to establish the state of the art in the usage of AR in biology and environmental sciences education. Therefore, we conducted a systematic review, covering a period between the years 2012 and 2017, on CAPES database, on both previous state of the art studies on education (Step 1), as well as experimental or development research (Step 2) on AR in the detailed fields of biology and environmental sciences education (ISCED-F 2013). A total of five and nine articles were selected in steps 1 and 2 respectively. Our findings reveal that although AR has shown to be an effective tool for biology and environmental sciences education, studies on these topics are still scarce, especially on application development.

RESUMO
A miniaturização de *hardwares* e o aumento da capacidade computacional de grandes volumes de dados tornou possível a difusão da Realidade Aumentada (RA). Em educação, RA tem estabelecido novas formas de visualizar informação, comunicar ideias e interagir com pessoas e conteúdo. Isso é particularmente importante na educação em biologia e ciências ambientais para representar fenômenos não facilmente observáveis a olho nu devido a seu tamanho diminuto ou natureza abstrata e, em alguns casos, para reduzir complexidade evitando sobrecarga cognitiva. Sendo uma tecnologia emergente, o desenvolvimento de aplicativos educativos com RA é bastante dependente de reflexões e investigações de experiências em andamento nas fronteiras do conhecimento. Essa necessidade orientou o presente estudo. Nosso objetivo foi estabelecer o estado da arte no uso de RA na educação em biologia e ciências ambientais. Deste modo, foi conduzida uma revisão sistemática, abrangendo os anos de 2012 e 2017, na base de dados da CAPES de pesquisas de estado da arte anteriores em educação (Passo 1) e pesquisas experimentais ou de desenvolvimento (Passo 2) em RA nos campos detalhados da biologia e ciência ambientais (ISCED-F 2013). Um total de cinco e nove artigos foram selecionados nos passos 1 e 2, respectivamente. Nossos achados revelam que apesar da RA ter se mostrado uma ferramenta efetiva para a educação em biologia e ciências ambientais, estudos nestes tópicos são escarços, especialmente no desenvolvimento de aplicativos.

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Categories and Subject Descriptors
[**Computer graphics**]: Graphics systems and interfaces *–Mixed / augmented reality, Graphics input devices, Perception.*

General Terms
Documentation, Performance, Design, Experimentation, Human Factors, Standardization, Theory, Verification.

Keywords
Augmented Reality; Mixed Reality; Education; Biology; Environmental Sciences.

1. INTRODUCTION
Mixed Reality (MR) may be understood as an environment or system which involves the combination of real and virtual elements within a Reality-Virtuality *continuum*. When there is a predominance of the firsts, it is referred to as Augmented Reality (AR) and when the opposite is true, Augmented Virtuality (AV) [29]. Some authors have established additional requirements to that AR definition, which include: real-time interaction [3, 23]; registration (alignment) of real and virtual objects with each other [3]; and possibility of use and operation in a 3D environment [23].

In this paper we refer to AR in the broader sense of an individual experience of reality - constructed by the occurrence of congruencies during nervous system reconfiguration as a result of repeated interactions during lifetime [28] – altered by means of computer generated (CG) information addition or suppression[1]. The crucial point to be made when differentiating AR from AV is

[1] Also referred to as diminished reality.

not if there is a predominance of *real* or *virtual*[2] entities presented in a given moment, but if the overall context of presentation relates mostly to that of everyday experience or to a computer generated scenario. That implies considering individual subjectivity. In an AR Head Mounted Display (HDM) a CG model of a car, for example, may take most or even the totality of the field of view, but if the user is able to recursively analyze the situation and infer it to be projected over a physical substrate, such as his garage floor, which is located inside a house, and so forth, we are talking about AR.

AR experiences are commonly created with apparatus capable of generating sensorial *stimuli* in patterns according to virtual representations – like visual and auditory clues – and present them in concomitance with those originated from real objects. These normally include displays (e.g., HMD, computer, tablets and smartphone screens), input devices (e.g., gloves, cameras), tracking and computational systems [10].

With hardware miniaturization and increased computing capacity of great data volumes, the use of AR has spread thorough many fields of knowledge. Applications include: visualization of inner body structures on site for surgery operations [33] and blood extraction [26]; phobia treatment trough controlled exposure to potentially fear triggering virtual objects [8]; maritime navigation with immersive systems [16]; microscopic inspection with time-lapse imaging [5]; and superimposing relevant information over geographic features as a means to assist maintenance of riverbanks [30].

Notably in education, the use of AR has become more frequent as a new way of formalizing ideas, visualizing, communicating and interacting with people and information [43]. All innovative way of teaching and learning, by its turn, demand investigation work for producing specific materials and means to attend the demands that are presented while being implemented [25].

Many attempts have been made in applying AR to education, in both formal and informal contexts, in different levels and with a variety of subjects. Examples include use for: narrative creations in storytelling activities [41] and library instruction with elementary school students [11]; serious games for cultural heritage education in demonstrations and virtual museums [2]; distance interaction with robots associated to virtual objects in remote laboratories in an electrical engineering course [7].

Particularly relevant to science teaching is the possibility to use AR to represent *phenomena* that cannot be seen with the naked eye, simulate potentially dangerous situations and visualize abstract concepts [39]. Besides the increasing interest for experimenting with AR in science education, the body of knowledge in the field is yet to be consolidated. In general terms, there is a lack of literature reviews in the pedagogical use of AR [1].

That may be a problem for project developments in the area, once this type of study is of the most significance to: summarize empirical evidence of the potential benefits and limitations of specific methods and technologies; identify gaps in current researches to suggest future investigation; as well as providing subsides to position new research activities [24].

It was our objective with this work to shorten that gap. Therefore, we conducted a systematic review as to establish the state of the art in the usage of AR in the detailed fields of biology and environmental sciences education, as described by the International Standard Classification of Education (ISCED) [36, 37, 38]. Our research questions (RQ) were:

RQ1: Are there recent studies in CAPES database about the state of the art in the educational use of AR and do they target the detailed fields of biology or environmental sciences (ISCED-F 2013)?

RQ2: What were the main AR system technologies identified, their applications, audiences, advantages, limitations, challenges and orientations for further research?

RQ3: What are the experimental or development studies in the use of AR in biology or environmental sciences education in CAPES database and the subjects (ISCED-F 2013) targeted?

RQ4: What were the main AR system technologies used, development tools, applications, audiences, place of instruction, advantages, limitations, challenges and orientations for further research?

2. METHOD

We have conducted a systematic review of the literature, understood as "means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest" [24, p.3), using rigorous, reliable and auditable method.

For searching primary studies we've elected CAPES database because of the quality and amplitude of its more than 38 thousand national and international periodical publications, as well as the presence of advanced search tools [9]. The most important tools for our work were: material type selection; search place within articles (title, author, subject or any); choice and combination of terms with logical operators (*and* or *or*); period of publication; language; peer review refinement.

Considering that the first two RQs have a different object then the lasts – namely, previous state of the art researches and experimental or development studies, respectively - we have divided ours into two different steps.

2.1 Step 1

The main purpose of this step was to identify and qualify potentially existing recent state of the art reviews in the educational use of AR in CAPES database.

2.1.1 Search strategy

For targeting state of the art type studies which involved the use of AR, we have created two term groups, as presented in Table 1. The first group consists of the main term *state of the art* and two related ones, to broaden the *spectrum* of possible finds. The second include *augmented reality*, the targeted technology, as well as the higher in hierarchy *mixed reality* and its less known synonym, *blended reality* (BR).

[2] In philosophical terms, not necessarily opposing concepts. Virtual may be understood as a part of reality [14]. In this paper we employ the term in a more common sense to designate entities generated by a computer.

Table 1. Search terms used in Step 1.

Group 1	Group 2
State of the art; Cutting edge; Systematic review	Augmented reality; Mixed reality; Blended reality

Each term in Group 1 was searched in combination with each term in Group 2, both as exact terms and using the logical operator *and*, in a total of nine independent searches. We limited our search to articles revised by peers, as an attempt to find scientific works in the frontiers of science, more adequate to our intents. We used only English words since most scientific studies have a title and abstract in this language. No automatic language filter was placed in search and no restriction was applied concerning the section to be searched within the article.

Since our goal was to find recent studies, we limited our search to those published between January 2012 and 20 September 2017. To restrain the research to those related to education, we further used this topic as a refinement tool for the initial results.

2.1.2 Inclusion and exclusion criteria

Inclusion and exclusion criteria were used to focus the analysis on our intended goals, and are presented as follows:

Inclusion criteria:

- The material includes research question, objectives, methods and results.
- Study focus on the use of AR in education.
- Designed to present a review of literature or experiences.

Exclusion criteria:

- Doesn't include research question, objectives, methods and results.
- The technology in focus does not combine *real* and *virtual* elements.
- Study focus on the use of AR but not education.
- Study focus on education but not AR.
- Does not present a review.

2.1.3 Analysis and data selection

After searching according to our established strategy, titles and abstracts were read and inclusion and exclusion criteria applied. When not enough information was to be found in those, articles were read in whole. To the selected articles, we used the following category for analysis, chosen in the basis of the research questions pertinent to this step.

For RQ1

- Study type
- Fields and detailed fields (if applicable)

For RQ2

- AR system technologies identified
- Applications
- Audiences
- Advantages
- Limitations
- Challenges

2.2 Step 2

The main purpose of this step was to identify and qualify experimental or development researches in biology and environmental sciences education in CAPES database.

2.2.1 Search strategy

Table 2 presents the searched terms in this step. As in Step 1, besides *augmented reality*, we used the broader term *mixed reality*, as well as *blended reality* (BR). Based on *biology* and *environmental sciences* detailed fields of education (ISCED-F 2013), the terms in group 2 where selected. We took in consideration the subjects as described in the ISCED-F to try retrieving as many matches as possible. Closely related subjects like biochemistry were not included since they are classified in their specific detailed field. Some additional variations of terms were also included for expanded search.

Table 2. Search terms used in Step 2.

Group 1	Group 2
Augmented reality; Mixed reality; Blended reality	Bacteria*; Biology; Botany; Cell Biology; Ecology; Entomology; Environmental education*; Environmental sciences; Genetic*; Genetics; Limnology; Microbiology; Molecular Biology; Mycology; Ornithology; Parasitology; Zoology

*Variation of term contained in the ISCED-F 2013.

In a similar manner as proceeded in Step 1, each term from Group 1 was searched in combination with each term from Group 2, as exact matches and using the logical operator *and*. In total, 51 independent searches were performed. The remaining steps of search strategy were not altered with exception of the topic used for refinement, which for this step were either *augmented reality*, *mixed reality* or *blended reality* matched accordingly with the term from Group 1 that was being searched. We proceeded in that manner as to assure the results referred to the main topic. Further refinement using the topic *education* was not convenient since in many cases that topic was not available for selection. That was also the case in some searches that had few results. In those situations, the totality of results was scrutinized.

2.2.2 Inclusion and exclusion criteria

Inclusion and exclusion criteria were used to focus the analysis on our intended goals, and are presented as follows:

Inclusion criteria:

- The material includes research question, objectives, methods and results.
- Study focus on the use of AR in biology and/or environmental sciences education.
- Focus on usage experiences or development.

Exclusion criteria:

- Doesn't include research question, objectives, methods and results.
- The technology in focus does not combine *real* and *virtual* elements.

- Study focus on the use of AR but not biology and/or environmental sciences education.
- Study focus on biology and/or environmental sciences education but not AR.
- Does not present usage experiences or development.

2.2.3 *Analysis and data selection*

Analysis and data selection were done in a similar manner as in Step 1. The analysis categories were chosen according to the research question pertinent to this step:

For RQ3

- Study type
- Fields and detailed fields

For RQ4

- AR system technologies used
- Development tools and procedures
- Teaching or Learning theories used
- Applications
- Audiences
- Place of instruction
- Advantages
- Limitations
- Challenges

3. RESULTS AND DISCUSSION

Based on the results obtained after following the described procedures we address and discuss the proposed research questions for each step.

3.1 Step 1 results

3.1.1 *RQ1*

Are there recent studies in CAPES database about the state of the art in the educational use of AR and do they target the detailed fields of biology or environmental sciences (ISCED-F 2013)?

Independent searches in CAPES database for the terms indicated for this step returned 764 results in total. From this number, only two were obtained using the term *blended reality*, which suggest the expression may have become obsolete in scientific literature. After refinement, the total number dropped to 85, including duplicates. After analysis, five of them were shown to be recent state of the art researches in the use of AR in education, which included: four reviews on the field of education in general [1,4,31,35] - being the [35] and [31], respectively, on online education and augmented paper systems - and one on the broad field of health and welfare education [42]. None of them addressed the state of the art of AR use in biology or environmental sciences education, which highlights the importance of the present study.

Considering the diversity of broad fields in the area of education, the number of identified state of the art studies is rather small. That fact may change in the upcoming years since the topic seems to be an emergent one, as pointed out by [4] and [1]. The first targeted researches between the years 2003 and 2013 and verified increasing numbers towards the end of the *spectrum*, which was also the case for [35] and [1] that analyzed, respectively, papers from 2003 to 2012, and from 2007 to 2015.

3.1.2 *RQ2*

What were the main AR system technologies identified, their applications, audiences, advantages, limitations and challenges?

AR system technologies

Classifications varied according to each study. [4] presented the following as the major AR system technologies used: marker-based AR (59%); marker-less AR (12%) and location-based AR (21.88%). Among marker-less AR, the use of Microsoft Kinect was pointed as a beginning trend. [1] concentrated on equipment for classification, being the most used mobile devices (60%) and desktops (24%). They also reported the use of Kinect, HMDs, 3D vision glasses and others developed by researchers. [42] divided technologies in both categories, concluding that the majority employed mobile laptops (50%), followed by stationary desktop computers and mobile devices (smart phone, tablet, personal digital assistant and e-book readers). Regarding systems, it was reported that most studies used marker-based AR, being a camera and a marker as a tracking device the most common configuration (68%). The author also states that other configurations used different components such as: electromagnetic tracker; radiographic marker; anatomical landmarks; hybrid optical tracker and Wi-Fi signal; and head-and-hand tracking system. Also, one work projected the virtual picture on a manikin. [31] concentrated on a specific type of AR, augmented paper systems (paper-based computing technologies), which included: Augmented Cards and Post Its; Augmented Books; Augmented Notebooks; Augmented Printed Documents; and Augmented Tablets, Flipcharts and Whiteboards.

Applications

[4] found that most studies of AR use in education were applied in the field of *Science*, followed by *Humanity & Arts* (language learning, visual art and painting appreciation, and culture and multiculturalism). The greatest use in science was attributed to the effectiveness of AR for visualizing abstract or complex concepts and, in general, things that cannot be seen in real world or without specialized equipment aid. Usage in language learning was justified for presenting contextual information, proving new experiences. Enhanced experience was also the reason for usage in painting appreciation. The less explored fields were *Health and Welfare* and *Services and Others*. *Educational*, which includes teacher training in all levels of education, as well as agriculture had no results. The main purposes of AR use were found to be explaining a topic and augment information. Usage in educational games and lab experiments were also present. [31] presented the following examples of the use of Augmented Paper Systems found in literature: environment for students to create and retell stories using augmented cards with barcodes as placeholders for drawings, audio and other media; augmented notebooks for creating and sharing content; mobile devices to access additional information in printed documents; and augmented table using paper elements to manage simulations in logistics vocational education. Uses reported included subjects like math, science and history, as well as specific tasks like storytelling, guitar playing and note-taking. Contexts of interaction varied from individual activities to ones that involve entire classes. [35] reported that computer sciences was the major domain covered in the reviewed studies (26.3%), possibly because some researchers were also teachers in computer sciences and had the skills to develop and apply them. Second, were Science, Medical and Comprehensive Fields (15.8% each). For [42] the main use was to provide feedbacks, followed by usage as an innovative interface and for

simulation. Other uses included: navigation; working regenerative concept; remote assessment and training; as meaningful information tool; to reduce resources; offer immersion in a scenario; and give participatory reality. Among applications there were as many as 15 subjects in the field of healthcare. Most papers were within the topic of surgery. [1] did not focus on fields and specific applications.

Audiences

[4] reports that AR has been mostly applied in compulsory and higher education settings. Early childhood, post-secondary non-tertiary and short-tertiary education had little or no occurrence. The absence in the first case was theorized to be due to the technology not being ready for use with such young audience. Studies with master or equivalent level, and doctoral, were also not found. [1] verified the following distribution: 51% K-12 students; 29% University Students; 7% adults, including elderly; 3% teachers and 1% kindergarden. [31] highlighted that augmented paper has been proposed for almost every educational level, including: pre-school and elementary school; secondary; vocational training; and university level. [35] concluded that online use of AR had university students (42,1%) as their main targeted audiences, followed by elementary (10,5%), secondary, basic education (10,5%), masters' (10,5%), and Ph.D. students (5%). One supposition for the predominance of university students was the use of the technology for developing professional skills. [42] reported a varied of participants, including children, high school students, medical students and medical staff.

Advantages and effectiveness

[4] reported as the main advantages, in this order: increased learning, motivation, facilitating interaction and collaboration. In general, AR showed to be a promising technology in education. The increase in learning performance and motivation were assumed to be due to the type of interaction and graphical content presentation. [1] verified in relation to learners: improved learning, motivation and attitude. Pedagogically, it was reported satisfaction; engagement level; higher concentration on subjects; and help in collaborative learning for mobile AR. [31] report that advantages include immersive experience with visual, audio and other media, as well as ease of searching, sharing, duplicating, converting, archiving and retrieving content. Some advantages related to intrinsic properties of paper like intuitive use, ease of navigation through content and flexibility. The advantage of merging paper and AR was reported to enable complex interaction without excessive cognitive overload. The learning process can also be readily available for analysis through recording and tracking interactions with the systems. Another potential benefit was enhancing students visual and spatial abilities. Even though there were many advantages, the author underlines that few studies actually conducted reliable and statistically significant measure of learning effects. For [42], in general, learners accepted AR as a learning technology. Most papers (96%) claimed AR was useful for improving healthcare education. Among the reasons attributed to improved learning were "acquisition of skills and knowledge, understanding of spatial relationships and medical concepts, enhancing learning retention and performance on cognitive-psychomotor tasks, providing material in a convenient and timely manner that shortens the learning curve, giving subjective attractiveness, and simulating authentic experiences" [42, p.9]. [35] did not address this issue.

Limitations, challenges and orientations for further research

[4] identified as the main limitation difficulties in maintaining superimposed information, which may lead to student's frustration. As the authors put it, this issue may be overcome with better tracking algorithms and technology improvements. The next two most relevant difficulties were associated with students paying too much attention to virtual information and the technology being intrusive. The latest was especially true in the case of Head-Mounted Displays (HMDs) that could interrupt the natural interactions with others. Other limitations included the fact that applications were designed for a specific knowledge field and that teachers could not create new learning content. [1] found the main issue to be usability. The system was hard for students to use which caused time loss (probably bad for classes with many students) and make it harder to understand the proposed theme. Another problem may be cognitive overload due to the amount of material and tasks complexity. Others related to technical issues, especially involving location tracking. [31] states that several studies report additional teacher effort in material preparation. The fact that materials tend to cover only a small part of the curriculum is also a factor that may affect adversely its adoption. Lack of a teacher-specific user interface with special capabilities, even when the teacher has a central role in conducting the activity, was a downside. [42] considered the major downsides of the studies to be: lack of learning theories to guide the design of AR; tendency to apply traditional learning strategies to AR; and the phase of the developed technologies applied, which were mostly prototypes. [35] did not address the topic.

In their studies, the authors identified a serious of issues to be addressed in future researches. [4] sees the improvement of marker-less AR technology as an important challenge to be faced. For future research the main recommendations were: usability studies for AR applications in education; guidelines for designing AR-based educational settings; authoring tools for creating AR activities, usable by teachers; new methods for creating 3D content for AR learning environments; creating multisensory experiences with AR and explore their impact; further studying learning processes involved; addressing diversity and special needs in learning. [1] highlighted: more studies related to the development and usability of AR applications; creating design principles (empirically proven) for AR environment; additional research toward student satisfaction, motivation, interactions, and student engagement. [31] directions for future research included: design of novel systems with augmented paper; need of specific design guidelines and processes for the conceptualization and implementation of this kind of systems; augmented paper toolkits and user-created paper UIs. [42] saw identification of learning theories to better guide application of AR in healthcare education as an important issue. [35] did not address this issue.

We've noticed none of the reviews highlighted the environment in which researches were conducted. Another important omission was the development tools used to create applications, as well as the development process, who was involved, among other issues related to the creation of AR experiences. The main learning theories used as a foundation for AR applications were also absent.

3.2 Step 2 results

3.2.1 RQ3

What are the experimental or development studies in the use of AR in biology or environmental sciences education in CAPES database and the subjects (ISCED-F 2013) targeted?

For this step, the 51 independent searches in CAPES database returned a total of 356 results after refinement, including duplicates. From that number, only 5 were correspondences to the term blended reality, reinforcing the previously observed obsolescence of the term in scientific literature. Analysis of that total resulted in nine articles which described experimental or development studies addressing the use of AR in biological or environmental sciences education. The small amount of articles that matched our criteria reveals the necessity of further investigation in this specific detailed fields. The main subjects (ISCED-F 2013) addressed by these works were: Environmental Sciences [18,19,22]; Microbiology [20]; Molecular Biology [6]; Botany and Zoology [12]; Ecology [34]; and Biology [21]. Abstracts from two additional studies indicated they belonged to the detailed field of Biology and used AR for education, but we didn't get access to the full article of one of them [27] and the other [32] was written in Indonesian, which the authors of the present article did not master. Table 3 presents the journals in which the selected studies were found.

Their purposes were: comparing 3D physical objects and 2D teaching materials with AR [20]; testing the use of AR and probeware in field trips [22]; describing a method for the production of 3-D interactive images of protein structures that can be manipulated in real time through the use of augmented reality software [6]; developing an eco-discovery AR-based learning model (EDALM) which is implemented in an eco-discovery AR-based learning system (EDALS) [19]; comparing size and weight factors in an educational game about the water cycle for an iPhone and a Tablet PC [15]; examining effectiveness of AR inquiry-based learning activities for learning and motivation [12]; developing a virtual butterfly ecological system based on AR [34]; developing an AR system for learning while exercising and comparing with regular computer assisted instruction [18]; and creating a series of interactive visualizations of biologically inspired complex systems [21].

Table 3. Number of studies analyzed in Step 2 by journal.

Biochemistry and Molecular Biology Education	1
Computers & Education	3
Educational Technology & Society	1
IEEE Computer Society	1
Interactive Learning Environments	1
Journal of Computer Assisted Learning	1
Virtual Reality	1

3.2.2 RQ4

What were the main AR system technologies used, development tools, applications, audiences, place of instruction, advantages, limitations, challenges and orientations for further research?

AR system technologies used

Most systems relied on computer vision for the AR experience, being marker-based AR more recurrent. Systems used for AR are presented as follows:

- Marker-based AR [6,15,18,20]
- Marker-less AR [21]
- Location-based AR [19,22,34]
- Location and marker-less AR [12]

The equipment used varied according to each studies' purposes. [20] used Virtual Reality HMDs with camera associated with tracking markers in pages of an augmented book. The HMDs were connected with cables to a computer. [22] used wireless-enabled mobile devices associated with water measurement tools. [6] used a computer and camera, like [18] who included a projector. [34] and [15] used iPhones and Tablet PCs taking advantage of accelerometer and touch screen. [12] used tablet PCs and their GPS, Camera, Digital Compass, three-axis gyro, accelerometer and AR display to create AR. [21] used projectors, computers, sand and RGB-D cameras. [19] used Tablet PCs, but did not disclose the system in details.

Development tools and procedures

Among the tools used to create AR experiences the most common was ARToolKit [6,15,20], not surprisingly since it's one of the leading softwares on the market. FreshAiR™ development platform (no programming experience required) was also used [22]. [12] used JAVA in programming for website, Oracle for database and Xcode for iPad mini. Among resources used by [15] there were also: Xcode 4 IDE and the iPhone SDK 4.3 for games, Blender for 3D scene creation, OpenSceneGraph (OSG) toolkit, OSGplugin osgART 2.0 RC 3. [34] used 3DS Max for 3D models and Shiva 3D for animations. JDK, Android 1.5 SDK, Eclipse and Android Development Tool Plug-in software were also used.

The process of creating the AR experience is seldom described, which may highlight the fact that little or no specific guidelines for science education with AR are followed. As pointed in Step 1, additional research in this topic is needed. [15] and [34] were the only examples with more detailed information on this issue. The first included in their development process: professionals in education to determine the subject preferences for educational computer games and literature study for principles guidance, then created 3D models in Blender and later imported them in other development program (SIO2 1.4 version, for iPhone, and OpenSceneGraph, for the Tablet PC). An external case to protect devices was also built. The second scanned pictures of butterflies and inserted them in a 3D model in *3DS Max*. Later, the result was exported to Shiva 3D, a 3D animation software, where the flying motion was assigned. It relies on an API program based on a probabilistic model. The final product was published on Google Play for download.

[21] used AR experience in installations for the general public, and thus, was less constrained with instruction on the way it is normally addressed in schools. One configuration used consisted of an array of RGB-D cameras mounted above a container with sand representing islands to determine the landscape's topography, shaping the adaptive conditions of fictional species inhabiting it. Computer algorithms were used to mimic evolution of such species.

Teaching or Learning Theories Used

Five of the articles analyzed supported the AR experiences in some kind of learning or cognitive theory/construct, being them: multiple resource theory [20]; inquiry based learning [12]; situated learning [22]; Kolb's experiential learning theory [15,19]; Gardner's theory of Multiple Intelligences, M-learning and edutainment [15].

Applications
Applications included: augmented book to present models of six bacteria with different characteristics [20]; combining AR experience with use of environmental probeware during field trips to address ecosystem science learning goals [22]; navigation in outdoor areas to focus on specific places with educational purposes, integrating virtual information into the actual ecological environment and to strengthen the impact of exploratory learning [19]; creating educational game about the water cycle for an iPhone and a Tablet PC [15]; conducting inquiry-based learning activities [12]; simulating butterflies ecology, including breeding [34]; teaching ecosystems concepts while exercising [18] and inviting participants to become part of an ecosystem through responsive environments that utilize immersive or mixed-reality audio-visual displays [21].

Audiences
Most of the intended audiences of the interventions were in the levels of primary or lower secondary education, including fourth-graders [12] [34], fifth-graders [20]; sixth-graders [22] and seventh-graders [18,19]. [15] worked with children from 8 to 10 years old attending summer school, while [21]'s audiences could include, as described by the authors, since a three-year old child until an 80-year-old scientist. The absence of post-secondary education audiences may be in part due to the exclusion of subjects that were classified in ISCED in other fields, as is the case for healthcare education. That way, some subjects that may be related to biology in a broader sense and are part of universities' curriculum did not make part of our study. [6] did not specifically describe the intended audience.

Place of instruction
We found four works using AR mobile systems outdoors in fieldtrips to ponds and gardens [22] [19] [12] [34]. That finding makes sense since the main subjects were related to environment, ecology, botany and zoology, but also reflect the technology flexibility. That also is the case for installations described in [21]. [20], [18] and [15] used the systems in regular classrooms. [6] did not specify the location to deploy the developed 3D AR models.

Advantages
As described by authors, the main advantages in the use of AR systems were:

- Practical and hands-on way to explore and learn [20]
- Increase in interest/motivation [12,19,20,34]
- Gains in student affective measures [22]
- Increased learning [12,19,22,34]
- Student-centered rather than teacher-directed interaction with subject and peers [22]
- Stimulate positive emotions [19]
- Facilitates exercise while learning [18]
- Ease of use/adaptation to devices [15,34]
- Increased confidence [12,18]
- Realism of experience [34]
- More time and space independence in comparison to some traditional environments [34]
- Low maintenance cost [34]

[15] highlights that screen size and weight of the different devices used (iPhone and Tablet PC) did not influence the children's acquired knowledge, engagement, satisfaction, ease of use, or AR experience.

As seen in the previous review studies in Step 1, increased learning seems to be prevalent in the results. The same can be said about interest and motivation. AR has been shown to be a valuable tool for teaching, but those results need to be seen with caution, since novelty is an issue. In all studies practices using AR were not ordinary and that fact may have driven part of the enthusiasm. More research is recommended on this topic.

Limitations, Challenges and orientations for further research
Some authors mentioned points in which the use of AR has come short. [20] concluded that although efficient, AR didn't prove to be superior to 2D images or 3D physical objects. In [22]'s teachers' surveys, there were no indication of strong conviction about effectiveness of AR. The authors also raise questions about the persistence of learning gains, which may also orient future investigations.

Another factor to be considered is the price of equipment, that can be expensive [19]. This tends to be reduced as time goes by since an increase in hardware computational power relative to price has been the trend. The possibility to use equipment that students may already have, like smartphones, may also reduce costs. It is important to mention that in some cases the alternative to AR may be more expensive, like is the case for real-life butterfly gardens [34].

When considering the weight of equipment, although there was no big impact in learning, some 8-year-old children had a little trouble holding the Tablet PC since it was too big or too heavy for them [15]. Some needed help pointing the devices to the markers. That should be taken into consideration when designing for that audience. One option as pointed out by authors would be to include pauses to rest arm when in use. In location-based AR, as verified in the previous reviews, GPS precision may still be an issue [12].

[18] highlight as important aspects to be concerned while developing AR systems: providing training to operate the technology to both students and teachers; having a good teaching proposal for all the teaching steps and equipment preparation and a good guide book for AR teaching directions as a way to reduce teacher's resistance towards its adoption; and making AR flexible with complexity level selection. Timing of the activity must also be considered since AR experiences may take longer than regular instruction.

[19] propose further research on: intermediary effect of different emotional capacities in a single environment; and using AR technology to combine sensing devices to enhance emotional competence. Research on emotional design is also needed to integrate affective and cognitive processes. [15] suggest that game could be improved adding multiplayer, adding competitive and collaborative functionalities.

4. CONCLUSIONS

In this study we searched and presented previous reviews in the state of the art of AR in education and found that no such work had been done in the detailed fields (ISCED-F 2013) of biology and environmental sciences. We've also noticed that none of the reviews highlighted the environment in which researches were conducted, nor did they address development processes or tools used to create applications. The main learning theories used as a foundation for AR applications were also not addressed. We then conducted a systematic review of CAPES database for scientific articles on the use of AR in biology and environmental sciences education published since 2012. There were very few researches in those areas. Their main featured characteristics where presented, including technologies used, development tools, applications, audiences, place of instruction, advantages, limitations, challenges and orientations for further research. AR systems and equipment have been used in applications with arrays combining computer vision, sensors and GPS. In general, there was little or no description of the development process which indicates that to be a potential area of investigation. We support previous suggestions for the creation of specific guidelines for that purpose. There are experiences using this type of technology inside the classrooms as well as outdoors, especially in environmental sciences. Most studies focused on children on primary or lower secondary education. AR has showed to be a practical and hands-on way to explore and learn, stimulate positive emotions, increase interest, motivation, confidence and learning. It is also a possibility for students to interact with subjects and peers in a student-centered rather than teacher-directed base. Limitations include equipment price, high preparation time and weight of equipment (especially for smaller children). Costs, on the other hand, may be reduced for some situations where traditional methods involve expensive materials and maintenance. Overall, research has been gaining momentum but preliminary results must be taken with caution considering sample size. Identified topics of interest for further research include: usability, application development procedures and guidelines, effects of continuous and consistent use on learning, and location and synching technology refinement.

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