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Review Article

# Effects of using augmented reality on students' learning

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## Abstract

This article presents the results of a systematic review of the literature regarding the effects of using Augmented Reality (AR) on the learning of science students (Natural Sciences and Biology).

The PRISMA methodology was used. Ten articles were selected from indexed journals, in a period of time between 2010 and 2022, after applying the inclusion and exclusion criteria. The main inclusion criteria were: only articles with students from Basic and Secondary Education (equivalent to ISCED 2 and 3) and that report results in students' learning. The main exclusion criteria were: duplicate articles and those that did not present a teaching strategy associated with the use of AR. The databases consulted were Scopus, ScienceDirect, Springer Link, EBSCO and Web of Science.

Eight out of ten of the selected articles used an experimental methodology.

The results indicate that AR had positive effects on students' learning and motivation, as well as on other variables such as visuospatial skills and student involvement in tasks.

## Abbreviations

AR: Augmented Reality; STEM: Sciences, Technology, Engineering and Mathematics

## Introduction

The integration of Augmented Reality (AR) in work and learning contexts was due to Engineer Tom Caudell, in the mid-90s [1,2]. AR can be integrated into a broader context, which also includes virtual reality and mixed reality [2,3]. AR stands out in this continuum as it combines images generated by technology, i.e., unreal images, with the real world, but without the user being immersed in a virtual scenario [2,4-6]. The use of AR is diverse. We highlight the military, industry, medicine, museums, entertainment, and navigation [2]. The evolution of mobile systems, with the pertinent development of AR apps, and the fact that they are accessible, has favored their integration in formal and informal learning contexts [7,8]. AR makes visible microscopic aspects, as well as simulated manipulation of potentially dangerous situations [9,10].

The systems that generate AR can function with or without the use of markers [1,11]. However, it is important that they are used properly. The literature highlighted that systems with little immersion, such as those generated from smartphones, promote learning when the principles of the Cognitive Theory of Multimedia Learning are taken into account [12]. Marker-based systems include the use of QR (quick response) codes and images. There are three fundamental components: information about markers, a camera to capture the image, and the 3D information that will be formed. On the other hand, applications without the use of markers require a Global



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Positioning System (GPS), a compass, and a monitoring system composed of an image recognition device [1,13-15], aspects that current smartphones integrate.

The analysis of the studies we carried out was guided by the following questions:

1. What are the effects of using AR on students' learning?
2. Are there other variables that are associated with the positive performance of students who used AR as part of teaching and learning activities?

## Materials and methods

We performed a systematic review of the literature following the PRISMA methodology [9]. The period considered was between 2010 and 2022. For this article, we analyzed 10 publications obtained from a more extensive survey on the integration of AR in teaching and learning contexts of Natural Sciences and/or Biology (Table 1). These 10 articles used different research designs: quasi-experimental (5 studies), experimental (3 studies), pre-experimental (1 study), mixed method (1 study), and case study (1 study), as illustrated in Figure 1.

We proceeded to a description of the research questions and results raised by the authors of the 10 articles related to students' learning or students' achievement, which can be observed in Table 2.

## Results and discussion

The analysis of Table 2 shows that nine of the 10 studies analyzed indicated improvement in students' academic results who used AR in a learning context when compared with the students' outcomes who used the conventional method. Only one study [5] mentions that there was no difference in the students' learning when comparing the results between the two groups: those who used AR and those who did not. However, the results of this study have shown that AR facilitates the perception of 3D concepts or processes that facilitated the development of visuospatial skills. In the study [4] the authors point out that AR favors problem-solving and self-control in students. One study [3] presents as a limitation the fact that there is no control group.

The authors of the 10 articles are unanimous in indicating that students are more connected to the class and teaching when AR is present. The aspect is supported by other research and literature reviews with students from other levels of education and in the learning of other subjects.

We emphasize that this positive impact of AR on student learning is referred to through greater proximity between theoretical knowledge and non-visible aspects of reality

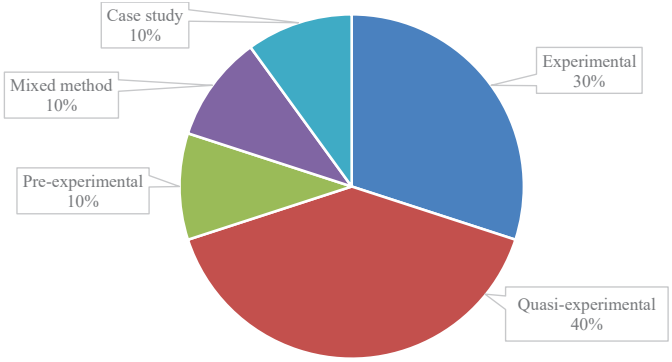


**Figure 1:** Methodology of the analyzed studies.

**Table 1:** Study methodology, country, sample, duration, and AR system used.

| ID | Study Methodology | Country | N (CG + EG) | Context | Duration | app and system (with/without marker) |
|---|---|---|---|---|---|---|
| [16] | Experimental | Malaysia | 140 (70 + 70) | Classroom | Pre-test 20 minutes; A week of work; post-test 20 minutes | eStar app*, computer (with marker) |
| [17] | Quasi-Experimental | Colombia | 13 (0 + 13) | Learning didactic sequence | Un | Arloon Anatomy AR app, mobile (with marker) |
| [18] | Quasi-Experimental | Slovenia | 51 (0 + 51) | Classroom | June (pre-test, teaching, and post-test), September (post-test and questionnaire) | Mirage AR9 app*, mobile phone (with marker) |
| [1] | Experimental | Un | 147 (70 + 77) | Classroom | 14 weeks of knowledge pre and post-test | Aurasma app*, mobile phone (with marker) |
| [14] | Experimental | Taiwan | 72 (24 + 24 + 24) | Classroom | Un | The built app, AR glasses (with marker) |
| [13] | Quasi-Experimental | Turkey | 100 (50 + 50) | Classroom | Four weeks (16 hours); assessment test | app Ud, computer (with marker) |
| [15] | Quasi-Experimental | Indonesia | 68 (34 + 34) | Classroom | 90 Minutes (organized in 20+5+45+20); pre and post-test | the app built and mobile (with marker) |
| [19] | Pre-Experimental | Chile | 162 | Classroom | Un | Mitotic Division app, mobile or tablet (with marker) |
| [10] | Explanatory Mixed Method | Turkey | 53 (27 + 26) | Classroom | One month; pre and post-test | The built app, tablet (with marker) |
| [5] | Case Study | Bulgaria | 80 | Classroom | One school year; pre and post-test | zSpace app, computer, and 3D glasses (no marker) |

ID: Article reference Identification; N: Sample; CG: Control Group; EG: Experimental Group; Un: Undefined; *: app discontinued



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**Table 2:** Research questions presented in the articles and results related to the use of AR in student learning/performance.

| ID | Research questions / Purpose of the study | Conclusions |
|---|---|---|
| [16] | Students using the eSTAR have a better score in the post-test which eventually resulted in a better learning performance compared to those who were exposed to conventional science learning. | ...through the use of the eSTAR application, the students from the experimental group have a better score in the post-test which eventually resulted in a better learning performance compared to those who were exposed to conventional science learning. |
| [17] | Evaluate the appropriation process reached by the students during the implementation of the didactic sequence. | The results of the didactic sequence... showed that this type of strategy has, indeed, a positive impact on the teaching-learning processes. For example, one of the challenges in teaching the human body and its anatomy is the impossibility of actually observing its characteristics and functioning, so there is a disconnect between theory and its practical understanding. ... In this sense, the hypothesis that suggested that ICTs and the use of tools such as Augmented Reality helped to face this rupture in learning was confirmed. |
| [18] | How do AR-based educational materials help students understand the human circulatory system? | The instructional activity in this study significantly improved students' knowledge about the basic anatomy and physiology of the human heart, Furthermore, the delayed posttest showed that the conceptual change achieved in students' understanding was stable over a period of two months. The results ... confirm the first research question that AR-based educational materials helped students in understanding the complexity of the human circulatory system ... |
| [1] | The purpose of this study is to determine the impact of an augmented reality application designed for secondary 7th-grade science teaching on the achievement and problem-solving skills of students | ... the achievement post-test scores of students at the end of the semester showed that there was an increase in achievement scores of students in both groups but that the increase in the experiment group which was supported by AR technology was higher. |
| [14] | Can AR improve students' learning performances compared with conventional teaching materials - picture books and physical interactions? | Results of the analyses can answer the first research question: AR graphic book offers a practical and hands-on way for children to explore and learn about bacteria, and AR improves students' learning performances to a similar extent as conventional teaching materials, such as picture books and physical interactions. ... Results showed that, after all, AR produced similar educational benefits as those traditional teaching materials did. |
| [13] | Is there a significant difference between the academic achievement of middle school students using AR applications and those using traditional methods? | A significant difference was observed between the experimental and control group in academic achievement, such that students who took their science lessons with AR technology scored higher on a science course achievement test than those who learned via traditional methods. ... In conclusion, it is clear that AR positively affects students' academic achievement. |
| [15] | What is the effect of using AR in a biology book on the students' learning outcomes? | The study found that AR technology significantly enhances learning outcomes at the analyzing level of Bloom's taxonomy but does not significantly enhance learning outcomes at the remembering and understanding levels. Thus, AR technology may have the potential to be useful in the development of students' higher-order cognitive skills. |
| [19] | Detect changes in the levels of representation of the student body that participates in the study when working with a sequence that promotes visualization through the use of augmented reality. | All of the above allows us to infer that augmented reality allows students to observe an abstract and decontextualized phenomenon from different points of view, favoring the selection and use of previous mental schemes to process new information, optimizing their working memory in pursuit of new mindsets. ... That is why we consider that the resource as a whole (Sequence and App) offers effective, active and ubiquitous learning opportunities (Cabero et al., 2019), generators of more complex and robust representations in the explanation of a phenomenon. complex biology such as mitotic division. |
| [10] | ... the study tried to investigate the impact of AR on the attitudes and success of the students. | It has been found that the student's academic achievement levels increase more with the education provided by AR cards. ... From all these, it is thought that AR is an effective material in teaching and should be used. |
| [5] | This paper aims to explore the impact of an AR tool on students' learning performance. | The study has shown a substantial improvement in students' understanding of the matter studied. ... Based on an analysis of the data on the effectiveness of learning through augmented environments and written tests, it can be affirmed that the integration of AR in the above-mentioned learning unit had significant effects on the learning of the associated content. |

AR: Augmented Reality; ICT: Information and Communication Technologies

[2,3,7,13,14]. This aspect helps students to learn the internal anatomical structures [2] and the complex aspects of the subjects studied [3], fosters the development of higher-order cognitive skills [13], and working memory, by generating more complex and robust representations [14]; it also supports meaningful learning [7].

Except for one study [7] that used a computer system, which the authors point out as a limitation due to the high cost of the system, all other studies used smartphones or tablets, an aspect that makes the use of AR more accessible.

In our analysis, we found studies that used apps created for the content taught and analyzed in the research, but which no longer exist, which does not allow the replication of the activity with new groups of students. Some apps continue to exist, but only part of their use can be explored for free [2] and others continue to exist and allow full and free exploration [14].

## Conclusion and recommendations

It is common to all analyzed articles that AR reveals itself, in the teaching and learning process, as an innovative and motivating tool, which promotes students' attention and involvement in learning tasks. It also stands out as a complementary means to the use of other tools, namely in science teaching (STEM), given the possibility of making the non-visible visible. The aforementioned aspects, in the opinion of the authors of the 10 analyzed studies, lead students to a greater connection, involvement, and enthusiasm with the learning tasks, which translates into greater confidence.

We recommend that new studies be carried out to review the literature on the integration of AR in science teaching and that new investigations include the use of AR with certain teaching strategies to verify which are the most appropriate and advantageous in promoting student learning.



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