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Educational Applications of Augmented Reality: A Bibliometric Study

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Abstract

Augmented Reality (AR) has been used successfully in several industries; one of these is education. A systematic understanding of how AR contributes to education still lacks studies about the content type and its effects on learning outcomes. This article systematically analyzes the AR state-of-the-art in education, determines productivity and publication indicators in this field, and identifies research works that have studied how content type affects the learning outcomes. The methodology was performed through a bibliometric analysis using the Scopus database, focusing on AR's educational uses. *Engineering education* is the primary research trend, followed by *simulation*, *tracking*, and *virtual reality*. Education and e-learning also have leading roles within this analysis, along with *gamification* and *human-computer interaction*, whose impacts are further explored. There is no preferred design methodology for creating AR content. In its absence, most of the works suggest a design based on the developers' and researchers' experience.

Keywords: Augmented reality; educational innovation; educational technology; human-computer interaction; simulation, higher education

1 Introduction

In recent years, Augmented Reality (AR) has significantly impacted the scientific and industrial fields due to its potential for deploying new content and affecting user perceptions [1]. There are several complementary definitions around the concept of AR. For example, [2] states that AR is a 3D technology that improves the user's sensory perception in the real world by generating a contextual layer of information to augment the users' perception of reality. Chien et al. [3] define AR as a technology that develops a combination of virtual and real-world images made by a computer. Similarly, Akçayir and Akçayir [4] define it as a technology that superimposes virtual objects in the real world, giving the impression that virtual objects coexist as real in the surrounding reality.

The authors define AR as modifying the perceptual reality by applying digital layers over the users' reality. The digital layers are created to stimulate the user's sensory system, including vision, hearing, touch, taste, or smell. The AR applications must recognize the user's real environment, so the fit between the digital and real environments is dimensioned to provide a sense of realism. An application must accomplish these three requirements to be considered augmented reality:

- Real-time.
- Natural registration.
- Semantic context within the real environment.

Augmented Reality has been used in several areas such as healthcare [5], manufacturing [6], agriculture [7], and maintenance [8] (Siew, Ong, and Nee, 2019); however, one of the most potential and uses cases implemented is in the field of education [4,9]. This technology offers exceptional pedagogical opportunities for educational users, including mobility, visualization, alternative perspectives, comparison/contrast of multiple perspectives, and integration of multiple perspectives. Through a relevant formative assessment mechanism, AR-based learning significantly enhances the learners' achievements and motivation and reduces their cognitive load [10]. The contributing factors to its acceptance in the education sector include the availability of low-cost mobile devices with specialized hardware that allows AR applications' deployment. For example, the New Media Consortium and the Educause Learning Initiative have recognized AR as one of the most promising technologies to support K-12 education teaching and higher education [11].

The remainder of this paper is organized as follows. Section 2 gives an overview of the related research and presents the theoretical framework. Section 3 describes the methodological design for the systematic review. Section 4 presents the study results, where the analysis is performed, and section 5 presents concluding remarks.

2 Theoretical framework

Augmented reality is considered an essential technology in the education sector. It employs sensory immersion, navigation, and information manipulation to promote emotional mediators for improving the learning process and learning outcomes [12,13].

In the educational field, AR has achieved significant benefits in teaching processes inside and outside the classroom. It holds multiple advantages such as (i) the capacity to promote kinesthetic learning; (ii) the ability of students to analyze a 3D object from a variety of perspectives or angles to improve their understanding; (iii) an increase in the commitment and motivation of students in academic activities; and (iv) provision of contextual information - virtual data related to the learning activity and the real objects in the scene [14].

Radu [15] concludes that AR is useful for increasing student motivation, promoting student collaboration, developing spatial skills, and improving physical task performance. According to [16], AR's most significant advantage is its unique ability to create immersive hybrid learning environments that combine digital objects with physical ones, thus facilitating critical thinking, problem-solving, and communication.

Considering the negative impact of AR, Radu [15] emphasized that it imposes an extra cognitive burden on students, resulting in usability problems; [17] determined that students find AR challenging to use. Additionally, [18] established that cumbersome technologies such as HMDs (Head Mounted Displays) are easy to use - AR should be accessible in much small, light, and portable devices with graphics that render faster.

The contents displayed in an AR application are of two types, static or dynamic [19]. Texts, visual cues, or 3D models whose appearance does not vary during the user interaction are defined as static content. On the other hand, dynamic contents vary their appearance during user interaction; an example of dynamic content is animations. Dynamic visualizations, such as animations and videos, change over time and represent a continuous flow of movement, while static visualizations do not show any movement [20]. It is worth mentioning that the type of content that should be implemented in an AR application depends on the subject and the learning experience intended for the student [21].

Most research projects related to the design and evaluation of static and dynamic content have considered the Cognitive Theory of Multimedia Learning (CTML) framework and the Cognitive Theory of Load [22]. This framework establishes that a student should select, organize, and integrate new information to understand any instructional material fully. According to CTML, selecting and organizing verbal information implies constructing a verbal-mental model, while the selection and organization of visual information imply the development of a visual-mental model. This framework also establishes that the construction and integration of these two mental models lead to a deeper understanding of a specific topic and a better connection with previous knowledge, facilitating the storage of the new knowledge in long-term memory. For this reason, several studies have explored whether there is a difference in learning when the contents are presented in textual form, visual representation, or both [23].

Researchers have explored different learning strategies or cognitive activities applied to students when using text or content based on diagrams [24]. Two of these learning strategies are the protocol of thinking aloud and coded cognitive activities. Based on experimental tests conducted in biology subjects, the authors found that students perform more elaborate cognitive activities when they learn through diagrams rather than text. However, the studies did not determine whether the performance or perception of learning was better in one over the other [24].

Other works have focused on assessing whether there is an effect on learning when students use static or dynamic content. An analysis of how different student skills and knowledge affect the comprehension of dynamic content has been described [25]. The authors of this research also reported eight studies that assess the understanding of a complex mechanical system that uses static and animated diagrams with and without verbal instructions. From the results, it was possible to determine that spatial ability does not significantly affect understanding the content. Possibly, this ability is more useful when the content is textual or verbal, and the student must mentally create a visual representation of it [25]. Finally, the authors determined that there is no significant impact on learning when static or dynamic content is used.

Several authors have written about the states-of-art to analyze AR's use and success in the teaching and learning processes. For example, [12] developed a review that identified two approaches toward utilizing AR technology in science education: (i) image-based AR, related to spatial ability, practical skills, and conceptual understanding [26], and (ii) location-based AR, which is usually applied in inquiry-based, scientific activities. Dunleavy and Dede [27] focused their review on AR deployed in mobile technologies such as smartphones or tablets, enabling participants to interact with digital information embedded within the physical environment, emphasizing the limitations associated with AR around teaching, learning, and instructional design.

Also, [4] reports a systematic review of AR literature used in educational settings of formal learning, informal learning, and job training. In their review, the authors shared findings about the types of apprentices participating in the research, the most used AR technologies, the advantages of AR in educational settings, and the challenges imposed by AR. The authors stated that, to date, there is no clear explanation about the effects and implications of AR in education; also, they argued that AR can be difficult to use and imposes a high cognitive load on the brain, which can saturate users' attention span. The authors [4] concluded that 3D texts and models are the most used AR content; however, the type of content used (i.e., static or dynamic content) is uncertain. They did not analyze how the type of content influences the applications' effectiveness.

On the other hand, a systematic review of state of the art analyzing AR's use in learning via the STEM (Science, Technology, Engineering, and Mathematics) methodology is reported by [28]. This review answers the following research questions: (i) What are the general and specific design features of AR-based learning applications using STEM? (ii) What are the instructional processes followed by the studies using AR and STEM? (iii) What are the metrics considered in the studies applying AR and STEAM? Additionally, it analyzes and categorizes different studies about AR applications' general characteristics, the instructional process applied, and the purpose, methods, and conclusions. In [29] 's review, the authors delved deeper into the types of content used in AR applications, differentiating them between text, video, animations, 3D models, and images. However, nothing was concluded about the types of contents used between the different studies and their impact on affective and cognitive learning outcomes.

Most state-of-the-art studies have focused on evaluating and categorizing how different authors developed AR applications in education and learning. However, within the proposed category, the type of content displayed or used has not been thoroughly assessed, nor how this can affect the user's perception and learning.

3 Methodological design

The methodology was based on a structured search of journal papers developed through a bibliometric analysis of information collected from the Scopus database with a set of search criteria to quantify and qualify the research written on this subject. It represents a quantitative approach for evaluating the data obtained [30], thus carrying out the record and detailed description of how the different variables examined in a series of specific periods evolve or behave [31].

Bibliometrics can be defined as the science that studies the nature and course of a discipline through its publications [32]. Thus, it is an appropriate tool for this analysis because it usefully measures scientific activity and repercussions through quantifying publications and citations by an individual, research group, institution, or country. It allows monitoring associated trends and changes, contributing to the clarity and work mapping [35]. This type of analysis is approached from quantity, quality, and structural indicators that shape the study of the topic of interest, which, in this case, is Augmented Reality.

This bibliometric analysis offers a detailed scope examining the current conditions and trends related to AR research in education from 2003 to 2018 by the characteristics defined for the research processes. Quantitative techniques were used to review various scientific publications, exploring their development and derivations; a comparative analysis between the different variables such as type of publications, authors, countries, and institutions was also performed.

This search was conducted in 2019; the Scopus database was the primary source of bibliographic information. Logical operators were used in order to achieve a more thorough exploration [36]. The equation applied for the search is shown in Equation 1:

*(TITLE ({Augmented reality}) AND TITLE-ABS-KEY (learn * OR train *) AND TITLE-ABS-KEY (dynamic OR static))* (1)

This search resulted in 215 publications analyzed and interpreted using Microsoft Excel software, then filtered based on the title and keywords, *Augmented reality, learn, train, dynamic, and static.* After the first filter was applied, 112 papers remained.

The main findings highlighted information such as (i) quantifiable indicators (the most relevant journals, the productivity level of the most outstanding authors, institutions, and countries) and (ii) qualitative indicators showing the impact of citations by each author, journal, and year. This process was performed (a) to establish the topics related to *Augmented Reality* and *learning*, (b) to link those papers generally related to the topic researched in this article, the issues with development feasibility (supported in all publications and promoted by the topic connections previously stated), and (c) to integrate it with the terms used in the search: *Augmented reality and learn or train and dynamic or static.*

The methodology just described is shown in detail in Fig. 1. The steps are described in the results section.

As mentioned in the bibliometric analysis, applying step 1, 112 publications were found from the search equation. A second filter was applied to these publications based on exclusion criteria, and a third filter applied inclusion criteria (see Fig. 1.) Table 1 shows the inclusion and exclusion criteria considered to filter the works found.

Table 1.
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Published between January 2005 and November 2018	Studies that mentioned the term "AR" but were about "VR" or "MR"
Peer-reviewed journal article	Editorials are excluded
Describe the content or the AR application interacted by the user	Emphasized application design and testing or evaluation is not described
Describe the experimental design	
Available in full text	

Fig. 1. The methodology used for bibliometric and state of the art analysis.

4 Results

4.1 Bibliometric Analysis

4.1.1 Indicators of quantity and quality - Annual productivity of the journals

Concerning the number (quantity) of publications (annual productivity), the indicators show a significant increase recently in the interest in Augmented Reality and learning. However, the highest AR development year came 12 years after its first appearance on the scientific stage. The period between 2015 and 2018 shows the highest activity in article publishing on this subject, showing up to twenty-three documents per year in 2017 (see Fig. 2). This behavior could be related to the technological advances in the area in the last years, so the interest has increased to include more of these technologies in other contexts.

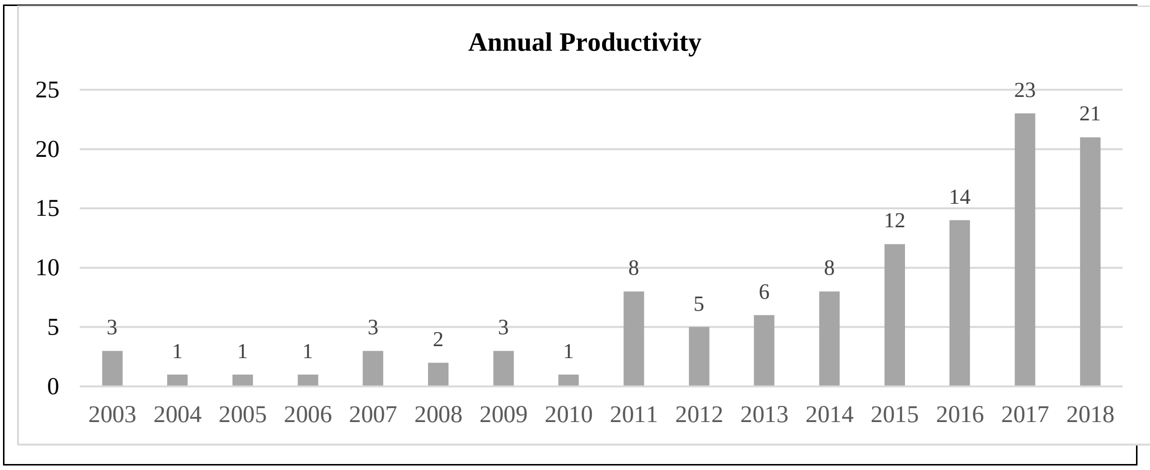

Fig. 2. The number of publications by year

Table 2 shows the top 10 journals with the most significant amount of publications and citations related. First, in the ten journals with the highest number of publications on the subject, the Journal *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* took the first place with eight papers. Second, at a considerable distance, *Communications in Computer and Information Science* had four documents. Next were *Multimedia Tools and Applications* with three, and then *Procedia CIRP, Procedia Computer Science, Educational Technology and Society, Proceedings - IEEE 18th International Conference on Advanced Learning Technologies, ICALT 2018, Proceedings - IEEE Virtual Reality, Turkish Online Journal of Educational Technology and Studies in Health Technology and Informatics* with two publications each. This information acquires relevance when assessing the existence of possible gaps or particularities of the journals' diffusion.

Fig. 2 shows the ten journals that have the highest number of citations per publication. The magazine that exhibits the highest index of citations per publication (66) corresponds to *Computers and Education*; in second place, the *International Journal of Mobile and Blended Learning* with 57 mentions for each publication, and then *Advances in Engineering Software,* with 34 mentions.

Table 2.
Publications (on the left) and citations (on the right) per journal

Journal	# Publications	# Citations	Journal
Lecture Notes in Computer Science	8	66	Computers and Education
Communications in Computer and Information Science	4	57	International Journal of Mobile and Blended Learning
Multimedia Tools and Applications	3	34	Advances in Engineering Software
Procedia CIRP	2	27	Computer-Supported Collaborative Learning
Procedia Computer Science	2	25	TechTrends
Educational Technology and Society	2	22	CEUR Workshop Proceedings
Proceedings - IEEE 18th International Conference on Advanced Learning Technologies, ICALT 2018	2	20	IHM 2013
Proceedings - IEEE Virtual Reality	2	19	Journal of Computing in Civil Engineering
Turkish Online Journal of Educational Technology	2	19	Virtual Reality
Studies in Health Technology and Informatics	2	17	Proceedings - 12th Conference

None of the journals coincide in both listings, indicating that the journal's academic productivity level does not directly correlate with the citation index that can be achieved [33]. In this way, even when the number of publications is not that big compared to the citations, some journals have many citations that reflect the field's impact, such as *Computers and Education* and the *International Journal of Mobile and Blended Learning*.

4.1.2 The productivity of the authors

As for the most prominent authors, this list of the ten researchers with the highest number of products is headed by Yimin Chen, Chen Huang, and Zeyu Li, with three articles related to the subject. Then follow Lotfi Abdi, Anne Adams, Russell Bregman, Chunju Chang, Jensuh Chern, Dana Cobzas, and Neven ElSayed with two publications each, as shown in Table 3.

Table 3.
The number of publications (on the left) and citations (on the right) of the first ten authors.

Author	# Publications	# Citations	Author
Yimin Chen	3	40	Anne Adams
Chen Huang	3	40	Rebecca Ferguson
Zeyu Li	3	40	Elizabeth Fitzgerald
Lotfi Abdi	2	40	Mark Gaved
Anne Adams	2	40	Yishay Mor
Russell Bregman	2	40	Rhodri Thoma
Chunju Chang	2	34	Amir Behzadan
Jensuh Chern	2	34	Feng Chen
Dana Cobzas	2	34	Suyang Dong
Neven ElSayed	2	34	Neven ElSayed
		27	Mingfong Jan
		27	Eric Klopfer
		27	Judy Perry
		27	Kurt Squire

These indicators allowed us to identify the main referents in this research subject: *Anne Adams, Rebecca Ferguson, Elizabeth Fitzgerald, Mark Gaved, Yishay Mor,* and *Rhodri Thomas* with 40 citations are the authors at the top, followed by *Amir Behzadan, Feng Chen, Suyang* and *Neven Elsayed* with 34 mentions each; finally, there are *Mingfong Jan, Eric Klopfer, Judy Perry,* and *Kurt Squire*, who present 27 citations each (see Table 3). Note two authors in the first and second columns of Table 3: Anne Adams (2 papers and 40 citations) and Neven ElSayed (2 papers and 34 citations). These authors have several citations, indicating that the scientific community considers their publications significant contributions to the field.

In terms of productivity, according to the type of publication, it is relevant to consider that 66.1% of total publications correspond to documents from conferences, possibly revealing the rate of evolution or novelty in the subject.

4.1.3 The productivity of institutions and countries

When classifying the institution's productivity, it was found that 148 institutions are responsible for all publications, in which 112 of these (75.63%) produced 80% of the publications, indicating that in this situation, Pareto's law does not apply; this means the academic production was not concentrated in a tight cluster of institutions. Segmenting the universities by the degree of relevance (quartiles) reveals that 13.51% of the institutions published 25.56 % of articles, and 69.59% of institutions generated 75% of publications.

Additionally, 95.95% of the organizations published two or fewer articles, corroborating a high degree of knowledge dispersion in the subject. The top institutions with the largest number of publications are universities in various countries like China, Spain, the USA, Taiwan, Universidad de la Laguna, Shangai University, University of Pennsylvania, which have programs in developing technologies.

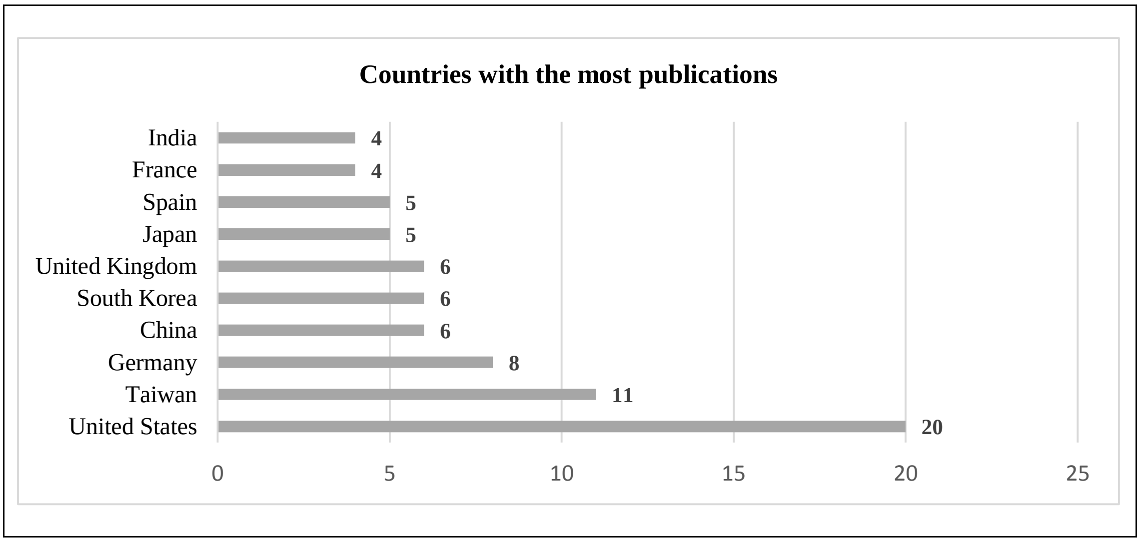

Fig. 3. The productivity of institutions and countries.

The reviewed authors represented 32 countries worldwide, of which 31.25% generated 63.03% of the papers found, where Parto's law also does not apply. Fig. 3 shows that the dominant country is the United States, with 20 publications. In the second place, markedly behind, is Taiwan with 11, then Germany with eight, followed by China, South Korea, and the United Kingdom with six each. The ten countries in the first positions (shown in Fig. 3) accounted for 75 articles out of 119 records in the databases consulted, corresponding to more than 63% of the publications; 56.25 % of all the countries had one or two publications. This list also represents the institutions that generate knowledge and promote advanced AR research progress, showing the global effort and interest in the field.

4.1.4 Augmented Reality Trends in Engineering Education

The main trends were identified from the dynamic analysis using the keywords presented during this study-period, focusing on research areas that had the most relevance to augmented reality in education. The keywords' behavior shows that trends have even participation. The educational ones lead the list, followed by more specific fields like simulation and applications and features related to AR's technological advances.

There are issues and areas with significant relationships, especially in engineering programs' academic training due to the evolution of learning processes in the current technological context. Individuals are widely assimilated into the technological culture. The use of electronic devices has become popular as an essential tool in academic activities. Usually, these activities apply didactic materials using AR to stimulate learning and improve student performance. Engineering courses leverage instruments that promote learning through standardized mechanical components [34], make AR an ally in developing training tools, and support discussions and research through the relationship network created in this field.

Additionally, the improvement of space-time visualization is determinant because it is the basis for understanding and problem-solving in academic settings and engineering activities. Augmented reality improves mathematics learning by stimulating the development of mental models of mathematical entities or objects from oral narrative practices or graphics through the interactions of real and virtual elements. Specialized augmented reality software boosts collaboration skills using simulations; it promotes exchanges among the participants to solve challenges or problems defined in any scenario [35].

Also, tracking is the third area of interest in the list of trends, a significant concept in this analysis. Monitoring agile and effective augmented reality systems become relevant from gesturing actions and locating immovable objects designed in real-time interactive environments. This technology tracks manual gestures or features based on precise search algorithms, improving the user immersion experience [36-38].

Regarding "gamification," it is crucial to implement game dynamics in informal educational activities through AR mobile applications. Games supplement textual documents. Their incorporated (superimposed) information supports user interaction's dynamization and strengthens experiences to improve the processes of transfer and appropriation of learning [39-40].

The reviewed authors mention gesture recognition; they describe these AR systems applied in training processes as a tool that provides real-time information on static and dynamic gestures and their location, increasing the level of user satisfaction and impacting the training obtained [41].

Regarding the head-up display topic, the increase in the development of various advanced augmented reality instruments (intelligent systems) is used in different fields to obtain information about the environment that may affect users or help them understand a complicated situation. The head-up displays are usually applied in aerial activities (pilotage) and military training. This intelligent technology facilitates the detection of objects while maintaining a broad view of the context, enhancing aspects such as security in various environments [42].

4.1.5 Trends related to the content type

The trend analysis in the use of augmented reality for educational purposes is oriented towards a dynamic-content perspective. The contents and appearance vary when the user interacts with them [20]. 72% of the articles analyzed sought to leverage this potential in augmented reality technologies to propose more useful tools from different knowledge areas. For example, in higher education, the dynamic approach has encouraged the fast and safe exploration of complex engineering concepts, overcoming access difficulties in the classroom due to hardware costs and requirements [43].

In this context, [44] propose geographic information systems from an interface that allows visualizing risks, offering simulations that educate and involve the local community through the interactive visualization of risk and vulnerability. The objective is to achieve integral learning. From other perspectives, dynamic augmented reality components have been incorporated to integrate virtual objects and video clips into the interactive environment for learning a second language [45]. It has also been used in firefighter training with virtual and augmented cognitive stimulation integrated with computational models and decision tools to raise awareness of the situations and challenges that firefighters face [46].

This boom of increasingly dynamic approaches to augmented reality has been taking place due to the static technologies' limitations in achieving better performance and process control [47]. For example, in the control of uncrewed aerial vehicles, the 2D screen is too limited to visualize the scenarios. In this case, the static data is complemented with dynamic scenarios that simulate route points and flight status, contributing more significantly to its operation precision. Additionally, although less potential and efficient, the static scenarios can support the development of 3D dynamics, arriving at a better approach to the technological needs of augmented reality development [48]. In medical education, static-gesture-recognition algorithms, dynamic-gesture recognition, and recognition algorithms complement each other to perform human-computer interactions (HCI) in a friendly and synchronous way [49].

It should be clarified that the type of content to be used in an augmented reality application (static or dynamic) depends on the subject and the learning experience intended to be provided to the student [21]. Additionally, most of the development and design projects of this type of application consider the Cognitive Theory of Multimedia Learning and the Cognitive Load Theory as bases for its development [22].

4.2 Article comparison based on the content type

From the articles compiled in the bibliometric analysis, the following research questions were analyzed in-depth; these had not been directly addressed by the articles found in the state-of-the-art analysis:

1. What are the types of content used in AR?
2. How do the types of content affect learning?
3. What are the methodological approaches applied in content development?
4. How should the impact of educational content be assessed?

Once the inclusion and exclusion criteria were applied, 29 research papers were obtained. These were analyzed considering several criteria, such as the type of content, and an evaluation of how it affected the subject's affective and cognitive results was performed. The analysis summary is shown in Table 4, including the 23 research works that offer details for each of the interests' features.

Table 4.
Comparative table of augmented reality research works considering content type, methodology, variables, experimental design, and results.

Authors /year	Type of content	Methodology	Studied variables	Experimental design	Experimental Results
Akçayir et al. 2016 [50]	Text, video, animations	Storyboard	Affective: *Satisfaction, motivation, joy, attitude;* Cognitive: *memory*	Quasi-experimental and interpretive	Dynamic content such as video and animations provided better recall and higher motivation.
Bursztyn et al. 2017 [51]	Text, images, videos	Not specified	Affective: *Motivation;* Cognitive: *memory*	Quasi-experimental	No differences in memory were reported; however, the images and video provided more motivation.
Cai et al. 2017 [52]	Animations	Not specified	Affective: *Attitude;* Cognitive: *memory*	Quasi-experimental	The animations improved the attitude and memory
Cascales-Martinez et al. 2017 [53]	Text	Scrum	Affective: *Motivation;* Cognitive: *Apply knowledge*	Quasi-experimental	No significant differences were found.
Chen et al. 2016 [54]	Text, image, 3D models	Storyboard	Affective: *Motivation;* Cognitive: *understanding*	Experimental design	There were differences between the types of content considering the comprehension
Chen and Wang 2015 [55]	Image	Use of references	Affective: *Joy;* Cognitive: *self-assessment*	Quasi-experimental and interpretive	No significant differences were found.
Chiang et al. 2014 [56]	Image, text	Storyboard	Affective: *Engagement;* Cognitive: *knowledge creation*	Content Analysis	The image achieves greater engagement than the text
Cuendet et al. 2013 [14]	Image	Not specified	Cognitive: *Understanding*	Interpretative	No results of interest are reported

Dünser et al. 2012 [57]	Text, video, animations	Not specified	Cognitive: *memory*	Quasi-experimental	Animations and videos make remembering easier than text
Enyedy et al. 2015 [58]	Video	Use of references	Affective: *Engagement;* Cognitive: *knowledge creation*	Case study	No results of interest are reported
Estapa and Nadolny 2015[59]	Video, websites, audio, images	Storyboard	Affective: *Motivation;* Cognitive: *Memory*	Quasi-experimental	No significant differences were found.
Frank and Kapila 2017 [60]	Video, text	Not specified	Affective: *Engagement;* Cognitive: *Memory*	Experimental and interpretive design	The video provides more engagement and recall than the text
Gutiérrez de Rave et al. 2016 [61]	3D models	Storyboard	Cognitive: *Memory*	Experimental	No significant differences were found.
Ibañez et al. 2016 [28]	Text, images, animations	Storyboard	Cognitive: *Memory*	Content analysis	The animations allow having higher recall than the text
Kamarainen et al. 2013 [62]	Text, images, audio, video	Not specified	Affective: *Effectiveness, Engagement, attitudes;* Cognitive: *Memory*	Experimental and interpretive design	There are no significant differences.
Lin et al. 2015 [63]	3D objects	Storyboard	Affective: *attitudes;* Cognitive: *Memory*	Experimental and interpretive design	3D objects favor motivation and memory
Liou et al. 2016 [64]	3D objects, animations, video, audio	Use of references	Cognitive: *Memory*	Quasi-experimental	Although they do not directly contrast the contents, a better recall is achieved with 3D objects and animations
Salmi et al. 2017 [65]	Not specified	Not specified	Affective: *The interest and enjoyment;* Cognitive: *Memory*	Quasi-experimental	No information is reported.
Sommerauer and Muller 2014 [66]	Video	Use of references	Cognitive: *Memory*	Experimental design	There are no significant differences.
Wang et al. 2014 [67]	Text, 3D models, animations	Storyboard		Content Analysis	No results of interest are reported
Yoon et al. 2017 [68]	Animations	Storyboard		Quasi-experimental and interpretive	No results of interest are reported
Zimmerman et al. 2016 [69]	Text, images	Scrum	Affective: *Attitude,* Cognitive: *Memory*	Quasi-experimental and ethnographic	There are no significant differences.
Hincapié Montoya et al. 2016 [47]	3D models, animations, text, audio	Storyboard	Affective: *Motivation;* Cognitive: *Understanding*	Experimental and interpretive design	3D animations and models achieve better motivation and understanding

In the analysis, there were ten quantitative studies, seven qualitative studies, and 12 mixed studies. The mixed studies were the most used, with a percentage of 41.3%. The mixed studies used an experimental and interpretive design, that is, a qualitative and quantitative focus.

Cognitive and affective level categories are proposed to determine the impact of the research works on learning. Twelve research works do not report information about the results, and five research works do not report significant differences, considering how the type of content impacts learning. Regarding the research works in the literature review, only 17 studies measured the possible effects of using different contents. The most evaluated affective variable was *motivation*, and the most evaluated variable from the cognitive point of view was *memory*.

When analyzing the content type, it was found that 12 of the studies used text-based content, nine used 2D images, eight studies used animations, six used 3D objects, and videos were used in six of the applications.

Regarding the content design methodology, ten articles reported storyboards, two used agile development methodologies such as Scrum, six used references as edited images and videos but did not use a content design methodology. Eleven did not use a specific content design methodology for the augmented reality application.

5 Conclusions

This research aimed at studying the Augmented Reality educational applications and content type by using a bibliometric and state of the art analysis. The specific conclusions about the use of different content paradigms are the following:

- Several works considered different content types in their augmented reality applications designs; however, none contrasted the difference in content types with the affective and cognitive results quantified in the experimental approaches. Only a few studies contrasted the influence of the type of content on the quantified variables.
- There is no preferred design scheme, framework, or methodology for the development of augmented reality content. Most of the works proposed a design based on the developers' and researchers' expertise without specifying the methodology.
- The content-type defined as 3D models and animation has a better impact on memory and motivation than other content such as text, images, and videos.

The findings in this study provide the following insights for future research: There is a need to apply adoption models that allow us to understand the factors that condition the use of Augmented Reality in emerging economies, mainly because these technologies have been prioritized in developing countries. There is, therefore, a definite need to apply new Augmented Reality technologies that consider potential users' cultural factors when attempting to improve the dissemination of technology. There is also the need to explore Augmented Reality applications designed for people with special learning needs or cognitive or motor limitations. Several questions remain to be answered. For example, an intriguing research question concerns what the research groups are doing (per university or across universities) to identify future applications and collaborations in Augmented Reality.

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