International Journal of Learning, Teaching and Educational Research
Vol. 22, No. 2, pp. 302-322, February 2023
https://doi.org/10.26803/ijlter.22.2.17
Received Dec 27, 2022; Revised Feb 19, 2023; Accepted Feb 22, 2023

Contribution of Augmented Reality in Teaching and Learning, in the Midst of COVID-19: Systematic Review

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Abstract. The state of emergency declared in many countries due to the pandemic led universities to consider the incursion of technological

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tools to give continuity to the teaching and learning process; therefore it is significant to explore results regarding the application of augmented reality (AR) in education. The objective of the research is to generate knowledge from the systematic review of the literature framed in the context of virtual teaching in the midst of COVID-19. A bibliographic review was carried out under a mixed approach, exploratory and descriptive level. The findings showed that the application of AR in learning is not exclusive to any engineering specialty, but, on the contrary, it is versatile and adapts to various curricular contents; Also, the way in which augmented reality is applied is more focused on the use of mobile augmented reality (mobile AR) technology with markerless activation. In addition, it was identified that the factors that were analysed to demonstrate the contribution of AR were: the effectiveness of learning, the predisposition to use AR and the motivation generated by AR. With which it can be concluded that AR in this context has managed to position itself as a learning resource that goes beyond a tool linked to a virtual classroom, since it allows the student to transcend towards immersion in environments with high contextual fidelity. Future research should address which factors influence the improvement of mobile AR activation sensitivity, in different contexts.

Keywords: augmented reality; engineering students; virtual teaching; systematic review

1. Introduction

The state of health emergency declared due to the global pandemic generated a situation in the social, economic and educational fields of having to use technological tools and virtual platforms in contributing to the development of remote education (Nikimaleki & Rabbi, 2022; Pinzón, 2020). Remote education is strongly characterised by the use of technology for both theory and practice sessions and it is part of the responsibility of the educational institution, teachers and students, who, together, must dedicate efforts to achieve success in both a synchronous or asynchronous modality (Ferreira et al., 2021). Synchronous tools in remote education require that the teacher and the student be connected since it is a scenario of mutual interaction; however, the interaction is not a guarantee of quality (Avendaño et al., 2021; Zea et al., 2020). Therefore, this interaction must be presented through activities that present an intuitive interface that allows the rapid correction of errors and has a constructivist character, in which participation and exchange between students are encouraged, through presentation of objects with character multimedia (Barroso-Osuna et al., 2019; Muñoz & Rigondeaux, 2020).

Education in recent years has changed the way of transmitting and delivering knowledge to students through emerging technologies which are dynamic and flexible when implemented in the teaching-learning process and which can be accessed through smart devices (Vicenzi, 2020; Zuñiga et al., 2021). The emerging technologies, especially information and communication technologies (ICTs), allow access, management and exchange of information through different tools such as intelligent equipment (Díaz, 2020; Zindón-Calle & Avila-

Mediavilla, 2021). The use of ICTs improves student learning, which is why it has become an indispensable resource in schools and universities (Ojeda-Chimborazo, 2020). Thus, the rapid development of ICTs has generated new technologies such as big data, virtual reality and augmented reality (Romano, 2022).

From the 1980s until now, technologies such as virtual reality and AR have been in constant evolution (Alvarado et al., 2019), managing to mix real-world objects in a virtual environment (Basogain et al., 2007; Martínez et al., 2021). AR is a non-traditional interface and, therefore, arouses a lot of interest due to its technological development and its applications (Akçayır & Akçayır, 2017; Romano & Moyano, 2021 Ruiz et al., 2017); Therefore, it is increasingly used in different disciplines (Mitaritona, 2018) such as in the field of education for teaching and learning (Low et al., 2018) since they promote new forms of education and guarantee equal opportunities. AR can also be used in different fields such as medicine, engineering or education, for training and trials, for example Chang & Hwang, 2018; Otero & Galindo, 2017; Rodríguez et al., 2019).

The massive use of mobile devices such as cell phones or tablets has contributed to the stronger insertion of AR in university education (Çelik & Ersanli, 2022), evidencing improvements in the development of cognitive skills, motivating and increasing the degree of student participation (Leiva & Moreno, 2015; Osuna & Pérez, 2016; Sumardi et al., 2022). As such, it arouses interest in learning since it is seen as an interaction strategy between two different scenarios, such as the real world and virtual objects (Cevahir et al., 2022; Ziden & Ifedayo, 2022) in addition to which it also increases the positive attitude, managing to extract creative capacity from the student (Cabero-Almenara et al., 2018; Marín-Díaz et al., 2022). Thus, AR has advantages over other technologies such as virtual reality, since, in laboratory practices or workshops, it allows performance in a real-world scenario and tactile interaction of the student (Iqbal et al., 2022).

Based on what has been described, the relevance of the research is to generate knowledge from the systematic review of the literature framed in the context of virtual teaching and learning in the midst of COVID-19, seeking to answer the following research questions: RQ1: In what areas or specialties of engineering was AR applied? RQ2: How was AR applied in the different areas or specialties of engineering? and RQ3: What were the factors analysed that evidenced the contribution of AR in learning? For which the PRISMA (Preferred Reporting of Items for Systematic Reviews and Meta-Analysis) method will be used, which will allow the selection of scientific articles from a process based on inclusion and exclusion criteria. The study seeks to contribute to the exploration of the state of the art or state of the question regarding the applications that have been developed in the field of university education to improve the learning of engineering students and which can be replicated in fields of teaching and learning, whether face-to-face or hybrid.

2. Methodology

2.1 Type and level of investigation

From the methodological point of view, the research is of a theoretical type that starts from an exploratory level to reach a descriptive level, using the mixed approach, regarding the contribution of AR in the continuity of learning in engineering students in the context of virtual teaching and learning amidst COVID-19. It is of a theoretical type because it is intended to explore the state of the art or state of the question of AR and its contribution to the teaching and learning process of engineering students in the midst of COVID-19. Thus, it is also of an exploratory and descriptive level because it intends to address essential aspects of a specific problem identified and defined through research questions; reaching a descriptive level while seeking to express the level of frequency of the dimensions explored in each research question based on the results found from the systematic review.

Concerning the eligibility of the scientific articles reviewed, PRISMA was used to identify, select, evaluate and synthesise results and importance of scientific evidence on the subject in question (Dreifuss-Serrano et al., 2018). In this regard, the use or application of the PRISMA statement in research based on systematic reviews contributes to reducing the risk of bias in the choice and compilation of bibliographic sources (Echeverry et al., 2018).

2.2 Search strategy

The search strategy was focused on the identification of keywords written in English and Spanish, such as "Augmented reality", "(realidad aumentada)", "improvement", "(mejora)", "contribution", "(contribución)", "application”, “(aplicación)”, “learning”, “(aprendizaje)”, “university”, “(universidad)”, “engineering students”, and “(estudiantes de ingeniería)”, in four prestigious databases namely: SAGE, Taylor & Francis, ERIC and Scopus. In order to achieve an optimal search of the literature, this study adapted the suggestions of Santiago et al. (2019), in which, to be relevant, the identification of descriptors should be linked to keywords of the topic under study.

Table 1 shows the search equation established for each database, in which an equation was designed with the combination of Boolean operators. Linares-Espinós et al. (2018) recommend using a wide variety of synonyms and terms related to these descriptors through “OR” and “AND” Boolean operators, which this study also followed.

Table 1. Search Equation through Boolean indicators

Database	Search equation
SAGE	((((“realidad aumentada”) OR (“augmented reality”)) AND ((“estudiantes de ingeniería”) OR (“engineering students”))) AND ((“contribución al proceso de aprendizaje”) OR (“contribution of the learning process”)))
Taylor & Francis	((((“realidad aumentada”) OR (“augmented reality”)) AND ((“estudiantes de ingeniería”) OR (“engineering students”))) AND ((“contribución al proceso de aprendizaje) OR (contribution of the learning process”)))
ERIC	(((“realidad AND aumentada”) OR (“augmented AND reality”))) AND (((((“contribución del proceso de aprendizaje”) OR (“aplicación del proceso

	de aprendizaje") OR ("aportes del proceso de aprendizaje"))) OR ((("contribution of the learning process") OR ("application of the learning process") OR ("contributions of the learning process")))) AND ((("estudiantes de Ingeniería") OR ("alumnos de Ingeniería") OR ("estudiantes de pregrado de Ingeniería") OR ("engineering students") OR ("engineering undergraduate students"))))
SCOPUS	((TITLE-ABS-KEY (realidad AND aumentada) OR TITLE-ABS-KEY (augmented AND reality))) AND ((((TITLE-ABS-KEY (contribución AND del AND proceso AND de AND aprendizaje) OR TITLE-ABS-KEY (aplicación AND del AND proceso AND de AND aprendizaje) OR TITLE-ABS-KEY (aportes AND del AND proceso AND de AND aprendizaje))) OR ((TITLE-ABS-KEY (contribution AND of AND the AND learning AND process) OR TITLE-ABS-KEY (application AND of AND the AND learning AND process) OR TITLE-ABS-KEY (contributions AND of AND the AND learning AND process)))) AND ((TITLE-ABS-KEY (estudiantes AND de AND ingeniería) OR TITLE-ABS-KEY (alumnos AND de AND ingeniería) OR TITLE-ABS-KEY (estudiantes AND de AND pregrado AND de AND ingeniería) OR TITLE-ABS-KEY (engineering AND students) OR TITLE-ABS-KEY (engineering AND undergraduate AND students))))

Furthermore, as part of the search strategy process, inclusion and exclusion criteria were defined, thereby reducing bias and eliminating irrelevant and low-quality studies, which led to the identification of bibliographic references or scientific articles eligible to be included in the systematic review process. López and Lopez (2022) point out that it is fundamental and important to determine exclusion and inclusion criteria in the search for scientific articles in order to obtain more relevant sources that contribute to the systematic review process. Table 2 shows the inclusion and exclusion criteria established for the eligibility of scientific articles. Likewise, with the purpose of reducing the risk of bias, the initial phase was the review of each scientific article by pairs of authors, and, in the event of any discrepancy or difference, it was transferred to another pair of authors for a second review. However, in order to be even more rigorous with respect to the presence of risk of bias, the articles that reached the eligibility phase were evaluated by independent reviewers (López-Angulo et al., 2020; Saéz et al., 2020), who verified the content of each scientific article with respect to the information provided on the inclusion and exclusion criteria as well as the research questions.

Table 2. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Articles that have been developed under the scope of university education	Scientific articles that have been developed in the field of primary or secondary education
Scientific articles that focus on the learning of students in professional engineering careers	Scientific articles that do not focus on the learning of engineering students
Articles developed during the years 2020 to 2022.	Articles published before the year 2020.
Open access scientific articles	Scientific articles that are not open access, books, and conference proceedings.
Articles written in Spanish or English	Articles that have not been written in Spanish or English

2.3 Data extraction and critical evaluation

After the application of inclusion and exclusion criteria, in the process of eligibility of scientific articles, a critical review was carried out, which consisted of the total review of each scientific article with the purpose of finally establishing the eligible sources for the review and further eliminating the possible bias present in the selection of bibliographic references. In this regard, Correa and Rosa (2019) pointed out that, for the eligibility of articles, the titles, abstracts and keywords of all the identified studies must be initially reviewed and, in the event that the abstract does not make it possible to assess the eligibility of the same, proceed with the review of the complete article as part of a critical and exhaustive evaluation; through this it will be possible to establish the scientific articles included for the systematic review.

In order to show the sequence of selection of scientific articles determined under the application of the inclusion and exclusion criteria, Figure 1 shows the flow chart for the selection of scientific articles as established using PRISMA.

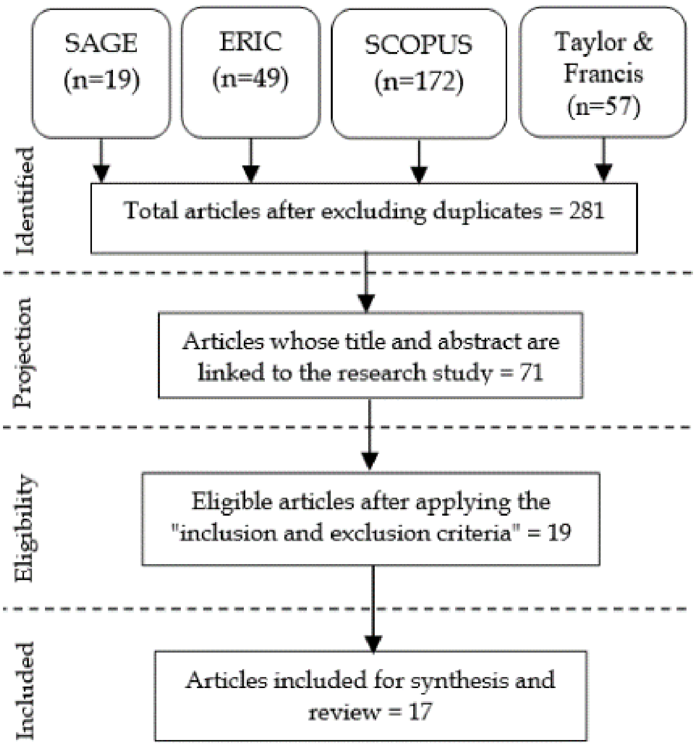

Figure 1. Article extraction procedure based on PRISMA statement

3. Results

3.1 Scientific articles included for the systematic review

For the articles finally included in the review and development of the synthesis of results and scientific evidence regarding the applications of AR in improving learning in engineering students, Figure 2 shows the distribution by year of publication of the 17 selected scientific articles.

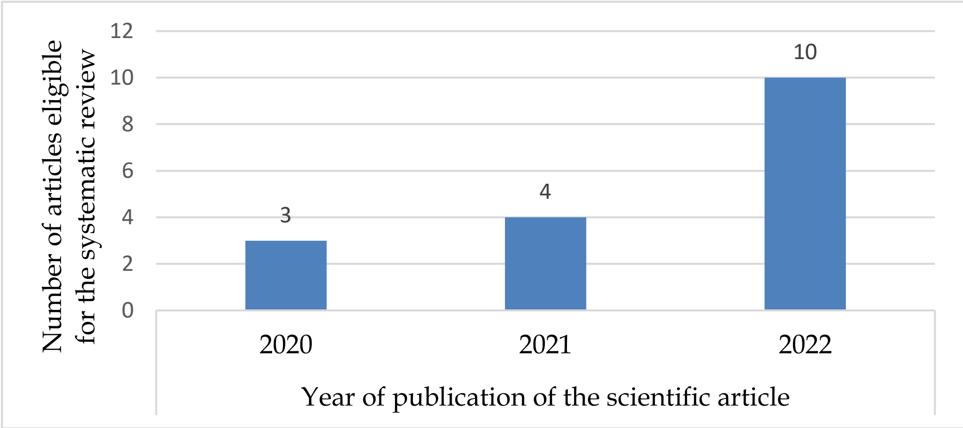

Figure 2. Distribution by year of publication of scientific articles included for the systematic review

As can be seen in Figure 2, from the 17 scientific articles eligible for the systematic review, there is a trend towards an increase in the publication of scientific articles, which shows that augmented reality is one of the emerging technologies in these times and whose incidence is greater with respect to the field that universities have been developing jointly with the intent to give continuity to academic service in the context of virtual teaching due to the pandemic and post-pandemic era.

3.2 Engineering areas or specialties in which augmented reality was applied

From the systematic review of the literature and as shown in Figure 3, it was identified that, to a greater proportion, AR technology is applied in the area or specialty of mechanical engineering. In this regard, Akkuş and Arslan (2022) applied AR to a group of 33 students, with the purpose of investigating the improvement of spatial skills in the subject of technical drawing, for which they carried out an exploratory quasi-experimental type of investigation. Peng-Fei et al. (2022) developed an investigation on a sample of 104 students divided into two groups, in which one of them was considered the control group, with the purpose of investigating the effect of the application of AR in the improvement of learning of the subject of mechanical assembly. Prasetya et al. (2020) carried out research to measure the impact of the application of AR in the development of worksheets, to improve the ability to understand subjects related to the development of drawings and mechanised processes with programming CNC machines (numerical control machining).

Maltais and Gosselin (2022) developed an investigation regarding the application of AR to generate virtual tours in heating and air conditioning installations, which helps learning, in the context of the pandemic. Likewise, Mariakis et al. (2021) developed an application based on AR to improve the learning of the mechanical drawing book, in which they sought for students to have a better idea of the object when analysing it in 3D.

Another engineering specialty in which AR is applied is electronic engineering. In this regard, Kumar and Mantri (2022) evaluated the intention to use the

ARITE system (Augmented Reality Interactive Table-top Environment) in real time, using a sample of 34 teachers, for the teaching of the subject of embedded systems through the use of the acceptance of technology model. Tuli et al. (2022) developed a quasi-experimental investigation evaluating the intervention of AR in the learning of fundamentals of electronics in first-year students, for which they used two groups of students, with a total sample of 107 participants. Dutta et al. (2022) carried out an experimental investigation to identify thinking regarding the use of mobile AR applications in a sample of 90 engineering students divided into two groups based on keyboard and marker. Likewise, through a pilot application of AR, Silva et al. (2022) developed a study on identifying the level of knowledge of students about this technology, as well as establishing the feasibility in the context of distance education; in addition they also sought to obtain whether students are interested in using it to improve their learning.

Finally, it was also possible to identify other areas of engineering that applied AR to a lesser extent for the continuity of learning, as found in Laurens-Arredondo (2022), when developing an application for industrial engineering students, Enzai et al. (2020) for electrical engineering students, Thornton and Lammi (2021) for graphic engineering students, Nadeem et al. (2021) for computer engineering students, Lam et al. (2020) in the area of chemistry, Opris et al. (2022) for power engineering students, Sidhu and Ying (2022) for radio engineering students, and Sugandi et al.(2022) for civil engineering students. Figure 3 shows the percentage distribution of the reviewed publications that applied RA by area or specialty in engineering, in which 29% of reviewed references correspond to the specialty of mechanical engineering, 23% to electronic engineering specialty, and 6% all other specialties.

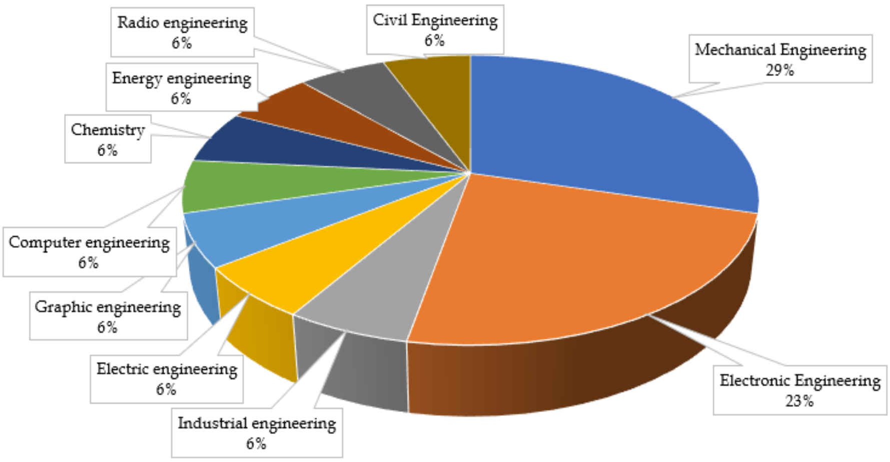

Figure 3. Percentage distribution of scientific articles by specialty in engineering

3.3 Application of AR in the different engineering areas or specialties

From the systematic review, it was determined that, for the application of AR, there are two hardware-based techniques that have been used to carry out the continuity of learning in the context of virtual teaching, mobile augmented reality (mobile AR) and AR through computer and web camera, which I will call PC-camera. Thus, it was also identified from the systematic review that three types are used to activate or trigger the AR application: activation by marker, activation without marker and activation by QR code. Table 3 shows the technique used as well as the type of activation per scientific article reviewed.

Table 3. Technique and type of activation used in AR applications

Bibliographic reference	AR technique		AR activation type		
	Mobile AR	PC-Camera	with marker	no marker	by QR code
Kumar and Mantri (2022)		x	x		
Tuli et al. (2022)	x		x		
Dutta et al. (2022)	x		x		
Laurens-Arredondo (2022)	x		x		
Enzai et al. (2020)	x		x		
Thornton and Lammi (2021)	x			x	
Nadeem et al. (2021)	x			x	
Akkuş and Arslanb (2022)		x			x
Peng-Fei et al. (2022)	x			x	
Prasetyaet al. (2020)	x			x	
Lam et al. (2020)	x		x		
Opris et al. (2022)	x				x
Daineko et al. (2022)	x			x	
Silva et al. (2022)	x				x
Sugandi et al. (2022)	x			x	
Maltais and Gosselin (2022)	x			x	
Mariakis et al. (2021)	x			x	

Based on the findings of the systematic review, we proceeded to obtain a cross-tabulation analysis between the area or specialty and the AR technique in the development of the application, for the continuation of learning in the context of virtual learning. From Table 4, it can be identified that of the two AR techniques identified, 88.2% of reviewed scientific articles have used the mobile AR technique (Mobile AR), of which 41.1% have focused on applications for mechanical engineering and electronic engineering specialties. However, when focusing on these two areas or engineering specialties, it can be identified that in both the AR technique with computer and camera (PC-Camera) has been used which allows establishing that the techniques used are independent of one or another area or specialty.

Table 4. Result of the cross-tabulation analysis between the area or specialty and the AR technique

		AR technique		Total
		Mobile AR	PC-Camera	
Area or specialty	Chemistry	5.9%	0.0%	5.9%
	Civil engineering	5.9%	0.0%	5.9%
	Computer engineering	5.9%	0.0%	5.9%
	Electrical engineering	5.9%	0.0%	5.9%
	Electronic engineering	17.6%	5.9%	23.5%
	Energy engineering	5.9%	0.0%	5.9%
	Graphic engineering	5.9%	0.0%	5.9%
	Industrial engineering	5.9%	0.0%	5.9%
	Mechanical engineering	23.5%	5.9%	29.4%
	Radio engineering	5.9%	0.0%	5.9%
Total		88.2%	11.8%	100.0%

Likewise, from the systematic review it was possible to identify that of the three types of activation used to implement the AR technology, 35.3% of the total articles used "with markers", of which 17.6% were applied in the specialty of electronic engineering. While of the 47.1% of the total articles that used "without markers", 23.5% were applied in the specialty of mechanical engineering. On the other hand, 17.6% used activation by "QR code". Table 5 shows the results of the cross-tabulation analysis.

Table 5. Result of the cross-tabulation analysis between the area or specialty and the type of activation

		Augmented reality activation type			Total
		with marker	no marker	by QR code	
Area or specialty	Chemistry	5.9%	0.0%	0.0%	5.9%
	Civil Engineering	0.0%	5.9%	0.0%	5.9%
	Computer engineering	0.0%	5.9%	0.0%	5.9%
	Electrical engineering	5.9%	0.0%	0.0%	5.9%
	Electronic engineering	17.6%	0.0%	5.9%	23.5%
	Energy engineering	0.0%	0.0%	5.9%	5.9%
	Graphic engineering	0.0%	5.9%	0.0%	5.9%
	Industrial engineering	5.9%	0.0%	0.0%	5.9%
	Mechanical Engineering	0.0%	23.5%	5.9%	29.4%
	Radio engineering	0.0%	5.9%	0.0%	5.9%
Total		35.3%	47.1%	17.6%	100.0%

Finally, a cross-tabulation analysis was carried out between the AR technique and the type of activation, in which it was obtained that, for the cases in which the "mobile augmented reality" technique was used, these in greater proportion used the activation "without markers" representing 47.1%, followed by activation "with markers" representing 29.4%, while 11.8% used activation by QR code. In the case of those who used the technique supported by a computer and web camera, 5.9% used the "markerless" activation, while the other 5.9% used “QR code” activation. Table 6 shows the results of the cross-tabulation analysis between the dimensions under study.

Table 6. Results of the cross-tabulation analysis between the augmented reality technique and the type of activation

		AR activation type			Total
		with marker	no marker	by QR code	
AR technique	Mobile AR	29.4%	47.1%	11.8%	88.2%
	PC-Camera	5.9%	0.0%	5.9%	11.8%
Total		35.3%	47.1%	17.6%	100.0%

3.4 Factors that analysed the evidence of the contribution of AR in learning

From the review of the different investigations on AR and its contribution to the learning of engineering students in the field of virtual teaching, it was possible to identify that the results are mainly focused on three factors, these being: "learning effectiveness" representing 58.82% of the total scientific articles reviewed; "predisposition to use AR in learning", representing 23.53%; and "motivation generated by AR in learning", representing 17.65%. In addition, all the scientific articles reviewed present qualitative results, while only 41.18% present quantitative results. Table 7 shows a classification of scientific articles reviewed by type of study factor and results found of the qualitative and quantitative type.

Table 7. Factors analysed and results that show the contribution of AR in learning

Factors	Results	Reference
Learning effectiveness	Qualitative: It identified a positive relationship between participation in experiences with mobile AR technology and learning. Quantitative: It evidenced an 11.4% increase in the level of student learning when applying AR technology.	Laurens-Arredondo (2022)
	Qualitative: They found that from the application of AR, learning attitudes and their academic performance have a significant positive relationship.	Akkuş and Arslan (2022)
	Qualitative: They evidenced that, through AR, the efficiency of learning mechanical assembly content was significantly improved.	Peng-Fei et al.(2022)
	Qualitative: They identified that there is evidence of improvements in the ability of students before and after the application of AR.	Prasetya et al. (2020)
	Qualitative: They developed an AR system for remote laboratories whose application led to the	Opris et al. (2022)

	conclusion that these allow greater learning possibilities. Quantitative: They identified through a survey that the advantages generated by the application of AR are focused on: 69% compared to a connection closer to practice 69% and 68% accelerating and deepening of learning, respectively.	
	Qualitative: They concluded that AR improved the student experience due to the level of interactivity and involvement, as well as the freedom it offers improves the process of understanding class material.	Daineko et al. (2022)
	Qualitative: They concluded that the application of augmented reality content significantly improved learning.	Maltais and Gosselin (2022)
	Qualitative: They concluded that the use of AR in geometric conversions to three-dimensional CAD models improves the understanding of 3D figures.	Mariakis et al. (2021)
	Qualitative: In relation to the use of ARChemEx as an AR tool applied to student learning, it is concluded that the greater the use or involvement of students in the application, the more knowledge they can retain.	Lam et al. (2020)
	Qualitative: They managed to identify the stages for the development of content based on AR for student learning, which establishes that competencies must be identified, content and learning media designed, and finally dissemination and evaluation carried out.	Sugandi and Wena (2022)
Predisposition to use AR in learning	Qualitative: They managed to show that there is a predisposition of teachers for the use of the ARITE system based on AR to improve student learning. Quantitative: They determined that the level of attitude of teachers towards the use of the ARITE system is 0.924 and intention to use 0.918.	Kumar and Mantri (2022)
	Qualitative: They identified that the keyboard-centric AR application has a significant interaction with the student, which will contribute to the improvement of their learning. Quantitative: The level of interaction reached a perceived softness score of 84.57 and a general average score of 4.17 for manipulative capacity and comprehension.	Dutta et al. (2022)

	Qualitative: They determined that the application developed through augmented reality is accepted by teachers, so it can be perceived that it will involve students to improve the learning process. Quantitative: It was possible to determine that more than 70% of those surveyed agree and strongly agree that they know the basic operation of AR technology.	Enzai et al. (2020)
	Qualitative: They determined that the markerless AR technology supported by multimedia resources was a useful and supportive method that motivates and helps the student to understand the handling of laboratory equipment. Quantitative: They were able to determine that the aforementioned application has an acceptance level of more than 87% of the students consulted.	Nadeem et al. (2021)
Motivation generated by AR	Qualitative: They determined that students have a positive attitude to the application of AR. Quantitative: They showed that there is a direct relationship between the use of the AR application and the academic performance of the students, with a Cohen value of 0.91.	Tuli et al. (2022)
	Qualitative: They determined that, through the Purdue spatial visualisation test, the augmented reality-based application has a positive influence on students' learning motivation.	Thornton and Lammi (2021)
	Qualitative: They determined as results of their research that some students, although they were unaware of AR technology, there is great interest in the use of this technology in their learning process; in this way students, teachers and the university institution benefit.	Silva et al. (2022)

Based on the results obtained in Figure 4, a model is shown in which it is possible to categorise the results obtained based on the research questions, the same ones that focused on identifying the areas or specialties in which AR were applied, as well as the techniques used and forms of activation or triggering of the AR application, and finally the factors analysed that evidenced the contribution of augmented reality in the learning of engineering students. In this way, in the model presented, the starting point is augmented reality, and that, when applied to different areas or specialties, relying on activation or firing techniques and elements, results in the categorisation of three contribution groups on the students of engineering in the field of virtual teaching and learning in the midst of COVID-19.

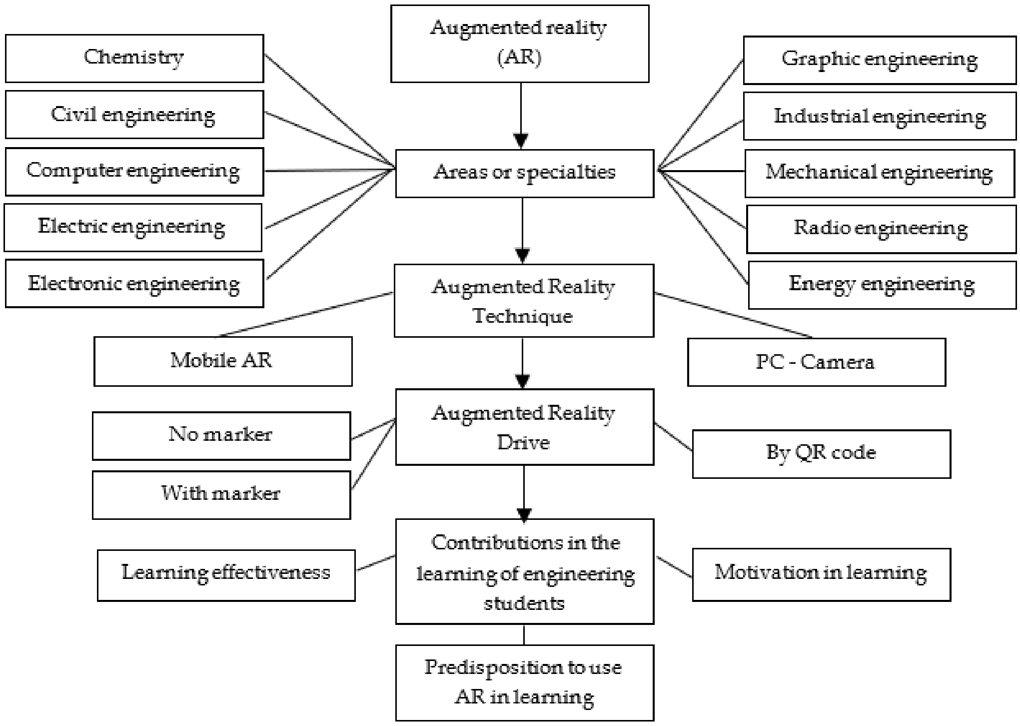

Figure 4. AR model and its application in the contribution of the learning process

4. Discussion

4.1 Regarding the areas or engineering specialties in which AR was applied

Based on the result regarding the areas or engineering specialties in which AR was applied to improve learning, it was possible to identify from the systematic review that were applied to a greater extent in the area of mechanical engineering and electronic engineering; however, results also showed that, in other specialties there is a lesser extent, so it can be inferred that it is not exclusive to any engineering specialty, but rather, on the contrary, it is versatile and adapts to various curricular contents and it is not even limited to subjects that, within their pedagogical hours, require laboratory hours or workshop hours, since it can easily be used to provide conceptual aspects through texts or books whose contents are activated through AR. Coinciding with the findings of this systematic review, Álvarez-Marín and Velázquez-Iturbide (2021) point out that the engineering areas in which AR is most applied is technical drawing and electronics; subjects related to the areas of mechanical engineering and electronic engineering which were found in this systematic review. Likewise, Anjos et al. (2020) found that,, when seeking to identify the area in which AR techniques are most applied through a systematic review that takes Web of Science (WoS) as a database, and a timeframe defined between 2000 and 2018, one of these areas is mechanical engineering; Based on what has been indicated, it can be evidenced that there is a coincidence in the identification of the engineering area; however, in the case of the specialty of electronic engineering, it is possible that they have not identified it because their temporal spectrum of study reached investigations up to the year 2018, while this systematic review focuses on the context of the results of scientific publications during the period of the COVID-19 pandemic, a period in which there is evidence of a boom in AR publications in the area of electronic engineering. However, as could also be evidenced from this systematic review, it is not possible to affirm that there are unique areas of application of augmented reality, so they can be applied to any area or specialty of engineering and even in other areas or specialties that are not linked to engineering studies such as medicine and architecture, graphic design, supporting what was indicated in the research by García et al. (2019) who, by carrying out a systematic review on augmented reality and the fields of application, found that it is applied in different areas.

4.2 Regarding the way in which AR was applied in the different areas or engineering specialties

From the result on how AR was applied in the different engineering areas or specialties, it was possible to identify that of the two AR techniques identified, 88.2% of scientific articles reviewed, while only 11.8% actually used computer augmented. Thus, it was also determined that 35.3% of the total articles reviewed used activation "with markers", 47.1% used activation "without markers", and 17.6% used activation through "QR code". In this regard, in their systematic review Papakostas et al. (2021) identified, that, of a total of thirty-two articles reviewed, the majority made use of tools for the application of AR such as smartphones or mobile devices, the same ones that make use of markers with 3D content. With this, it is possible to improve the spatial capacity of students in the use of AR in their learning. Based on what has been stated, it is evident that, given the build of mobile devices and the displacement capacity that these smartphones present in comparison to a computer, the interfaces and actuation elements linked to the mobile augmented reality technique (Mobile AR) stand out. However, one aspect to be analysed in future research is the factors that are linked to the improvement of the activation sensitivity of AR applications in different contexts.

4.3 Regarding the factors analysed that evidenced the contribution of AR in learning

Likewise, regarding the result of which of the analysed factors evidenced the contribution of AR in learning, it was possible to identify from the systematic review that they mainly focused on three factors: "learning effectiveness" representing 58.82% of the total articles reviewed; "predisposition to use AR in learning", representing 23.53%; and "motivation generated by augmented reality in learning", representing 17.65%. In this regard, Anjos et al. (2020) concluded that, in all AR applications in the learning process, the results focus on improving the learning rate and academic performance, with both linked to learning effectiveness; they also pointed out that AR applications have a significant impact on the learning process. In the same line, Ali et al. (2017) concluded from a systematic review of the literature on AR applied to engineering learning sessions that this technology significantly improves visualisation and learning skills. It also represents a relevant factor as a learning material in class that contributes to the transfer of knowledge. The results show that AR has transcended significantly during the context of COVID-19, managing to position itself not only as a complement to virtual teaching, but also allowing the limitations of interactivity and student exploration to be overcome to link theoretical knowledge with practical ones in class sessions, achieving a high level of contextual fidelity, which has been much discussed around synchronous and asynchronous learning.

5. Conclusion

In relation to the formulation of the questions that led the systematic review, it is concluded that the engineering areas or specialties that applied augmented reality are diverse, finding applications to a greater extent in the areas of mechanical engineering and electronic engineering; however, augmented reality is not exclusive to any engineering specialty, but rather, on the contrary, it is versatile and adapts to various curricular contents; And it is not even limited to subjects that, within their pedagogical hours, require laboratory hours or workshop hours, since it can easily be used to provide conceptual aspects through texts or books whose contents are activated through augmented reality. In addition, it is evident that, given the build of mobile equipment and the displacement capacity that these smartphones present in comparison with a computer, the interfaces and actuation elements linked to the mobile augmented reality technique (Mobile AR) stand out; however, one aspect to analyse in future research is the factors of mobile equipment that are linked to the improvement of actuation sensitivity in different contexts. Finally, augmented reality has transcended significantly during the context of COVID-19, managing to position itself not only as another complement to virtual teaching, but also allowing the limitations of interactivity and student exploration to be overcome in order to link theoretical knowledge with practical ones in class sessions, achieving a high level of contextual fidelity, which has been much discussed around synchronous and asynchronous learning. Future research should address which factors influence the improvement of mobile AR activation sensitivity in different contexts.

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