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The Use of Augmented Reality in Latin-American Engineering Education: A Scoping Review

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Abstract

As part of a recent change, Augmented Reality (AR) has filled engineering classrooms, being employed for various pedagogical purposes around the world. However, little is known about the different features and uses of this technology in Latin America. This Scoping Review asks how are educational AR systems designed, used and evaluated in the region, comparing this to the international literature. To address this question, we charted 36 conference papers and scientific articles, taking care of the quality gaps and methodological diversity within our sample. Our results show that, even though most converge on conventional research, design and pedagogical practices, engineering educators working at institutes are taking the lead of design, pedagogical and research innovation. Furthermore, we show that Latin-American literature distinctively reveals how teachers adapt to the particular contexts of teaching, and the special importance of the usually overlooked conference papers literature.

Keywords: augmented reality, engineering education, post-secondary education, Latin America, PRISMA-ScR

INTRODUCTION

We tend to assume that, for pedagogical purposes, STEM faculties should be the first to adopt current teaching technologies before any other educational institution, as show various summaries of innovations (Hernandez-de-Menendez et al., 2020; Mkrttchian et al., 2019). But specialists seem to overlook the fact that this progressive change depends on a sum of external factors apart from the sole diffusion of innovations, as happens to be the case with AI, e-learning, and data mining (Aljawarneh, 2020; Alyahyan & Dustegor, 2020; Greenan, 2021; Zawacki-Richter et al., 2019). A case could be made for the inclusion, among these, of the global skill inequalities, which affect higher education in the developing world (Gómez-Tone et al., 2020).

At least since Ivan Sutherland's *The Ultimate Display* (1965), Augmented Reality (AR), referred as well as "advanced", "improved" and "enriched reality", has been understood as a set of applications that complement or combine real and digital environments, ideally blurring the difference between the two (Billinghurst, 2021; Iatsyshyn et al., 2020). The use of AR in education was first introduced by the aviation industry at the end of the twentieth century, transforming higher education ever since (Akcayır & Akcayır, 2017; Wang et al., 2018). However, the use of AR in higher education became a protagonist in devoted conferences and publications only during the last five years (Altinpulluk, 2019). As a consequence, numerous recent literature reviews report that the AR literature is filled with evidence-based pedagogical practices and innovative design procedures, benefiting students' motivation and learning (Altinpulluk, 2019; Garzón et al., 2019; Nesenbergs et al., 2021; Sommerauer & Müller, 2018).

AR seems to be especially useful for STEM education (Ibáñez & Delgado-Kloos, 2018; Sirakaya & Sirakaya,

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Contribution to the literature

- We focus on Latin-American publications, quite neglected on earlier reviews.
- Our PRISMA informed Scoping Review notably includes conference papers and scientific articles.
- We build a composite quality index for the quality appraisal of IT case presentations, observational and quasi-experimental studies.

2018, 2020). And since they are usually considered CTML and mobile-learning related technologies, the benefits of AR's environment enhancement for engineering education are well known (Diao & Shih, 2019; Hernandez-de-Menendez et al., 2020; Singh et al., 2019). But the adoption of AR in STEM teaching still faces some challenges, like the lack of knowledge and skills in teachers, as well as institutional barriers (Barroso Osuna et al., 2019). Additionally, the evidence about the use of AR in the very diverse field of engineering education is still quite unknown in contrast to its applications in other educational disciplines and levels. Considering the existing STEM education disparities in the world (Drew, 2020), we hypothesize that these issues may worsen in Latin-American universities, but there's scant evidence of this.

There are remarkable gaps in the extant literature. Diao and Shih (2019) and Singh et al. (2019) reviewed the research designs, educational outcomes and technological features of AR technologies in journal papers, focusing specifically on Architectural, Civil Engineering and Electronics education. Sirakaya and Sirakaya (2018) performed a similar systematic review including science education and medical training. Other reviews include technologies such as VR (Wang et al., 2020). However, we note a scarcity of variables measured, quality appraisal reports and a general lack of interest in this area of research. Moreover, there is a complete relegation of other literature types as part of these needed technology evaluation synthesis, even though most innovation reports are not published through journal articles. A scoping review under the PRISMA-ScR guidelines seem to be the best choice for an exploratory path.

Hence, this paper addresses the following questions: how are AR systems designed, used and evaluated in engineering education in Latin America, and how does this compares with the rest of the world? To address this question, we present a scoping review of papers and conference articles published by Latin-American authors. To do this, we chart publications from four international databases and perform a threefold quality appraisal according to the different literature types found. We draw inspiration from a wide diversity of contributions: among these, reviews about the use of dynamic and static contents, pedagogical affordances, evaluation types and outcomes of education-oriented AR.

METHOD

Scoping reviews are comprehensive literature reviews that bring provisional answers to general questions, not requiring the precision of a systematic review (Munn et al., 2018). Previous recent international literature reviews were normally systematic reviews, a few of them being meta-analyses (Garzón et al., 2019) or less systematic methods (Altinpulluk, 2019). This includes a previous scoping review published in this journal (Saltan & Arslan, 2016), which inspired this work. But, in contrast with the latter, we focus on one particular geographical region and follow the 20 PRISMA-ScR criteria for scoping reviews, proposed originally for literature reviews of medical journals and articles (Tricco et al., 2018).

Scoping reviews under the PRISMA framework proceed by defining research questions, inclusion criteria, search strategies and sources, literature screening, selection, extraction and analysis processes, and result reporting along with discussions (Peters et al., 2020). The protocol for this review was registered in OSF (Bellido García & Paucar Villacorta, 2021). The complete process is reported in Figure 1. Our research questions were the following:

- What are the main bibliometric patterns of the Latin-American literature reviewed?
- What types of software and hardware systems prefer Latin-American engineering educators employing AR?
- What pedagogical perspectives and practices guide the educational applications of this technology?
- What are the stated advantages and disadvantages of using AR systems in Latin-American engineering education?
- What are the research designs in Latin-American tests and evaluations of the said technology?
- Are there significant differences between our results and similar international reviews?

Earlier reviews typically focus on English-written academic papers gathered from sources like SSCI, Scopus, and Google Scholar. We chose to depart from this trend in three ways. First, we selected the databases considering their importance for Latin-American authors: Scielo, the *Red Iberoamericana de Información y Conocimiento Científico* (REDIB), Web of Science (WOS), and SCOPUS. Secondly, inspired on the recent appraisal

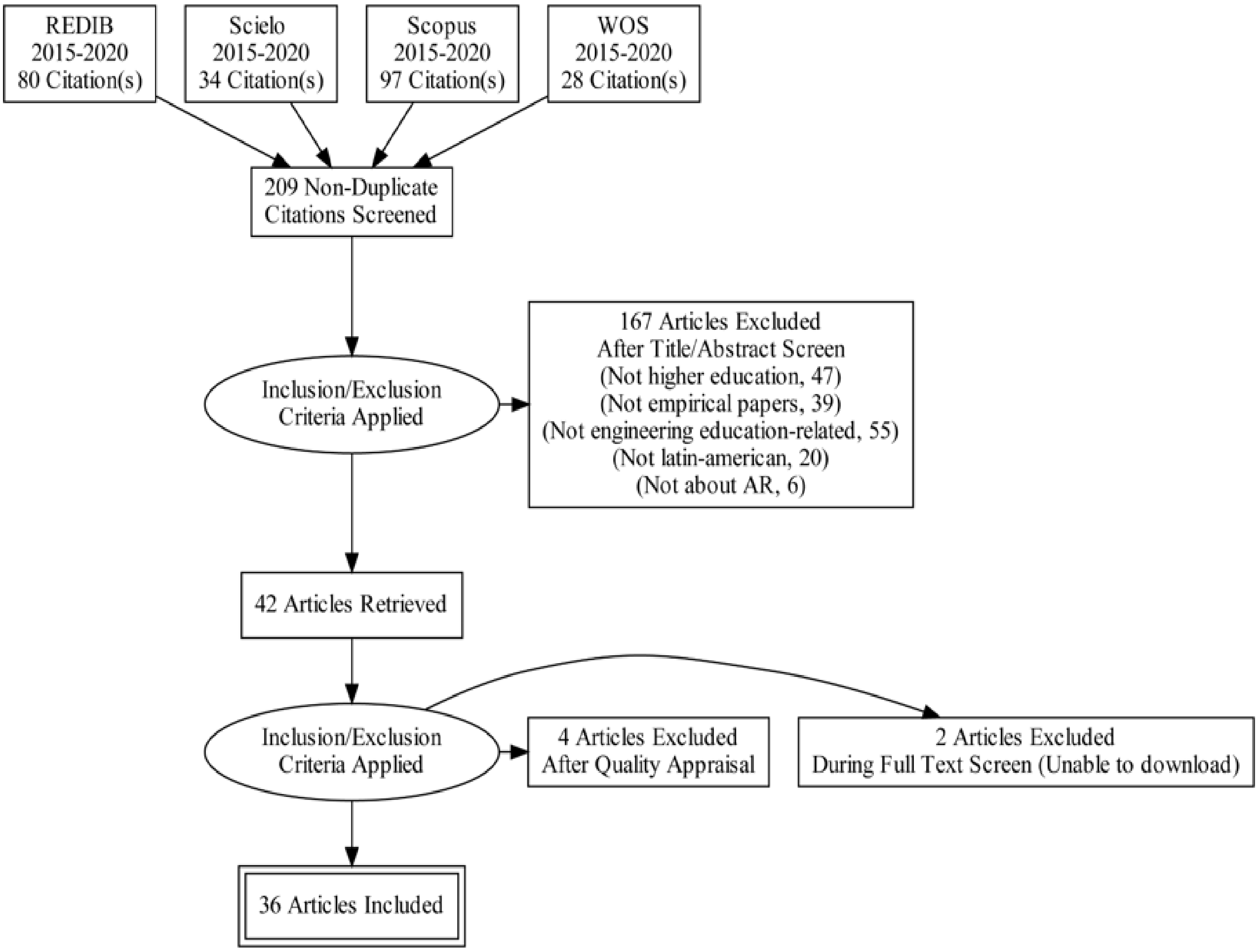

Figure 1. Flow diagram of the scoping review

Table 1. Criteria of inclusion and exclusion recommended by the PRISMA-ScR guidelines

Criteria	Inclusion	Exclusion
Context	Post-secondary educational programs (in general), including work-based skill training, with a focus on one or many engineering fields Papers written by authors from the following countries: Mexico, Brazil, Ecuador, Colombia, Peru, Chile, Costa Rica, Panama, Bolivia, Uruguay, and Venezuela	Papers about the use of AR in non-educational or work-based skill training contexts Reports about classroom experiences foreign to Latin America
Population	Papers that describe the use of AR by engineering students, professionals, and teachers in tertiary education institutions (including technical schools) in Latin America	Papers that solely describe AR applications by individuals of disciplines other than engineering specializations, or engineering related applications in school students, or students foreign to Latin America
Concept	Reports about the use of augmented, mixed, enriched or hybrid reality that describe the use of AR in tertiary education as a main goal, accounting for case studies (design) and evaluations	Education technology reports that do not account for the use of AR at all
Types of evidence sources	Conference papers and scientific articles that describe empirical uses of AR in the classroom	Literature reviews, essays, thesis, dissertations, and book chapters not interested in the description or evaluation of an AR application usage by students or teachers
Time period	Literature between 2015-2020	Literature outside this period

of grey literature to conduct literature reviews (Adams et al., 2017; Garousi et al., 2019; Hartling et al., 2017), we decided to include conference proceedings and scientific journals in my search. Note that the first were the most numerically dominant in Scopus database searches, despite being usually considered a "weak" form of white formal literature. Finally, my search was intentionally multi-linguistic, spanning to a broad English, Spanish and Portuguese-written literature.

I defined four inclusion and four exclusion criteria, listed in Table 1. The search and duplicate elimination

Table 2. Search strings used for each database

Database	Search strings
Scopus	(TITLE-ABS-KEY ("augmented reality") OR TITLE-ABS-KEY ("realidad aumentada") OR TITLE-ABS-KEY ("realidade aumentada") OR TITLE-ABS-KEY ("improved reality") OR TITLE-ABS-KEY ("realidad mejorada") OR TITLE-ABS-KEY ("realidad mixta") OR TITLE-ABS-KEY ("hybrid reality") OR TITLE-ABS-KEY ("realidad híbrida")) AND (TITLE-ABS-KEY (educación) OR TITLE-ABS-KEY (enseñanza) OR TITLE-ABS-KEY (aprendizaje) OR TITLE-ABS-KEY (ensino) OR TITLE-ABS-KEY (educação) OR TITLE-ABS-KEY (aprendizagem) OR TITLE-ABS-KEY (teaching) OR TITLE-ABS-KEY (learning) OR TITLE-ABS-KEY (education)) AND (TITLE-ABS-KEY (engenharia) OR TITLE-ABS-KEY (ingeniería) OR TITLE-ABS-KEY (engineering) OR TITLE-ABS-KEY (técnic*) OR TITLE-ABS-KEY (technic*)) AND (LIMIT-TO (AFFILCOUNTRY, "Mexico") OR LIMIT-TO (AFFILCOUNTRY, "Brazil") OR LIMIT-TO (AFFILCOUNTRY, "Ecuador") OR LIMIT-TO (AFFILCOUNTRY, "Colombia") OR LIMIT-TO (AFFILCOUNTRY, "Peru") OR LIMIT-TO (AFFILCOUNTRY, "Chile") OR LIMIT-TO (AFFILCOUNTRY, "Venezuela") OR LIMIT-TO (AFFILCOUNTRY, "Undefined")) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016)) AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch"))
Web of Science (WOS)	(TS=(ensino OR enseñanza OR teaching OR educación OR educação OR education OR aprendizagem OR aprendizaje OR learning) OR TI=(ensino OR enseñanza OR teaching OR educación OR educação OR education OR aprendizagem OR aprendizaje OR learning) OR AB=(ensino OR enseñanza OR teaching OR educación OR educação OR education OR aprendizagem OR aprendizaje OR learning) OR AK=(ensino OR enseñanza OR teaching OR educación OR educação OR education OR aprendizagem OR aprendizaje OR learning) OR KP=(ensino OR enseñanza OR teaching OR educación OR educação OR education OR aprendizagem OR aprendizaje OR learning)) AND (AK=("realidad aumentada" OR "realidade aumentada" OR "augmented reality" OR "hybrid reality" OR "realidad híbrida" OR "mixed reality" OR "realidad mixta" OR "enriched reality" OR "realidad enriquecida") OR TS=("realidad aumentada" OR "realidade aumentada" OR "augmented reality" OR "hybrid reality" OR "realidad híbrida" OR "mixed reality" OR "realidad mixta" OR "enriched reality" OR "realidad enriquecida") OR TI=("realidad aumentada" OR "realidade aumentada" OR "augmented reality" OR "hybrid reality" OR "realidad híbrida" OR "mixed reality" OR "realidad mixta" OR "enriched reality" OR "realidad enriquecida") OR AB=("realidad aumentada" OR "realidade aumentada" OR "augmented reality" OR "hybrid reality" OR "realidad híbrida" OR "mixed reality" OR "realidad mixta" OR "enriched reality" OR "realidad enriquecida") OR KP=("realidad aumentada" OR "realidade aumentada" OR "augmented reality" OR "hybrid reality" OR "realidad híbrida" OR "mixed reality" OR "realidad mixta" OR "enriched reality" OR "realidad enriquecida")) AND (TS=(ingeniería OR engineering OR engenharia OR technic* OR technic) OR TI=(ingeniería OR engenharia OR engineering OR technic* OR técnic*) OR KP=(ingeniería OR engenharia OR engineering OR technic* OR técnic*) OR AB=(ingeniería OR engenharia OR engineering OR technic* OR técnic*) OR AK=(ingeniería OR engenharia OR engineering OR technic* OR técnic*) OR TI=(ingeniería OR engineering OR engenharia OR technic* OR técnic*)) AND (CU=(Brasi OR Peru OR Argentina OR México OR Colombia OR Venezuela OR Chile OR Mexico OR Uruguay OR Bolivia OR Panama OR "Costa Rica" OR Ecuador))
Scielo	(((ti:(realidad aumentada)) OR (ti:(augmented reality)) OR (ti:(realidade aumentada))) AND (ingenería) OR (engineering) OR (Engenharia)))
REDIB	("realidad aumentada" OR "augmented reality" OR "realidade aumentada" OR "realidad híbrida" OR "realidad mixta" OR "mixed reality" OR "hybrid reality") (ingeniería OR engenharia OR engineering)

process was made during February 2021. The search strings used are shown in Table 2. Scopus and WOS allowed me to be much more specific with my search, and hence produced larger search strings. Abstract screening lasted for one month after the original search of databases, and the quality assessment of the collected evidence lasted for two more months. While this process was made by only one author, eligibility and quality criteria were chosen by debate and consensus after parallel readings of the extant literature.

Judging by the PRISMA-ScR criteria, research quality appraisals are uncommon and considered optional for scoping reviews. However, the authors felt that this review could be affected by the lack of effective peer-review practices in some Latin-American journals. This is supported by the fact that most journals listed in the largest Latin-American publications database, Latindex, don't reach the second quartile of the SCImago Journal Rank. On the other hand, conference papers can easily omit important details due to space limitations, and peer-reviewing before publication isn't usually

Table 3. Quality appraisal criteria considered by weight and applicability

No	Criteria	Weight	Applicable to
1	Is there a clear statement (definition) of the aims (goals, purposes, problems, motivations, objectives, questions) of the research?	1	All
2	Is there an adequate description of the context in which the research was carried out?	1	All
3	Does the report answer the research question defined or presents the results in a clear way?	1	All
4	Is the report based on research?	1	All
5	Is the report well-written?	1	All
6	Is there any intention to be a technological innovation?	1	All
7	Is the technological design based on recent innovations?	1.5	All
8	Does the author succeed in developing a legitimate innovation (e. g., is the software more useful than already existing software?)	1.5	All
9	Does the author add additional relevant information? (Code, operation steps, common problems and their resolution)	1.5	All
10	Does the report include images representing steps of operation?	1.5	All
11	Is there an explicit relationship between a pedagogical perspective and the technology described?	1.5	All
12	Are pedagogical concepts informed by recent literature?	1	All
13	Does it add a methodological innovation when evaluating the technology?	1	Case+Eval.
14	Was the simple selection criteria explicitly stated?	1.5	Case+Eval.
15	Does the sample seem representative of the wider population?	1	Case+Eval.
16	Are the sample traits relevant to the report's population?	1.5	Case+Eval.
17	Does it include sample bias/dropout measures?	1	Case+Eval.
18	Does the design answer the research questions?	1.5	Case+Eval.
19	Is the evaluation design stated with clarity and is there coherence between methodology and results?	1	Case+Eval.
20	Were the measures trustable, validated and equally applied to the whole sample?	1.5	Case+Eval.
21	Is there a good description of the measures used?	1	Case+Eval.
22	Are the results credible (are there other means of verification reported)?	1.5	Case+Eval.
23	Were there only positive results reported? (Check if not)	1.5	Case+Eval.
24	Are the study limitations discussed?	1.5	Case+Eval.
25	Do numerical results answer the study's research question?	1.5	Case+Eval.
26	Is the researcher & subjects relationship discussed?	1.5	Case+Eval.
27	Was pre/post change measured?	1	Case+Eval.: Comparative
28	Are individual and group outcomes compared?	1.5	Case+Eval.: Comparative
29	Are compared groups similar or is there an explicit comparability intention?	1.5	Case+Eval.: Comparative
30	Are baseline or descriptive data included?	1	Case+Eval.: Reggression-based
31	Is a control group included?	1.5	Cuasiexper.
32	Is there a discussion about causality?	1.5	Cuasiexper.
33	Is there an explicit mention of randomization?	1	Cuasiexper.
34	Was the randomization method correct?	1.5	Cuasiexper.
35	Was the randomization process blind?	1.5	Cuasiexper.
36	Was the study double-blinded (is the author intentionally unconscious about which subjects are assigned to each group)?	1	Cuasiexper.

registered in proceedings. And while the design of new quality criteria could be deemed as a risky task, it is true that various criteria exist (Garousi et al., 2019), and that usually recommended criteria is unsuitable for all types of engineering literature (Kitchenham & Brereton, 2013).

Hence, we iteratively designed and tested a weighted quality index for each report based on three components: an indicator of the quality of technology design presentations (based on the principles set by Isaksson et al. (2020), Petersen (2020) and Schön et al. (2017)), an indicator of the quality of the empirical testing or evaluation of the technology earlier presented, excluding design-only papers (Liu et al., 2016; Mårtensson et al., 2019), and an independent indicator of the quality of quasi-experimental designs (drawn mostly from Cochrane criteria). The final criteria list with weights and requirements is shown in Table 3. The indicators where defined as the division between the sum of weights and the weights of all applicable criteria for the current paper. The second component extended to three additional criteria when the papers where comparative or regression based- designs. All papers below the 40% threshold in all three indicators at the same time were excluded. The composite index was defined by $\sum \max(i) - \sum(i)$, where i are the existing indicators for the three types of literature, and quartiles where calculated as an additional variable for exploratory data analysis.

Following the selection of a final sample of documents (n=36), we automatically extracted bibliographic data using Zotero (database name, author, year, country, publication, item type, accessibility and URL/DOI). We defined thirty-five variables for the chart, divided in four big groups: bibliographic details, research design, AR design features, and pedagogical traits of the AR systems, along with a quality index variable and a final reviewer commentary. Many variables were inspired in earlier reviews; buy the variable "Application type", drawn from Altinpulluk (2019), was simplified to indicate exclusive categories. Only three variables of the second and third group weren't taken from the literature, including the presence of coding tasks, and the origin of 3D models in 3D-based AR applications. Furthermore, we grouped many of these variables, including: journal name, engineering specialization, type of educational institution, type of device, software name, pedagogical perspectives, pros and cons. The full list of variables along with their sources in the literature and examples are shown in Tables 4-9.

Table 4. Data extracted from the literature – Part 1

Code	Quality quartile	Title	DB	Country
[1]	Good	A mobile augmented reality system to support machinery operations in scholar environments	Scopus	Mexico
[2]	Weak	A pilot study on the use of mobile augmented reality for interactive experimentation in quadratic equations	WoS	Mexico
[3]	Weak	A relidade aumentadana apresent ação de produtos cartográficos	Scielo	Brazil
[4]	Regular	A smartphone-based augmented reality system for university students for learning digital electronics	Scopus	Mexico
[5]	Good	Adoção de realidade aumentada no ensino de resistência dos materiais	REDIB	Brazil
[6]	Optimal	An education application for teaching robot arm manipulator concepts using augmented reality	Scopus	Mexico
[7]	Weak	Aplicación de realidad aumentada para la enseñanza de la robótica	REDIB	Mexico
[8]	Weak	Aplicación móvil conrealidad aumentada para la asignatura de metodología de la investigación	REDIB	Mexico
[9]	Good	Aplicación móvil de realidad aumentada, utilizando la metodología mobile-d, para el entrenamient de técnicos de mantenimiento de maquinaria pesada en la empresa zamine service peru sac	REDIB	Peru
[10]	Regular	Arquitectura interactiva como soporte al aprendizaje situ ado en la enseñanza de la ingeniería	WoS	Colombia
[11]	Weak	Augmented reality and Matlab® for visuospatial competence development	Scopus	Mexico
[12]	Good	Determining which touch gestures are commonly used when visualizing physics problems in augmented reality	Scopus	Mexico
[13]	Good	Development of an augmented reality environment for the assembly of a precast wood-frame wall using the BIM model	Scielo	Brazil
[14]	Weak	Diseño y desarrollo de un sistema de realidad mixta para la enseñanza-Aprendizaje de la física de agujeros negros	Scopus	Colombia
[15]	Weak	Estrategia colaborativa en entornos trimensionales como estrategia didáctica de aprendizaje de estructuras iterativas en programación computacional	REDIB	Colombia
[16]	Weak	Evaluating the effect on user perception and performance of static and dynamic contents deployed in augmented reality based learning application	Scopus	Colombia
[17]	Regular	Handheld augmented reality system for resistive electric circuits understanding for undergraduate students	Scopus	Mexico
[18]	Good	Incidencia de la realidad aumentada sobre el estilo cognitivo: Caso para el estudio de las matemáticas	REDIB	Colombia
[19]	Regular	International comparative pilot study of spatial skill development in engineering students through autonomous augmented reality-based training	Scopus	Peru
[20]	Optimal	La formación de ingenieros en sistemas automotrices mediante la realidad aumentada	REDIB	Mexico
[21]	Regular	MATHPOL: Development of mathematical competencies in engineering students using project-oriented learning	Scopus	Mexico
[22]	Regular	Measurement of emotional variables through a brain-computer interface in the interaction with books with augmented reality in higher education	Scopus	Colombia
[23]	Good	PELE 4.0-Power electronics experiments: Towards laboratory tools for teaching-learning improvement	Scopus	Brazil
[24]	Good	Realidad aumentada como apoyo a la formación de ingenieros industriales	Scopus	Chile
[25]	Regular	Realidad aumentada como herramienta de apoyo al aprendizaje de las funciones algebraicas y trascendentes	WoS	Colombia
[26]	Good	Realidad Aumentada en la enseñanza de hormigón reforzado: Percepción de los alumnos	Scielo	Brazil
[27]	Optimal	Realidad aumentada: Propuesta metodológica para la didáctica de diseño industrial en el ámbito universitario	REDIB	Chile
[28]	Optimal	Self-learning guide for bioloid humanoid robot assembly with elements of augmented reality to support experiential learning in sauro research seeding	Scopus	Colombia
[29]	Optimal	Sistemas de aprendizaje colaborativo móvil con realidad aumentada	REDIB	Ecuador
[30]	Regular	Smart objects for engineering labs: Boosting exploratory learning in higher education	Scopus	Ecuador
[31]	Optimal	Teaching multidisciplinary teams requirements for undergraduate students: An approach to augmented reality software in design thinking context	Scopus	Brazil
[32]	Regular	Um material potencialmente significativo para o ensino da engenharia civil utilizando impressora 3D e realidade aumentada: Uma experiência com alunos do ensino médio e do ensino su...	REDIB	Brazil
[33]	Optimal	Use of augmented reality for the simulation of basic mechanical physics phenomena	Scopus	Colombia
[34]	Weak	Using augmented reality and kinect technologies to promote reading habits	Scopus	Mexico
[35]	Good	Virtual circuits: An augmented reality circuit simulator for engineering students	Scopus	Ecuador
[36]	Weak	Virtual environment for training oil & gas industry workers	Scopus	Ecuador

Table 5. Data extracted from the literature – Part 2

Author	Year	Journal	DOI
Monroy Reyes, A., Vergara Villegas, O. O., Miranda Bojórquez, E., Cruz Sánchez, V. G., & Nandayapa, M.	2016	Computer Applications in Engineering Education	10.1002/cae.21772
Castillo, R. I. B., Sanchez, V. G. C., & Villegas, O. O. V.	2015	Mathematical Problems in Engineering	10.1155/2015/946034
de Oliveira Souza, W., Mira de Espindola, G., Alves Pereira, A. R., & Marques de Sá, L. A. C.	2016	Boletim de Ciências Geodésicas	10.1590/s1982-21702016000400045
Avilés-Cruz, C., & Villegas-Cortez, J.	2019	Computer Applications in Engineering Education	10.1002/cae.22102
Silva, J.; Souza, F. da F. de, Sedraz, L., & Ramos, J. L. C.	2015	Anais dos Workshops do Congresso Brasileiro de Informática na Educação	
Hernández-Ordoñez, M., Nuño-Maganda, M. A., Calles-Arriaga, C. A., Montaño-Rivas, O., & Bautista Hernández, K. E.	2018	Mobile Information Systems	10.1155/2018/6047034
Mendoza Pérez, M. A., Cruz Flores, R. G., Villalba Hernández, A. A., Calderón Rodríguez, J. A., & Patiño, E. A.	2017	Pistas educativas	10.31876/ie.v1i1.6
Soberanes Martín, A., Castillo Mendoza, J. L., & Peña Martín, A.	2018	Pistas educativas	10.26871/killkana_tecnica.v1i2.78
Gamboa Cruzado, J., Larico Uchamaco, G. R., Soto Soto, L., Chacón Malasquez, N., Tuiro Achulle, J., & Guzman Chambi, S. C.	2017	Ceprosimad	
Gomez, J. E., Hernandez, V., & Morales, M.	2015	Revista Educacion en Ingenieria	10.26507/rei.v10n20.575
Flores-Amado, A., Diliegros-Godines, C. J., Trevino, J. P., Sayeg-Sanchez, G., & Gonzalez-Hernandez, H. G.	2020	IEEE Global Engineering Education Conference, EDUCON	10.1109/EDUCON45650.2020.9125205
del Rio Guerra, M., Martín-Gutiérrez, J., Vargas-Lizárraga, R., & Garza-Bernal, I.	2018	Lecture Notes in Computer Science	10.1007/978-3-319-91581-4_1
Cuperschmid, A. R. M., Grachet, M. G., & Fabrício, M. M.	2016	Ambiente Construído	10.1590/s1678-86212016000400105
Grimaldo, A. C. R., & Chaparro, E. M. V.	2019	Proceedings of the LACCEI international Multi-conference for Engineering, Education and Technology	10.18687/LACCEI2019.1.1.427
Jiménez Toledo, J. A., Collazos Ordoñez, C. A., Hurtado Alegría, J. A., & Pantoja Y, W. L.	2015	Revista Investigium Ire: Ciencias Sociales y Humanas	10.15658/CESMAG15.05060207
Montoya, M. H., Díaz, C. A., & Moreno, G. A.	2017	Eurasia Journal of Mathematics, Science and Technology Education	10.12973/eurasia.2017.00617a
Reyes-Aviles, F., & Aviles-Cruz, C.	2018	Computer Applications in Engineering Education	10.1002/cae.21912
Buitrago-Pulido, R. D.	2015	Educación y educadores	10.5294/edu.2015.18.1.2
Gómez-Tone, H. C., Martin-Gutierrez, J., Anci, L. V., & Luis, C. E. M.	2020	Symmetry	10.3390/SYM12091401
Cortés Caballero, J. M.	2016	Edutec. Revista Electrónica de Tecnología Educativa	10.21556/edutec.2016.58.838
Medina Herrera, L. M., Glaros, D., & Abalo, M. A.	2020	2020 5th International Conference on Information Technologies in Engineering Education, Inforino 2020	10.1109/Inforino48376.2020.9111856
Rojas-Contreras, M., Peña-Cortés, C. A., & Cañas-Rodríguez, S. M.	2020	Journal of Physics: Conference Series	10.1088/1742-6596/1674/1/012016
De Almeida Carlos, G. A., Ferro, V., Lisboa, R., & Da Silva, A.	2019	Proceedings of the International Conference on Power Electronics and Drive Systems	10.1109/PEDS44367.2019.8998825
Alvarez-Marin, A., Castillo-Vergara, M., Pizarro-Guerrero, J., & Espinoza-Vera, E.	2017	Formacion Universitaria	10.4067/S0718-50062017000200005
Marquez-Diaz, J. E., & Morales-Espinosa, L. A.	2019	Revista Educacion en Ingenieria	10.26507/rei.v15n29.1037
Nolasco de Almeida Mello, G., & Cabero Almenara, J.	2020	ALTERIDAD. Revista de Educación	10.17163/alt.v15n1.2020.01
Laurens Arredondo, L. A.	2019	Etic@net.	10.18779/ingenio.v1i1.11
Lemmel-Vélez, K., & Valencia-Hernandez, C. A.	2019	Communications in Computer and Information Science	10.1007/978-3-030-23528-4_17
Mendoza Morán, V. del R., Rivera Guevara, R., & Barriga Andrade, J.	2016	Revista Politécnica (Quito)	10.5335/rbca.v12i1.10139
Ullón, H., Zambrano, D., & Domínguez, F.	2017	12th Latin American Conference on Learning Objects and Technologies, LACLO 2017	10.1109/LACLO.2017.8120915
Almeida, E. M. D., Damasceno, E. F., & Lrerario, A.	2019	Proceedings - Frontiers in Education Conference, FIE	10.1109/FIE.2018.8658529
Rodrigues Júnior, A. S., da Costa Gomes, G. J., Caramez Berteges, L. F., de Souza Siqueira Pereira, C., & de Alencar Carvalho, C. V.	2020	Brazilian Journal of Development	10.34117/bjdv6n3-091
Morales, A. D., Sanchez, S. A., Pineda, C. M., & Romero, H. J.	2019	IOP Conference Series: Materials Science and Engineering	10.1088/1757-899X/519/1/012021
Ramirez Flores, P. G., Mendoza Medina, J. A., Gonzalez Mendivil, E., & Villegas Villarreal, A. R.	2018	Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering	10.1007/978-3-319-73323-4_8
Lucas, P., Vaca, D., Dominguez, F., & Ochoa, X.	2018	Proceedings - IEEE 18th International Conference on Advanced Learning Technologies, ICALT 2018	10.1109/ICALT.2018.00097
Garcia, C. A., Naranjo, J. E., Gallardo-Cardenas, F., & Garcia, M.V.	2019	Lecture Notes in Computer Science	10.1007/978-3-030-25999-0_32

Table 6. Data extracted from the literature – Part 3

Item Type	Population	Year	Course	Specialization	Educative institution	Research Design
Article	Students & teachers			Mechatronic Engr.	UACJ	Design & Evaluation
Article	Students & teachers	3	Math	Many	Universidad Autónoma Ciudad Juárez	Design & Evaluation
Article	Students	1		Cartographic Engr.	Universidade Federal do Piauí	Design & Evaluation
Article	Students	1		Electronic Engr.	UNAM	Design & Evaluation
Article	Students		Materials resistance	Engineering	Universidade Federal do Vale do São Francisco	Evaluation
Article						Design-only
Article	Students & teachers	5	Advanced Robotics	Computation Engr.	UAEM Valle del Chalco	Design-only
Article	Students & teachers		Research Methodology	Computation Engr.	UAEMEX	Design & Evaluation
Article	Employees		Unnamed Training Workshop		Zamine Service Perú SAC	Design & Evaluation
Article	Students	1	Introduction to Engineering	Many	Universidad de Córdoba	Design & Evaluation
Conference Paper	Students	2	Math III	Engineering (many)	Tecnológico de Monterrey	Design & Evaluation
Conference Paper	Students	1	Physics	Mechanical Engr.	Universidad de Monterrey	Design & Evaluation
Article	Students			Civil Engr.	Universidade de São Paulo	Design & Evaluation
Conference Paper	Students	many	Black holes and time machines (short course)		Universidad Nacional de Colombia	Design-only
Article	Students	1	Many (coding)	System Engr.	CESMAG/UAN	Design & Evaluation
Article	Students	1	Electronics basics	Electronic Engr.	Institución Universitaria Salazar y Herrera	Design & Evaluation
Article	Students	1	Electronics basics	Electronic Engr.	Universidad Aútonoma Metropolitana	Design & Evaluation
Article	Students	2	Vectorial calculus	Industrial Engr.	Escuela Colombiana de Carreras Industriales	
Article	Students	1	Graphic engineering	Many	UCSP(Perú), ULL(España)	Evaluation-only
Article				Automobile Engr.	Instituto Politécnico Nacional	Design-only
Conference Paper	Students & teachers		Calculus	Many	Tecnológico de Monterrey	Design & Evaluation
Conference Paper	Students		Algorithms and structures	System Engr.	Universidad de Pamplona	Design & Evaluation
Conference Paper	Students		Power electronics	Electronic Engr.	instituto Federal de Alagoas	Design-only
Article	Students		Fluid Mechanics	Civil Industrial Engr.	Universidad de La Serena	Design & Evaluation
Article	Students		Calculus I	System Engr.	Universidad de Cundinamarca	Design & Evaluation
Article	Students	4	Reinforced Concrete	Civil Engr.	Pontificia Universidad Católica de Minas Gerais	Design & Evaluation
Article	Students		Many (Structural Design)	Civil Industrial Engr.	Universidad Católica de Maule	Design-only
Conference Paper	Students			Mechatronic Engr.	Institución Universitaria Pascual Bravo	Design-only
Article	Students			System Engr.	Universidad de Guayaquil	
Conference Paper	Students	1	Physics I	Many	Escuela Superior Politecnica del Litoral	Design & Evaluation
Conference Paper	Students		Systems analysis	Software Engr.	Universidad Tecnológica Federal de Paraná	Design & Evaluation
Article	Students	1	Many (Structural Design)	Engr.	Universidade de Vassouras	Design & Evaluation
Conference Paper			Mechanical physics	Many	Corposucre	Design & Evaluation
Conference Paper	Students		Reading (short course)	Many	Tecnológico de Monterrey	Design-only
Conference Paper	Students	3	Electrical Circuit Analysis	Electric Engr.	Escuela Superior Politecnica del Litoral	Design & Evaluation
Conference Paper	Employees		HART object Training Workshop		Empresa de Petróleo y Gas (no dice)	Design-only

Table 7. Data extracted from the literature – Part 4

Evaluation design	Data Collection technique	Outcome variable	Sample Size	Coding	Input (Sirakaya & Sirakaya)	Software name	Device	App type
Observational Pre/Pos	Survey	Satisfaction & Performance	16	Yes	Labels	Vuforia	VR	Video-based
Case study	Questionnaire	Academic Achievement, Satisfaction & Performance	59	Yes	Labels	Vuforia	Smartphone & Tablets	Simulation-based
Observational Pre/Pos	Questionnaire	Satisfaction	32	No	Layers	Aumentary	PC	3D-image based
Observational Pre/Pos	Survey	Satisfaction	80	Yes	Object recognition	Own	Smartphone	Text-Based
Observational Pre/Pos	Questionnaire	Satisfaction	50	No	Labels	Aurasma	Tablet	Text-Based
Case study				Yes	Labels	ARToolkit	Smartphone	Simulation-based
Observational Pre/Pos	Interviews	Academic achievement	52	No	Labels	Aumentaty Author	PC	Video-based
Observational Pre/Pos	Survey	Academic achievement & Performance	51	Yes	Labels	Unity	Smartphone	Text-Based
Quasi-experiment	Observation	KPIs	30	Yes	Labels	Vuforia	Smartphone	Text-Based
Observational Pre/Pos	Test	Academic achievement	40	No	Labels	Flartoolkit	Smartphone & Tablets	3D-image based
Quasi-experiment	Test	Academic achievement	56	Yes	Labels	Own	Smartphone	3D-image based
Observational Pre/Pos	Interviews	Satisfaction	26	Yes	Labels	Vuforia	Smartphone	3D-image based
Observational Pre/Pos	Survey & Test	Satisfaction	28	No	Other (detector test)	Metaio	Smartphone & VR	Simulation-based
Case study				Yes	Labels	Vuforia	Smartphone	Video-based
Quasi-experiment	Test	Academic achievement	91	Yes	Layers		Smartphone	Simulation-based
Observational Pre/Pos	Survey & Test	Academic achievement & Satisfaction	16	Yes	Labels	Vuforia	Smartphone	3D-image based
Case study	Observation & Survey	Satisfaction & Performance	30	Yes	Object recognition	Own	Smartphone	Text-Based
Quasi-experiment	Test	Academic achievement	83	Yes		Arvirtual	Smartphone	3D-image based
Quasi-experiment	Survey	Habilidad espacial	312	Yes	Labels	Own	PC & Smartphone	3D-image based
Case study				Yes	Labels	Vuforia	Smartphone	3D-image based
Observational Pre/Pos	Survey	Academic achievement & Performance	239	Yes	Layers	Own	Tablet & Smartphone	Object Modelling
Observational comparative	Emotiv Insight	Emotions	5	No	Labels		Smartphone	
Case study				Yes	Labels	Vuforia	Smartphone	Simulation-based
Observational Pre/Pos	Survey	Satisfaction	61	No	Labels	Vuforia/Unity	Smartphone & Tablet	3D-image based
Case study	Survey	Satisfaction	60	No	Labels	Vuforia	Smartphone & Tablets	Text-Based
Observational Pre/Pos	Survey	Satisfaction	18	No	Labels	Sketchfab	Smartphone	3D-image based
Observational Pre/Pos	Test			Yes	Labels	Aumentary	PC & Smartphone	3D-image based
Case study					Labels	Build AR Pro	PC	3D-image based
Case study				Yes	Labels	AndroidIM	Smartphone	Location-based
Quasi-experiment	Questionnaire & test	Academic achievement & Satisfaction	40	Yes	Labels	Vuforia	Smartphone	Text-Based
Quasi-experiment	Questionnaire & test	Satisfaction	30					
Observational Pre/Pos	Survey	Academic achievement & Performance	30	No	Labels	Augment	Smartphone	Object Modelling
Case study		Performance		Yes	Labels	Vuforia	Smartphone	Simulation-based
Case study				No	Other (detector test)	Vuforia	Smartphone	Game-based
Observational Pre/Pos	Questionnaire	Satisfaction	100	Yes	Labels	Vuforia	Smartphone	3D-image based
Case study				Yes	Other (detector test)	Unity	Smartphone & VR	Simulation-based

Table 8. Data extracted from the literature – Part 5

Static / Dynamic (Montoya et al)	Materials (Chubukova & Ponomarenko)	Pedagogical Perspective (Wu et al.)	Focus (Wu et al.)	Evaluation Strategy (Diaio)	3D-Object Type	Usage (Diaio)	Interaction (Belén et al.)
Dynamic	Skill training	CTML	Tasks	Problem Resolution	Forms created by teacher	General (graphics, text)	Perception
Dynamic	Modelling	Situated Learning	Tasks	Problem Resolution		General (graphics, text)	Manipulation
Static	Modelling	Experiential Learning	Tasks	Problem Resolution	Forms created by teacher	General (graphics, text)	Perception
Static	Modelling	Mobile learning	Tasks	Problem Resolution		Espec. Aplic. (design, etc.)	Perception
Static	Skill training	Mobile learning	Tasks	Problem Resolution		General (graphics, text)	Perception
Dynamic	Modelling	Experiential Learning	Tasks	Problem Resolution		Espec. Aplic. (design, etc.)	Manipulation
Dynamic	Skill training	CTML	Tasks	Problem Resolution		General (graphics, text)	Perception
Static	Skill training	CTML	Tasks	Problem Resolution		General (graphics, text)	Manipulation
Static	Skill training	Mobile learning	Tasks	Problem Resolution		General (graphics, text)	Perception
Static	Skill training	Situated Learning	Tasks	Problem Resolution	Forms created by teacher	General (graphics, text)	Manipulation
Static	Skill training	CTML	Tasks	Problem Resolution		General (graphics, text)	Perception
Static	Skill training	Experiential Learning	Tasks	Problem Resolution	Forms created by teacher	General (graphics, text)	Manipulation
Dynamic	Modelling	Experiential Learning	Locations	Personal Project	Forms created by teacher	Espec. Aplic. (design, etc.)	Manipulation
Dynamic	Modelling	Mobile learning	Tasks	Problem Resolution	Forms created by teacher	General (graphics, text)	Perception
Static	Game alike	Mobile learning	Roles	Peer-work	Forms created in class	Espec. Aplic. (design, etc.)	Perception
Dynamic	Modelling	CTML	Tasks	Problem Resolution	Forms created by teacher	General (graphics, text)	Annotation
Dynamic	Modelling	CTML	Tasks	Problem Resolution		Espec. Aplic. (design, etc.)	Annotation
Dynamic	Modelling	CTML	Tasks	Problem Resolution		General (graphics, text)	Perception
Static	Textbook / manual	CTML	Tasks	Predefined forms	General (graphics, text)	Manipulation	Acquisition
Dynamic	Textbook / manual	CTML	Roles	Forms created in class	General (graphics, text)	Perception	Acquisition
Static	Object Modelling	Collaborative learning	Tasks	Proyecto grupal	Forms created in class	General (graphics, text)	Manipulation
Static	Textbook / manual	CTML	Tasks	Predefined forms	General (graphics, text)	Perception	Acquisition
Dynamic	Modelling	CTML	Tasks	Problem Resolution		Espec. Aplic. (design, etc.)	Perception
Static	Skill training	Mobile learning	Tasks	Problem Resolution	Forms created by teacher	General (graphics, text)	Perception
Static	Modelling	Mobile learning	Tasks	Problem Resolution		Espec. Aplic. (design, etc.)	Manipulation
Static	Skill training	CTML	Tasks	Problem Resolution	Predefined forms	General (graphics, text)	Perception
Static	Skill training	CTML	Tasks	Personal Project	Forms created in class	General (graphics, text)	Manipulation
Static	Textbook / manual	Situated Learning	Roles	Peer-work	Forms created by teacher	Espec. Aplic. (design, etc.)	Manipulation
Dynamic	Game alike	Situated Learning	Locations	Group-work sincrónico		General (graphics, text)	Annotation
Dynamic	Modelling	Experiential Learning	Tasks	Peer-work		General (graphics, text)	Perception
					Forms created by teacher	Espec. Aplic. (design, etc.)	Annotation
Dynamic	Object Modelling	Experiential Learning	Tasks	Personal Project	Forms created in class	Espec. Aplic. (design, etc.)	Manipulation
Dynamic	Modelling	Mobile learning	Tasks	Problem Resolution	Forms created by teacher	General (graphics, text)	Annotation
Static	Game alike	Situated Learning	Locations	Group-work sincrónico	Forms created by teacher	Espec. Aplic. (design, etc.)	Annotation
Static	Modelling	Experiential Learning	Tasks	Peer-work		General (graphics, text)	Manipulation
Static	Skill training	Mobile learning	Locations	Problem Resolution		General (graphics, text)	Manipulation

Table 9. Data extracted from the literature – Part 6

Affordances (Saltan/Arslan)	Pros	Cons	Comment
Acquisition	Robust, important and looks good	There are problems with VR view monoscopic (vs. Stereoscopic); inability to use by more than one person	
Concept development	It is intuitive and motivating for students	Endogenous design problems are major, "difficult to handle"	Nice presentation of results
Concept development	The possibilities for use of the sheath in cartography are many and still neglected		
Concept development	Useful and motivating, innovative use		
Concept Reinforcement	AR fundamental to learning	Many students said that RA is not	
Acquisition	Improves attention		
Acquisition	Knowledge and motivation		poor evaluation
Acquisition	pedagogical and technological aspects		Design AR? Pedagogical?
Concept development	Increases understanding, time is reduced, KPIs are met of thecompany		
Acquisition	superior performance	It is difficult to prepare all materials	Tasks have to do with cars
Concept Reinforcement	It's better than a software images	|	
Concept development	Students like the application	small sample, not all hand gestures were scheduled	
Acquisition	Much better than using paper and PC	The image is moved as it is too much updated; sometimes it does not correspond to the actual image	Innovative
Acquisition	contents		
Concept development	Attention and notes, with collaboration		Very good
Concept development	The parendizaje is facilitated by dynamic content		Are questions about the static and dynamic content
Concept development	Low recognition efficiency different shades of light	Neceista complemented by other measuring instruments	
Acquisition	AR can be adapted to the needs of learning styles, and improvement in all notes	It is particularly positive for the dependents of the field and those that are planned before working	Very good
Acquisition	It helps a lot and have acceptance	Does not eliminate local differences in skills regarding educational systems	Develop a book in another publication
Acquisition	Useful in forming		Very good
Acquisition			
Acquisition	AR increases integration with reality, relaxation and interest of students		
Acquisition	AR serves to remind students of concepts, but used in conjunction with other modules and tools		
Concept Reinforcement	The image helps the understanding of fluid mechanics through better visualization		
Concept development	Students feel great satisfaction with AR	There is a percentage of them do not feel that RA helped at all	
Concept development	Very popular among students	The phone takes to process many items to lavez; stable internet connection required	
Concept Reinforcement	Helps motivation, there is free software	RA is not compatible with old Smartphones, free software always requires internet	
Acquisition	Learning is easier for students and increases interest		Good summary of literature
Concept Reinforcement	Collaboration between students meet objectives achieved in a different way		It has literature review
Acquisition	great satisfaction	The difference in ratings is not statistically significant	
Concept development	great satisfaction	They could not identify either the data requirements	Very bad
Concept development	Useful in forming		poor evaluation
Acquisition	Accessible for students to come in mid-range phones		
Concept development	It is hilarious		hunting program books
Concept development	Ease, educational value and accessibility to complex concepts	Speed display GUI	
Acquisition	Specially appreciated by young workers and trainees	Older workers do not feel big difference.	It is part of a VR set

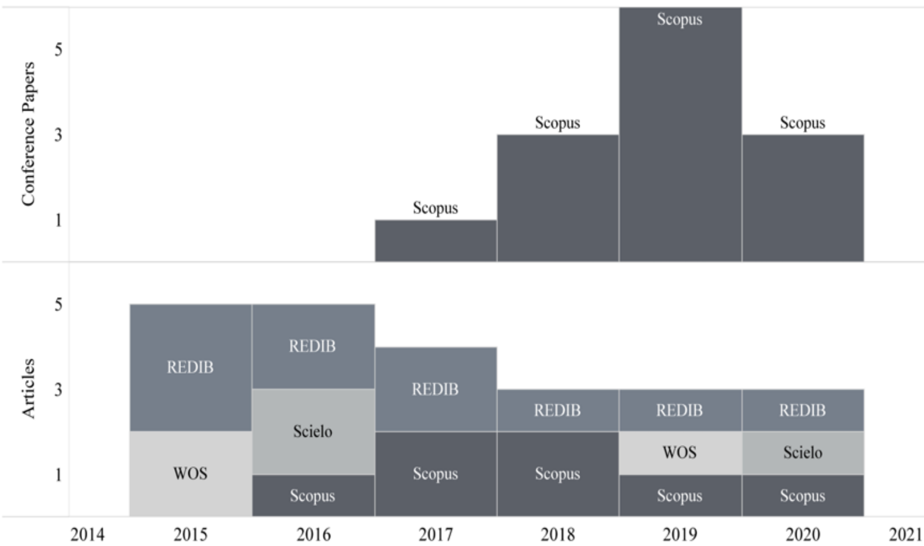

Figure 2. Number of documents by type and data-source per year

The results described below where obtained after exploratory data analysis and visualization during the last month of this research. We decided to add to this analysis the quality variable to minimize our bias against the supposed bad quality of Latin-American research, as stated in PRISMA guidelines. We carefully chose the most telling results, given the space limitations; however, we specifically compare our results with those in other reviews on the subject. We later summarize and interpret these findings within the bigger framework of education technology in the discussion.

RESULTS

Bibliometric Patterns

It is usually thought that Brazil is the Latin-American country with the largest scientific productivity in the region, given the prominence of Brazilian authors and journals in Scopus (UNESCO, 2021). However, the largest part of the documents reviewed were written by Mexican (n=12, 33%), Colombian (n=9, 25%) and Brazilian (n=7, 19%) authors. Ecuadorian, Chilean and Peruvian authors only authored 8 of the 36 reports (22%). Furthermore, we noticed that Brazil was the country with the least percentage of documents in Scopus, while the opposite happened with Mexico. This outstanding fact was also found in international reviews that give importance to less science-productive countries than the US or the UK in the pedagogical AR usage-related literature, like Taiwan and Spain (Altinpulluk, 2019; Diao & Shih, 2019).

The retrieved documents were usually published each in a different journal or conference proceedings book. *Computer Applications in Engineering Education*, *Lecture Notes in Computer Science*, *Pistas educativas* and *Revista Educación en Ingeniería* were the only publications with at least two documents from the sample. In contrast, previous reviews found that most of the related literature in the world was published in *Computers & Education*, *The Journal of Science Education and Technology*, *EURASIA Journal of Mathematics Science and Technology Education*, *Education Technology and Society* and *Computers in Human Behavior*, among others (Bacca et al., 2014; Iatsyshyn et al., 2020). In contrast, 50% of our sample was found in journals or proceedings primarily published in Spanish or Portuguese. Among the rest, just one paper was published in the third of the before listed journals.

Our sample seems to have been progressively accumulating in the span between 2015-2020, following the international trend (Altinpulluk, 2019; Diao & Shih, 2019; Ibáñez & Delgado-Kloos, 2018). However, we notice a delay in the productivity peak: Even though Altinpulluk (2019) shows an increasing rate of production during 2013-2016 and Diao and Shih (2019) between 2017-2018, we only found a notorious increase in the number of Latin-American documents between 2018-2019. Interestingly, this was driven by a numerical increase of documents from subscription-based journals indexed in Scopus, whereas open-access documents stagnated within the five-year period (except for the REDIB documents, that are decreasing in number versus new Scopus open-access documents). This pattern seems important, given that the extant literature usually rely on WOS or Scopus only. Figure 2 shows the number of documents by type and data-source per year.

Nonetheless, we believe that this change was rather related with an increase in the number of Scopus-indexed international conference papers. In fact, the number of papers published in peer-reviewed journals stagnated since 2018 at a rate of three papers per year. It is usually thought that the first are texts of lesser quality than the latter. Overall, we found six documents located in the first ("optimal") quartile of our quality index, and remaining quartiles contained ten documents each. The

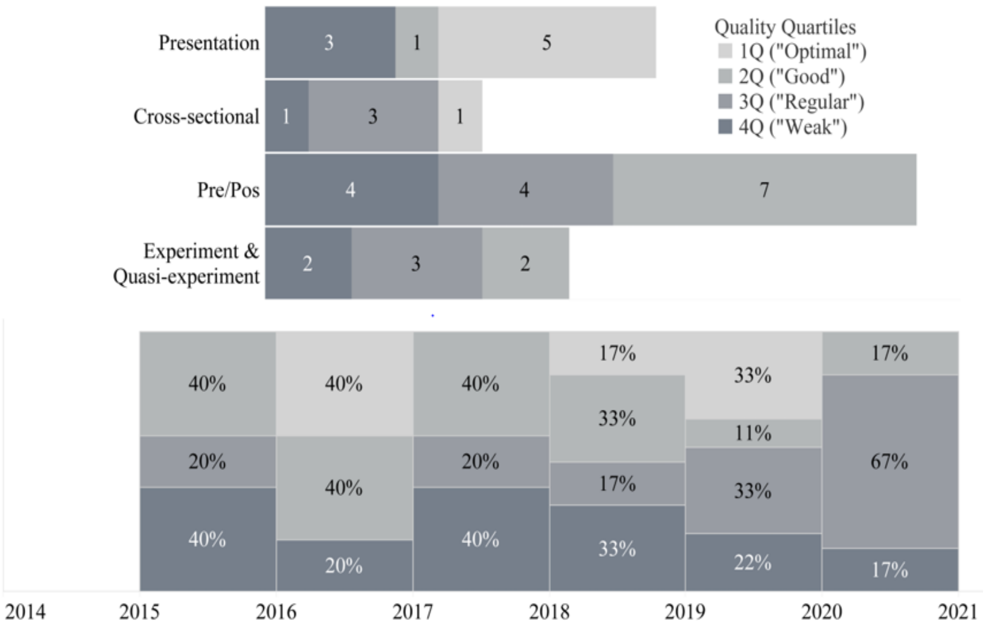

Figure 3. Number (above) and percentage (below) of research quality quartiles by research design and time

number of documents in the third quartile seems to be increasing with time, and in parallel, the fourth and first quartiles shrink. However, we report no relevant differences between the quality of documents screened from different databases or publication types. This finding contrasts with the current selection practices in other reviews, which seem to be guided by an exclusion bias.

Research Designs

Though some of the works reviewed are simple full-text descriptions of the design process of technologies or classroom activities (n=9, 25%), most include some form of empirical evaluation or testing, either by observational (n=5, 14%), pre/post (n=15, 42%) or quasi-experimental (n=7, 19%) designs. Two documents ([5], [19]) are only evaluations. Questionnaires (n=13, 36%), academic grades (n=4, 11%) and a mix of both (n=4, 11%) compose the largest part of data collection techniques used, although some documents also mention qualitative techniques as interviews and observational forms (n=4, 11%), two mention object recognition data ([4], [17]), one mentions Emotiv Insight cognitive sensory data ([22]) and another one system development outputs ([33]). In contrast, Diao and Shih (2019) find predominantly experimental designs in their engineering-themed review; the further importance of mixed methods and questionnaires for data collection was revealed by the wider reviews of Bacca et al. (2014) and Altinpulluk (2019). Figure 3 depicts the number and percentage of research quality quartiles by research design and time.

The authors in our review mainly engaged with engineering Students (n=26, 72%), a mix of Students and Teachers (n=5, 14%) and Employees (n=2, 6%). The subjects of these studies where systems (n=7), civil (n=4), mechatronics (n=2), and cartographic (n=2) engineering university students, as well as electric (n=1) and industrial (n=1) engineering institute students, and mechanical (n=3), electronic (n=4), and mixed (n=8) engineering specializations students from various institutions. Confirming a wider pattern in the secondary literature, sample sizes in evaluations ranged from 5 [22] to 312 ([19]) subjects, but 55% of the evaluations fell between 30-60 subjects (e. g., Bacca et al. (2014) found most of the samples in their population to be between 30-200 subjects, while Sirakaya and Sirakaya (2018) placed the sample mean between 31-100 subjects). Besides this, we registered the educational year corresponding to subjects or programs as described in the literature, when possible (n=16).

As shown in Figure 4, most authors worked with first-year students, but older students were also part of bigger sample sizes. Figure 5 shows that different

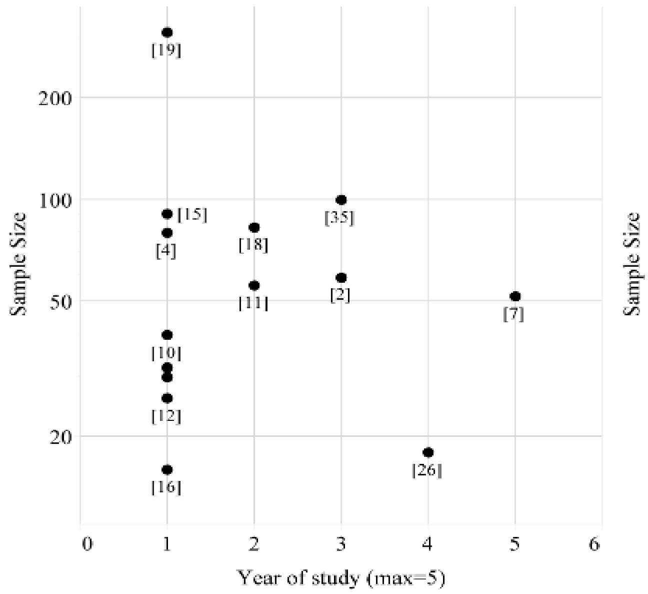

Figure 4. Sample size by year of study

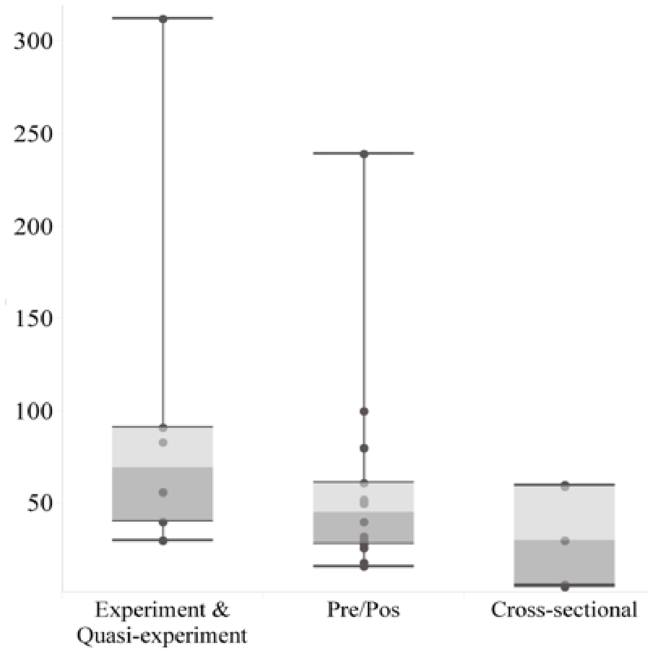

Figure 5. Sample size by research design

designs included differing sample size ranges: cross-sectional samples where smaller (median=30) and experimental samples where larger (median=70) compared with pre/post samples (median=45).

To explore this pattern, we observed the structure of research design quality and the main outcomes studied per design. Interestingly, almost 67% of the case presentations were placed either in the first or second quality quartiles (which can be interpreted as "optimal" and "good"), although this is true for just 36% of the texts that contain evaluations. No quasi-experimental design comes from a document deemed as "optimal" (considering that all the quasi-experimental studies included control groups, but only one was explicitly randomized, [18]). In parallel, 20%-33% of the literature was classified in the last quartile, irrespective of the research design followed. Secondly, we found that most quasi-experimental designs measured academic performance or less popular variables (spatial abilities in [19] and KPIs in [9]), compared with pre/post designs, that mainly focused on satisfaction measures, and cross-sectional research, primarily interested in satisfaction and system performance measurement. This does not mean that these were the only exclusive possibilities, as shown in Table 10.

Design Features

On the following lines, we will describe the hardware and software listed in the literature. Most of the devices used by the literature were only Smartphones (n=23, 64%), or both Smartphone and PC/Tablets (n=7, 21%). The second most used device was the PC (n=3, 8%), followed by Tablets (n=1, 3%) and VR/AR mixes (n=1, 3%). Apparently, the found dominance of Smartphones in higher education is supported by the literature on STEM education-focused AR (Shirazi & Behzadan, 2015) as opposed to reviews that include other education levels. On the other hand, earlier reviews state that teachers lean towards Junaio, ARMedia, and ARToolkit for designing their AR-based activities (Diao & Shih, 2019; Sirakaya & Sirakaya, 2018). It seems that Latin-American AR-based educational programs rather depend on Vuforia (n=14, 39%), Aumentary (n=3, 8%), Unity (n=3, 8%), and ARToolkit-based (n=2, 6%) applications. A small group (n=5, 14%) even favored native applications, despite being a percentage fewer than the 43% reported by Ibáñez and Delgado-Kloos (2018); nonetheless, 63% (n=23) report or included some form of coding, including all applications based on Vuforia.

Diao and Shih (2019) stablish a difference between "general" and "specific purpose" AR software. Half of the applications reviewed by them where of "general" use (displaying text or graphics, or allowing 3D-object manipulation, for example), and the other half were of "specific use" (for object or architecture design, for example). On the other hand, drawing from literature about different education levels, Altinpulluk (2019) typified AR applications and found that most of them where 3D-Image based, Location-based, Video-based, games, or simulations and text based (from 17 overlapping types). In opposition to this literature, 71% (n=25) of the applications in our review were of "general purpose" and mainly 3D-Image (n=12), Text (n=7), Simulation (n=6), and Video-based (n=3) software. Most of the general purpose software where largely 3D-Image

Table 10. Outcome variables and evaluation designs in the literature

Outcome variables measured	Evaluation design		
	Pre/Pos	Cross-sectional	Experiment & Quasi-experiment
Academic achievement	[7], [10]		[15], [18]
Satisfaction	[3], [4], [5], [12], [13], [24], [26], [35]	[25]	[31]
Performance		[33]	
Academic achievement and satisfaction	[16], [21]		[11], [30]
Academic achievement and performance	[8], [32]		
Satisfaction and performance	[1]	[17]	
Academic achievement, satisfaction, and performance		[2]	
Spatial skills, KPIs, and emotions		[22]	[9], [19]

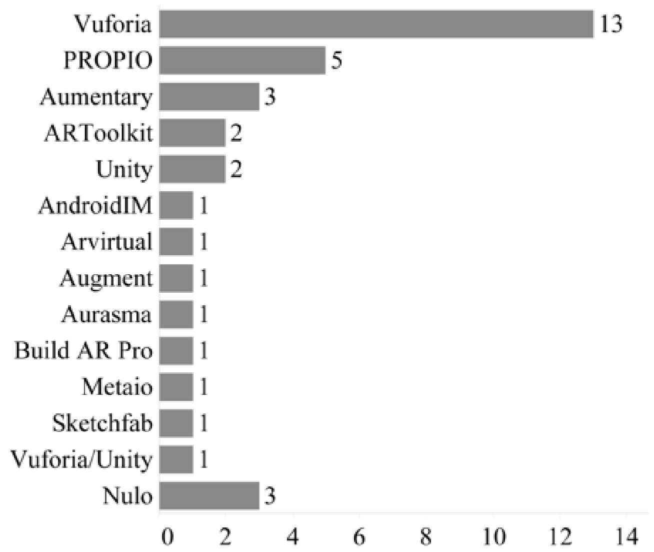

Figure 6. Distribution of documents according to software used

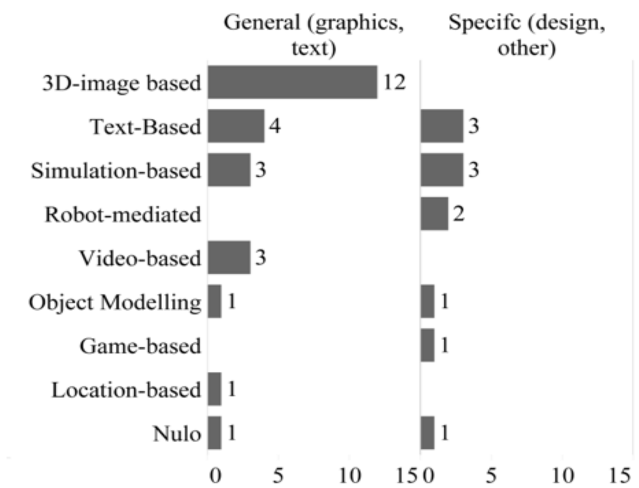

Figure 7. Number of documents by type of content and app type

(n=12), Text (n=4) and even Video-based (n=3), while the other group was composed by mainly Text-based (n=3), Simulation (n=3) and Robot mediated (n=2) software. Finally, no relevant differences were found between purpose and the use of native/non-native software. Figure 6 displays the distribution of documents according to software used while Figure 7 depicts the number of documents by type of content and app type.

The following paragraph describe additional AR software features in our engineering education literature. AR software based on marker or label recognition is predominant in the extant literature. We confirm this after finding 26 (72%) marker-based, 3 (8%) layer-based, and 2 (6%) object-recognition software. In the same vein, drawing from de Belen et al. (2019), we delimited a three-step interaction continuum for AR technology. Our results show that a big part of our AR technology in our sample only allowed Perception (n=16, 44%), some endorsed Annotation (n=6, 17%) and the rest where based on interaction by direct Manipulation (n=14, 39%). In addition to this, following the findings of Montoya et al. (2016), we coded the presence of dynamic content (n=15, 42%), as opposed to static content. Though all observed application types had some dynamic content-focused examples, dynamic contents were only predominant among all Location and Video-based as well as most Simulation apps (n=8, 22%). Finally, out of the 20 documents reporting both considerable and secondary use of 3D-Objects or images, most were created by the teacher (n=12), followed by those created by the class (n=5) and those downloaded or already part of the employed software (n=3).

Pedagogy

We coded the AR affordances and the main pedagogical perspectives linked with this technology. Saltan and Arslan (2016) suggested a seemingly useful categorization of three main AR pedagogical affordances. On the same line, AR in the reviewed literature afforded knowledge comprehension (n=17, 47%), concept development (n=14, 39%), and learning retention (n=5, 14%). Secondly, perhaps the pedagogical perspectives that frame educational practices linked with AR are more difficult to define. Despite the lack of consensus, we identified two favored cognitivist frameworks, CTML (n=13, 36%) and Mobile Learning (n=9, 25%), and three constructivist frameworks, Situated Learning (n=5, 14%), Experiential Learning (n=7, 19%), and Collaborative Learning (n=1, 3%) (Sommerauer & Müller, 2018). Examining the data, its easily seen that constructivist approaches favor AR concept development affordances in contrast with the other two. Interestingly, we also found a relationship between affordances and dynamic/static contents.

While most research engaged with engineering students, our literature populations pertained to a diversity of institutions: most of them to universities (n=25, 69%), some to technical schools (usually known as institutes, n=8, 22%), and a few to businesses (n=2, 6%). The latter were more prone to engage with a cognitivist framework, but half of the AR-related practices in institutes were constructivist. Besides, we analyzed teaching and academic evaluation practices related with AR, finding out that 78% were task-based and 69% (n=25) were problem-solving-focused activities (Diao & Shih, 2019; Wu et al., 2013). Following our analysis, we correspondingly saw the importance of technical schools for experimenting with more collaborative approaches to teaching (whether role or location-based) and evaluation activities (e. g., group or pair projects, peer-based work, etc.): most of the synchronic task-based activities ([30], [35], [34]) and the only group project-based course ([21]) were done in these institutions. Even if this trend contrasts with the project-based pedagogy prevalent in other AR education contexts (Diao & Shih, 2019), the relationship between constructivism and

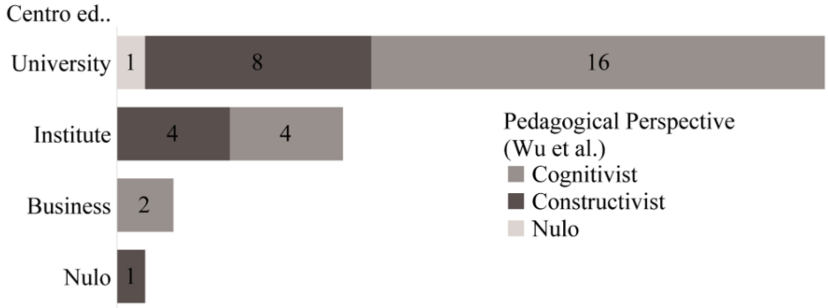

Figure 8. Number of documents by pedagogical perspective and post-secodary education institution

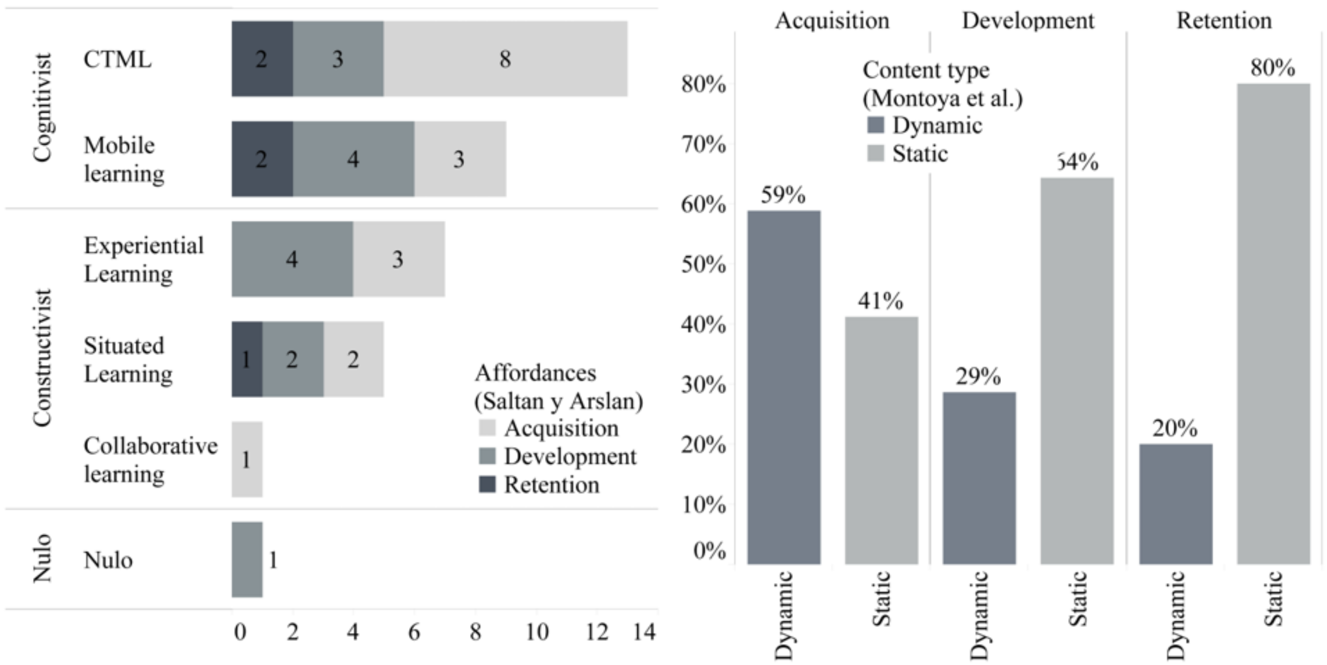

Figure 9. Number (left) and percentage (right) of documents according to their educational affordances by pedagogical perspective and content type

collaborative learning became apparent when we saw that the only remote-based collaborative course found ([21]) was supported by an institute (de Belen et al., 2019). Figure 8 shows the number of documents by pedagogical perspective and post-secodary education institution.

Another way to look at this is to understand the kind of pedagogical experiences that students undergo when using AR. Following Chubukova and Ponomarenko (2018), these can be: modeling situations (n=14, 39%), acquiring skills (n=12, 33%), learning with textbooks or manuals (n=4, 11%), game-like experiences (n=3, 8%), and 3D object modelling (n=2, 6%). We saw that skill training and game-alike experiences are the only ones that partly support knowledge retention, however content acquisition is helped by all experiences except for game-alike, and concept development is only entirely absent of textbook/manual-based experiences. On the other hand, it is interesting to note that dynamic contents are a minority in all experiences, except for modelling. Figure 9 depicts the number and percentage of documents according to their educational affordances by pedagogical perspective and content type.

What are the main advantages and disadvantages of the use of AR in engineering education? In our review, most authors (n=15) agreed that AR motivated students (n=15), followed by those who valued an increase in academic achievement (n=11), the ease of use (n=9), innovativeness (n=6) and collaboration (n=2). Interestingly, more authors with ideas closer to experiential and situated learning report motivation benefits; whereas, among those reporting increases in academic achievement, the mobile learning framework is more common. In spite of a common consensus of AR being beneficial for academic achievement among other advantages (Akcayir & Akcayir, 2017; Bacca et al., 2014; Singh et al., 2019), a recent meta-analysis point towards the more nuanced conclusion that AR actually helps student engagements and abstract concept understanding (Garzón et al., 2019; Liono et al., 2021).

To conclude, virtually all authors mentioned an advantage, but less than half (n=16) mentioned disadvantages, namely heterogeneous benefits for different types of users (n=6), demanding technical requirements (n=6), accessibility issues related with skill gaps (especially among teachers and older professionals, n=5), the complexity of the setups used (n=2) and pedagogical insufficiencies (n=1). Both the lack of limitations and the complexity and technical problems have been found before in the AR literature (Akcayir & Akcayir, 2017; Bacca et al., 2014).

DISCUSSION

AR is a nowadays considered a mainstream tool for engineering education in Latin America (Hidrogo et al., 2020). Although this technology enhances important research, social and work-related skills in higher education (Klimova et al., 2018), questions about human-based design, display technology, pedagogy and collaboration remain open (Billinghurst, 2021). In this work we reviewed conference papers and scientific articles published by Latin-American authors, focusing on AR uses in engineering education. Even though others reviewed experiences from different educational levels and disciplines, we tried to tackle many of the still open themes while only focusing on higher education.

One of the reasons to do this was to rethink the role of innovation to address the current knowledge gaps in the world. We found an increasing number of quality indexed conferences and a stagnant number of articles written by mainly Mexican, Colombian, and Brazilian authors. Even though most of the literature presented medium quality evaluations, different research designs seem to relate with corresponding sample sizes, variables measured and data collection techniques. At the same time, Latin-American engineering educators prefer conventional open-source AR software and Smartphone devices, incorporating some basic coding and 3D object modelling; however, we reported a big interest for manipulation and annotation based applications, as well as important object recognition software applications. Pedagogically, most university AR-related engineering programs and activities engage with cognitivist frameworks, but institutes seem to be embracing the emergence of constructivist and collaborative innovations. In general, authors highlight motivation academic achievement advantages, but overlook the disadvantages; when acknowledged, they emphasize accessibility and technical issues.

These findings integrate with the literature in two important ways. First, we can support the view that this literature leaves aside a needed focus on accessibility and longitudinal approaches (Bacca et al., 2014). Nonetheless, Latin-American authors, especially those affiliated with institutes, tackle, at least partly, collaboration, interaction issues and other largely overlooked UX design issues, as well as vocational learning, in a very intermingled way (Bacca et al., 2018; Ibáñez & Delgado-Kloos, 2018; Phon et al., 2014; Shirazi & Behzadan, 2015). These innovative authors seem likely interested in the motivational benefits of game and simulation-based learning (Ayer et al., 2016). Yet, contradicting earlier reviews, this trend is far from the mainstream. Our review also revealed a delay in evidence-based pedagogical practices, especially within universities: few authors seem interested in randomized controlled trials or mixed methods, and task-based evaluation practices within cognitivist pedagogies are still preferred over newer approaches.

We further believe to have shown the value of reviewing conference papers along with scientific articles. This helped us to learn about the importance of contextual factors before making assumptions about the advancement of Industry 4.0 technologies through AR-based engineering education (Hernandez-de-Menendez et al., 2020). We think that Latin-American university educators, which are the greatest part of our sample, prefer to report conventional AR uses under cognitivist approaches, in contrast with other technologies and pedagogies, given the cost of Smartphones for their students, the limitations of their university budgets, the accessibility of open-source 3D object modeling and AR software, and the greater simplicity of conference formats in contrast with the demanding formats of international journals.

The limitations of the following review include proceeding without a pairwise quality assessment, applying a largely experimental quality assessment tool (and including some low-quality documents, due to the nature of scoping reviews), unavertedly or intentionally over-simplifying non-exclusive categories of certain variables, and having worked against time with an extensive number of research questions and variables. Future reviews should a) attend to relevant or influential pedagogical and/or technological innovations in engineering education in different global regions, b) discover the barriers for the adoption of such innovations by more precise literature review questions and informative methods (ranging from meta-analyses to multivocal reviews), and c) develop recommendations to better manage the knowledge production in different higher education institutions. Finally, we confirm the lack of longitudinal studies, the small quantity of correlational and experimental research, and very few direct references to qualitative methodologies, which justifies future additional research.

CONCLUSIONS

This scoping review shows that the accumulating Latin-American literature regarding the use of AR in engineering education is mostly pedagogically and technologically conservative, and that the research designs behind this literature are diverse but still limited. Nevertheless, we believe to have found a positive and emerging trend among institute-based engineering education. Moreover, using a literature-based categorization, we found a diversity of application types and contents, contradicting the international trends in certain aspects, and even finding various direct mentions of software coding in all the literature. We also find that most advances are reported as mostly Scopus-indexed conference papers, which is the only literature type in expansion.

We believe that these results inform the management of STEM education policies in the region. Knowledge gaps around the world, including those in research quality, are relevant to the diffusion of innovations in engineering education. Universities and teachers might consider accessibility and performance issues when trying out AR-based courses, but also should experience more with other pedagogies and forms of evaluation. Finally, future literature reviews might consider our solutions to the lack of representation of developing regions, as well as the differences between international patterns and locally-based phenomena.

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