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 & Dusteog, 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 (Akçayır & Akçayır, 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,
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.

METHODOLOGY

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
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
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 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 (ingeniería) OR TITLE-ABS-KEY (engineering) OR TITLE-ABS-KEY (técnico*) OR TITLE-ABS-KEY (tecnic*))) 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)) AND (AK=(realidad aumentada) OR realidad 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 "realidad aumentada" OR "realidad híbrida" OR "realidad enriquecida" OR "realidad aumentada" OR "realidad híbrida" OR "realidad enriquecida") OR TI=("realidad aumentada") OR "realidad aumentada" OR "realidad híbrida" OR "realidad enriquecida") OR AB=("realidad aumentada") OR "realidad aumentada" OR "realidad híbrida" OR "realidad enriquecida") OR KP=("realidad aumentada") OR "realidad aumentada" OR "realidad híbrida" OR "realidad enriquecida") OR TS=(ingeniería OR engineering OR engenharia OR technic* OR técnica OR technic*) OR TI=(ingeniería OR engineering OR engenharia OR technic* OR técnica OR technic*) OR AB=(ingeniería OR engineering OR engenharia OR technic* OR técnica OR technic*) OR KP=(ingeniería OR engineering OR engenharia OR technic* OR técnica OR technic*) AND (TS=(ingeniería OR engineering OR engenharia OR technic* OR técnica OR technic*) OR TI=(ingeniería OR engineering OR engenharia OR technic* OR técnica OR technic*) OR AB=(ingeniería OR engineering OR engenharia OR technic* OR técnica OR technic*) OR KP=(ingeniería OR engineering OR engenharia OR technic* OR técnica OR technic*)) AND (CU=(Brasil OR Perú 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:(realidade aumentada)) OR (ti:(augmented reality)) OR (ti:(realidade aumentada)) AND (ingeniería 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) |
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.    |
| 28 | Are individual and group outcomes compared?                              | 1.5    | Case+Eval.    |
| 29 | Are compared groups similar or is there an explicit comparability intention? | 1.5    | Case+Eval.    |
| 30 | Are baseline or descriptive data included?                               | 1      | Case+Eval: Reggression-based |
| 31 | Is a control group included?                                             | 1.5    | Cuasiexp.     |
| 32 | Is there a discussion about causality?                                   | 1.5    | Cuasiexp.     |
| 33 | Is there an explicit mention of randomization?                           | 1      | Cuasiexp.     |
| 34 | Was the randomization method correct?                                    | 1.5    | Cuasiexp.     |
| 35 | Was the randomization process blind?                                     | 1.5    | Cuasiexp.     |
| 36 | Was the study double-blinded (is the author intentionally unconscious about which subjects are assigned to each group)? | 1      | Cuasiexp.     |

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 Altinnpulluk (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 | 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 aumentada para a 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 con realidad 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 entrenamiento de técnicos de mantenimiento de maquinaria pesada en la empresa Zamine Service Peru SAC | REDIB  | Peru    |
| [10] | Regular | Arquitectura interactiva como soporte al aprendizaje situado 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 | Scielo | Colombia|
| [15] | Weak    | Estrategia colaborativa en entornos tridimensionales 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 an 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 applications | 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 bioroid 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 el 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 |
| Author | Year | Journal | DOI |
|--------|------|---------|-----|
| Monroy Reyes, A., Vergara Villegas, O. O., Miranda Bojórquez, E., Cruz Sánchez, V. C., & Nandayapa, M. Castillo, R. I. B., Sánchez, V. G. C., & Villegas, O. O. V. de Oliveira Souza, W., Mira de Espinolda, G., Alves Pereira, A. R., & Marques de Sá, L. A. C. Avilés-Cruz, C., & Villegas-Cortez, J. Silva, J.; Souza, F. da F. de, Sedraz, L., & Ramos, J. L. C. | 2016 | Computer Applications in Engineering Education | 10.1002/cae.21772 |
| | 2015 | Mathematical Problems in Engineering | 10.1155/2015/946034 |
| | 2016 | Boletim de Ciências Geodésicas | 10.1590/s1982-21702016000400045 |
| | 2019 | Computer Applications in Engineering Education | 10.1002/cae.22102 |
| Hernández-Ordoñez, M., Nuño-Maganda, M. A., Calles-Arriaga, C. A., Montaño-Rivas, O., & Bautista Hernández, K. E. Mendoza Pérez, M. A., Cruz Flores, R. G., Villalba Hernández, A. A., Calderón Rodríguez, J. A., & Patiño, E. A. Soberanes Martín, A., Castillo Mendoza, J. L., & Peña Martín, A. Gamboa Cruzado, J., Larico Uchamaco, G. R., Soto Soto, L., Chacón Malasquez, N., Tuiro Achulle, J., & Guzman Chambi, S. C. Gomez, J. E., Hernandez, V., & Morales, M. Flores-Amado, A., Díliegres-Godines, C. J., Trevino, J. P., Sayeg-Sánchez, G., & Gonzalez-Hernandez, H. G. del Rio Guerra, M., Martín-Gutierrez, J., Vargas- Lizarraga, R., & Garza-Bernal, I. | 2018 | Mobile Information Systems | 10.1155/2018/6047034 |
| | 2017 | Pistas educativas | 10.31876/ie.v11i1.6 |
| | 2017 | Ceprosimad | |
| | 2015 | Revista Eduacion en Ingenieria | 10.26507/rei.v10n20.575 |
| | 2020 | IEEE Global Engineering Education Conference, EDUCON | 10.1109/EDUCON45650.20 |
| | 2018 | Lecture Notes in Computer Science | 10.1007/978-3-319-9181-

| Author | Year | Journal | DOI |
|--------|------|---------|-----|
| Grimaldo, A. C. R., & Chaparro, E. M. V. | 2019 | Proceedings of the LACCEI international Multiconference for Engineering, Education and Technology | 10.18887/11LACCEI2019.1.1.427 |
| Jiménez Toledo, J. A., Collazos Ordoñez, C. A., Hurtado Alegria, J. A., & Pantoja Y. W. L. Montoya, M. H. Díaz, C. A., & Moreno, G. A. Reyes-Aviles, F., & Aviles-Cruz, C. Buitrago-Pulido, R. D. Gómez-Tone, H. C., Martin-Gutierrez, J., Anci, L. V., & Luis, C. E. M. | 2015 | Revista Investigium Irc: Ciencias Sociales y Humanas | 10.15658/CESMAg15.0506 |
| | 2017 | Eurasia Journal of Mathematics, Science and Technology Education | 10.12973/eurasia.2017.0061 |
| | 2018 | Computer Applications in Engineering Education | 10.1002/cae.21912 |
| | 2015 | Educación y educaciónes | 10.5294/edu.2015.18.1.2 |
| | 2020 | Symmetry | 10.3390/SYM201401 |
| Cortés Caballero, J. M. | 2016 | Eduteck. Revista Electrónica de Tecnología Educativa | 10.21556/edutec.162016.58.83 |
| 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 |
| Rojas-Contreras, M., Peña-Cortés, C. A., & Cañas-Rodriguez, S. M. | 2020 | Journal of Physics: Conference Series | 10.1088/1742- |
| De Almeida Carlos, G. A., Ferro, V., Lisboa, R., & Da Silva, A. Alvarez-Marín, A., Castillo-Vergara, M., Pizarro-Guerrero, J., & Espinoza-Vera, E. Marquez-Diaz, J. E., & Morales-Espinosa, L. A. Nolasco de Almeida Mello, G., & Cabero Almenara, J. | 2019 | Proceedings of the International Conference on Power Electronics and Drive Systems | 10.1109/PEDS44367.2019.988825 |
| | 2017 | Formacion Universitariia | 10.4067/S0718-|
| | 2019 | Revista Educacion en Ingenieria | 10.26507/rei.v15n29.1037 |
| | 2020 | ALTERIDAD. Revista de Educación | 10.17163/vlt.v15n1.2020.01 |
| | 2019 | Etec@net. | 10.18779/inenio.v11i1.11 |
| | 2019 | Communications in Computer and Information Science | 10.1007/978-3-030-2528-

| Author | Year | Journal | DOI |
|--------|------|---------|-----|
| Mendoza Morán, V. del R., Rivera Guevara, R., & Barriga Andrade, J. Ullón, H., Zambrano, D., & Dominguez, F. Almeida, E. M. D., Damasceno, E. F., & Lrrario, A. Rodrigues Júnior, A. S., da Costa Gomes, G. J., Carmame Berteges, L. F., de Souza Siqueira Pereira, C., & de Alencar Carvalho, C. V. Morales, A. D., Sanchez, S. A., Pineda, C. M., & Romero, H. J. Ramirez Flores, P. G., Mendoza Medina, J. A., Gonzalez Mendivil, E., & Villegas Villarreal, A. R. Lucas, P., Vaca, D., Domínguez, F., & Ochoa, X. Garcia, C. A., Naranj, J. E., Gallardo-Cardenas, F., & Garcia, M.V. | 2017 | 12th Latin American Conference on Learning Objects and Technologies, LACLO 2017 | 10.1109/LACLO.2017.8120 |
| | 2019 | Proceedings - Frontiers in Education Conference, FIE | 10.1109/FIE.2018.8658529 |
| | 2020 | Brazilian Journal of Development | 10.34117/bjdvns-091 |
| | 2019 | IOP Conference Series: Materials Science and Engineering | 10.1088/1757-

| Author | Year | Journal | DOI |
|--------|------|---------|-----|
| | 2018 | Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering | 10.1007/978-3-319-73323-

| Author | Year | Journal | DOI |
|--------|------|---------|-----|
| | 2018 | Proceedings - IEEE 18th International Conference on Advanced Learning Technologies, ICALT 2018 | 10.1109/ICALT.2018.00097 |
| | 2019 | Lecture Notes in Computer Science | 10.1007/978-3-030-25999-

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Table 6. Data extracted from the literature – Part 3

| Item Type | Population | Year | Course | Specialization | Educative institution | Research Design |
|-----------|------------|------|--------|----------------|-----------------------|-----------------|
| 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   | 1    | Materials resistance | Universidade Federal do Vale Evaluation do São Francisco | Design & Evaluation |
| Article   | Students & teachers | 5    | Advanced Robotics | Computation Engr. | Design-only |
| Article   | Students & teachers | 1    | Research Methodology | Computation Engr. | Design & Evaluation |
| Article   | Employees  | 1    | Unnamed Training Workshop | Many | 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 |
| 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 Autónoma 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) Instituto Politécnico Nacional | Design-only |
| Conference Paper | Students & teachers | 1    | Calculus | Many | Tecnológico de Monterrey | Design & Evaluation |
| Conference Paper | Students | 1    | Algorithms and structures | System Engr. | Universidad de Pamplona | Design & Evaluation |
| Conference Paper | Students | 1    | Power electronics | Electronic Engr. | Instituto Federal de Alagoas | Design-only |
| Article   | Students | 1    | Fluid Mechanics | Civil Industrial Engr. | Universidad de La Serena | Design & Evaluation |
| Article   | Students | 1    | 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. | Instituto Universitaria Pascual Bravo | Design-only |
| Article   | Students | 1    | Physics I | System Engr. | Universidad de Guayaquil Escuela Superior Politecnica del Litoral | Design & Evaluation |
| Conference Paper | Students | Many | Many | Many | Corporoucre Tecnológico de Monterrey | Design-only |
| Conference Paper | Students | Many (Structural Design) | Mechatronic Engr. | Universidad de Vassouras | Design & Evaluation |
| Conference Paper | Students | 1    | Mechanical physics | Many | Tecnológico de Monterrey | Design-only |
| Conference Paper | Students | 1    | Reading (short course) | Many | Escuela Superior Politecnica del Litoral | Design & Evaluation |
| Conference Paper | Students | 3    | Electrical Circuit Analysis Electric Engr. | Many | Empresa de Petróleo y Gas (no dice) | Design-only |

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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 |
|-------------------|----------------------------|------------------|-------------|--------|-----------------------------|---------------|--------|----------|
| Pre/Pos Observation | 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 |
| Pre/Pos Observation | Questionnaire               | Satisfaction     | 32          | No     | Layers                      | Aumentary     | PC     | 3D-image based |
| Pre/Pos Observation | Survey                      | Satisfaction     | 80          | Yes    | Object recognition          | Own           | Smartphone | Text-Based |
| Pre/Pos Observation | Questionnaire               | Satisfaction     | 50          | No     | Labels                      | Aurusma       | Tablet  | Text-Based |
| Case study        | Interviews                  | Academic achievement | 52          | No     | Labels                      | ARToolkit     | Smartphone | Simulation-based |
| Pre/Pos Observation | Survey                      | Academic achievement & Performance | 51          | Yes    | Labels                      | Unity         | Smartphone | Text-Based |
| Quasi-experiment  | Observation                 | KPIs              | 30          | Yes    | Labels                      | Vuforia       | Smartphone | Text-Based |
| Pre/Pos Observation | Test                        | Academic achievement | 40          | No     | Labels                      | Flartoolkit   | Smartphone | 3D-image based |
| Quasi-experiment  | Test                        | Academic achievement | 56          | Yes    | Labels                      | Own           | Smartphone | 3D-image based |
| Pre/Pos Observation | Interviews                  | Satisfaction     | 26          | Yes    | Labels                      | Vuforia       | Smartphone | 3D-image based |
| Pre/Pos Observation | Survey & Test               | Satisfaction     | 28          | No     | Other (detector test)       | Metaio        | Smartphone & VR | Simulation-based |
| Case study        | Test                        | Academic achievement | 91          | Yes    | Layers                      | Vuforia       | Smartphone | Video-based |
| Pre/Pos Observation | 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                   | VR            | Smartphone | 3D-image based |
| Case study        | Survey                      | Habilidad espacial | 312         | Yes    | Labels                      | Own           | PC & Smartphone | 3D-image based |
| Pre/Pos Observation | Survey                      | Academic achievement & Performance | 239         | Yes    | Layers                      | Vuforia       | Tablet & Smartphone | Object Modelling |
| Pre/Pos Observation | Survey                      | Satisfaction     | 18          | No     | Labels                      | Sketchfab     | Smartphone | 3D-image based |
| Pre/Pos Observation | Test                        |                     |             | Yes    | Labels                      | Aumentary     | PC & Smartphone | 3D-image based |
| Case study        | Questionnaire & test        | Academic achievement & Satisfaction | 40          | Yes    | Labels                      | AndroidIM     | Smartphone | Location-based |
| Quasi-experiment  | Questionnaire & test        | Satisfaction     | 30          |        |                             | Vuforia       | Smartphone | Text-Based |
| Pre/Pos Observation | Survey                      | Academic achievement & Performance | 30          | No     | Labels                      | Augment       | Smartphone | Object Modelling |
| Case study        | Performance                 |                     |             | Yes    | Labels                      | Vuforia       | Smartphone | Simulation-based |
| Case study        | Questionnaire               | Satisfaction     | 100         | Yes    | Labels                      | Vuforia       | Smartphone | 3D-image based |
| Case study        | Other (detector test)       |                     |             | Yes    | Other (detector test)       | Unity         | Smartphone & VR | Simulation-based |
## Table 8. Data extracted from the literature – Part 5

| Static / Dynamic | 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                          | Experiential Learning            | Tasks            | Problem Resolution         | Forms created by teacher | General (graphics, text) | Perception               |
| Static           | Modelling                          | Mobile learning                  | Tasks            | Problem Resolution         | General (graphics, text) | Manipulation            | Perception               |
| Dynamic          | Modelling                          | CTML                             | Tasks            | Problem Resolution         | Espec. Aplic. (design, etc.) | Perception               |
| Dynamic          | Modelling                          | Mobile learning                  | Tasks            | Problem Resolution         | General (graphics, text) | Manipulation            | Perception               |
| Dynamic          | Modelling                          | CTML                             | Tasks            | Problem Resolution         | General (graphics, text) | Perception               |
| Static           | Skill training                     | Mobile learning                  | Tasks            | Problem Resolution         | General (graphics, text) | Perception               |
| Static           | Modelling                          | Situated Learning                | Tasks            | Problem Resolution         | Forms created by teacher | General (graphics, text) | Perception               |
| Dynamic          | Modelling                          | Experiential Learning            | Locations Personal Project | Forms created by teacher | Espec. Aplic. (design, etc.) | Manipulation            | Perception               |
| 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               |
| Static           | Textbook / manual                  | CTML                             | Tasks            | Predefined forms           | General (graphics, text) | Manipulation            | Perception               |
| Dynamic          | Textbook / manual                  | CTML                             | Roles            | Forms created in class     | General (graphics, text) | Perception               |
| 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               |
| 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           | Skill training                     | CTML                             | Tasks            | Problem Resolution         | Espec. Aplic. (design, etc.) | Manipulation            |
| Static           | Skill training                     | Mobile learning                  | Tasks            | Personal Project           | Forms created in class | General (graphics, text) | Perception               |
| 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                  | Forms created by teacher | General (graphics, text) | Perception               |
| 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 General teacher | Annotation               |
| Static           | Game alike                         | Situated Learning                | Locations Group-work sincrónico | Forms created by teacher | Annotation               |
| Static           | Modelling                          | Experiential Learning            | Tasks            | Peer-work                  | General (graphics, text) | Manipulation            |
| Static           | Skill training                     | Mobile learning                  | Locations        | Problem Resolution         | General (graphics, text) | Manipulation            |
| 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                  |                                              |                                              |
| Acquisition                | pedagogical and technological aspects     |                                              | poor evaluation                             |
| Concept development        | Increases understanding, time is reduced, KPIs are met of the company |                                              | Design AR? Pedagogical?                     |
| Acquisition                | superior performance                       | It is difficult to prepare all materials      | Taks 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 | Neciesta 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                         |                                              |                                              |
| 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                         |                                              |                                              |
| Acquisition                | Accessible for students to come in mid-range phones |                                              |                                              |
| Concept development        | It is hilarious                           |                                              |                                              |
| 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                     |
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
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 Altipulluluk (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

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

**Figure 4.** Sample size by year of study
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 Juniao, 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=5, 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) establish 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

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**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] | | [9], [19] |
| Spatial skills, KPIs, and emotions | | [22] | | |

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**Figure 5. Sample size by research design**

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Further, 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 describes 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%) (Sommervuer & 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 contexts.

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
collaborative learning became apparent when we saw that the only remote-based collaborative course found (de Belen et al., 2019). Figure 8 shows the number of documents by pedagogical perspective and post-secondary 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 (Akçayır & Akçayır, 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 (Akayir & Akayir, 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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**REFERENCES**

Adams, R. J., Smart, P., & Huff, A. S. (2017). Shades of grey: Guidelines for working with the grey literature in systematic reviews for management and organizational studies. *International Journal of Management Reviews*, 19(4), 432-454. https://doi.org/10.1111/ijmr.12102

Akçayir, M., & Akçayir, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, 20, 1-11. https://doi.org/10.1016/j.edurev.2016.11.002

Aljawarneh, S. A. (2020). Reviewing and exploring innovative ubiquitous learning tools in higher education. *Journal of Computing in Higher Education*, 32(1), 57-73. https://doi.org/10.1007/s12528-019-09207-0

Altınpulluk, H. (2019). Determining the trends of using augmented reality in education between 2006-2016. *Education and Information Technologies*, 24(2), 1089-1114. https://doi.org/10.1007/s10639-018-9806-3

Alyahyan, E., & Dustegor, D. (2020). Predicting academic success in higher education: Literature review and best practices. *International Journal of Educational Technology in Higher Education*, 17(1), 3. https://doi.org/10.1186/s41239-020-0177-7

Ayer, S. K., Messner, J. I., & Anumba, C. J. (2016). Augmented reality gaming in sustainable design education. *Journal of Architectural Engineering*, 22(1), 04015012. https://doi.org/10.1061/(ASCE)AE.1943-5568.0001995

Bacca, J., Baldiris, S., Fabregat, R., & Kinshuk. (2018). Insights into the factors influencing student motivation in augmented reality learning experiences in vocational education and training. *Frontiers in Psychology*, 9. https://doi.org/10.3389/fpsyg.2018.01486

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk. (2014). Augmented reality trends in education: A systematic review of research and applications. *Educational Technology & Society*, 17(4), 133-149. http://www.jstor.org/stable/jeductechsoci.17.4.133

Barroso Osuna, J., Gutiérrez-Castillo, J. J., Llorente-Cejudo, M. del C., & Valencia Ortiz, R. (2019). Difficulties in the incorporation of augmented reality in university education: Visions from the experts. *Journal of New Approaches in Educational Research*, 8(2), 126. https://doi.org/10.7821/naer.2019.7.409

Bellido Garcia, R. S., & Paucar Villacorta, D. M. (2021). The use of augmented reality (AR) in engineering education in Latin America: A scoping review. https://osf.io/w7hk4

Billinghurst, M. (2021). Grand challenges for augmented reality. *Frontiers in Virtual Reality*, 2. https://doi.org/10.3389/frvir.2021.578080

Chubukova, O. S., & Ponomarenko, I. (2018). Innovatsyiyni teknolohiyi dopovnenoiy real'nosti dlya vykladannya dysyplin u vysshychykh navchal'nykh zakladakh Ukrainy [Innovative technologies of augmented reality for teaching disciplines in higher educational institutions of Ukraine]. *Problemy innovatsiyno-investytsiynoho rozvytku [Problems of Innovation and Investment Development]*, 16. https://er.knutedu.ua/handle/123456789/11227

de Belen, R. A. J., Nguyen, H., Filonik, D., Favero, D. D., Bednarz, T., de Belen, R. A. J., Nguyen, H., Filonik, D., Favero, D. D., & Bednarz, T. (2019). A systematic review of the current state of collaborative mixed reality technologies: 2013-2018. *AIMS Electronics and Electrical Engineering*, 3(2), 181-223. https://doi.org/10.3934/ElectrEng.2019.2.181

Diao, P.-H., & Shih, N.-J. (2019). Trends and research issues of augmented reality studies in architectural and civil engineering education—A review of academic journal publications. *Applied Sciences*, 9(9), 1840. https://doi.org/10.3390/app9091840
Drew, D. E. (2020). STEM education, economic productivity, and social justice. In D. E. Drew (Ed.), *Oxford Research Encyclopedia of Education*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190264093.013.738

Garousi, V., Felderer, M., & Mäntylä, M. V. (2019). Guidelines for including grey literature and conducting multivocal literature reviews in software engineering. *Information and Software Technology*, 106, 101-121. https://doi.org/10.1016/j.infsof.2018.09.006

Garzón, J., Pavón, J., & Baldiris, S. (2019). Systematic review and meta-analysis of augmented reality in educational settings. *Virtual Reality*, 23(4), 447-459. https://doi.org/10.1007/s10055-019-00379-9

Gómez-Tone, H. C., Martin-Gutierrez, J., Valencia Anci, L., & Mora Luis, C. E. (2020). International comparative pilot study of spatial skill development in engineering students through autonomous augmented reality-based training. *Symmetry*, 12(9), 1401. https://doi.org/10.3390/sym12091401

Greenan, K. A. (2021). The influence of virtual education on classroom culture. *Frontiers in Communication*, 6. https://doi.org/10.3389/fcomm.2021.641214

Hartling, L., Featherstone, R., Nuspl, M., Shave, K., Dryden, D. M., & Vandermeer, B. (2017). Grey literature in systematic reviews: A cross-sectional study of the contribution of non-English reports, unpublished studies and dissertations to the results of meta-analyses in child-relevant reviews. *BMCMedical Research Methodology*, 17(1), 64. https://doi.org/10.1186/s12874-017-0347-z

Hernandez-de-Menendez, M., Escobar Díaz, C. A., & Morales-Menendez, R. (2020). Engineering education for smart 4.0 technology: A review. *International Journal on Interactive Design and Manufacturing*, 14(3), 789-803. https://doi.org/10.1007/s12008-020-00672-x

Hidrogo, I., Zambrano, D., Hernandez-de-Menendez, M., & Morales-Menendez, R. (2020). Mostla for engineering education: Part 2 emerging technologies. *International Journal on Interactive Design and Manufacturing*, 14(4), 1461-1473. https://doi.org/10.1007/s12008-020-00729-x

Iatsyshyn, A., Kovach, V., Romanenko, Y., Deinega, I., Iatsyshyn, A., Popov, O., Kutsan, Y., Artemchuk, V., Burov, O., & Lytvynova, S. (2020). Application of augmented reality technologies for preparation of specialists of new technological era. *Proceedings of the 2nd International Workshop on Augmented Reality in Education*, 181-200. http://ds.knu.edu.ua/pspui/handle/123456789/2184

Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education*, 123, 109-123. https://doi.org/10.1016/j.compedu.2018.05.002

Isaksson, O., Eckert, C., Panarotto, M., & Malmqvist, J. (2020). You need to focus to validate. *Proceedings of the Design Society: DESIGN Conference*, 1, 31-40. https://doi.org/10.1017/dsd.2020.116

Kitchenham, B., & Brereton, P. (2013). A systematic review of systematic review process research in software engineering. *Information and Software Technology*, 55(12), 2049-2075. https://doi.org/10.1016/j.infsof.2013.07.010

Klimova, A., Bilyaditinova, A., & Karsakov, A. (2018). Existing teaching practices in augmented reality. *Procedia Computer Science*, 136, 5-15. https://doi.org/10.1016/j.procs.2018.08.232

Liono, R. A., Amanda, N., Pratiwi, A., & Gunawan, A. A. S. (2021). A systematic literature review: Learning with visual by the help of augmented reality helps students learn better. *Procedia Computer Science*, 179, 144-152. https://doi.org/10.1016/j.procs.2020.12.019

Liu, S., Fang, Z., Shi, H., & Guo, B. (2016). *Theory of Science and Technology Transfer and Applications*. CRC Press. https://doi.org/10.1201/9781420087420

Mårtensson, P., Fors, U., Fröberg, E., Zander, U., & Nilsson, G. H. (2019). Quality of research practice - An interdisciplinary face validity evaluation of a quality model. *PLOS ONE*, 14(2), e0211636. https://doi.org/10.1371/journal.pone.0211636

Mkrtchian, V., Krevskiy, I., Bershadsky, A., Glotova, T., Gamidullaev, L., & Vasin, S. (2019). Web-based learning and development of university’s electronic informational educational environment. *International Journal of Web-Based Learning and Teaching Technologies*, 14(1), 32-53. https://doi.org/10.4018/IJWLTT.2019010103

Montoya, M. H., Díaz, C. A., & Moreno, G. A. (2016). Evaluating the effect on user perception and performance of static and dynamic contents deployed in augmented reality based learning application. *EURASIA Journal of Mathematics, Science and Technology Education*, 13(2). https://doi.org/10.12973/eurasia.2017.00617a

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMCMedical Research Methodology*, 18(1), 143. https://doi.org/10.1186/s12874-018-0611-x

Nesenbergs, K., Abolins, V., Ormanis, J., & Mednis, A. (2021). Use of augmented and virtual reality in remote higher education: A systematic umbrella
Sirakaya, M., & Sirakaya, D. A. (2020). Augmented reality in STEM education: A systematic review. *Interactive Learning Environments, 0(0), 1-14*. https://doi.org/10.1080/10494820.2020.1722713

Sommerauer, P., & Müller, O. (2018). Augmented reality for teaching and learning - A literature review on theoretical and empirical foundations. *Research Papers, 31*. https://aisel.aisnet.org/ecis2018_rp/31

Tricco, A. C., Lillie, E., Zarín, W., O’Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akb, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garrity, C., ... Straus, S. E. (2018). PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Annals of Internal Medicine, 169*(7), 467-473. https://doi.org/10.7326/M18-0850

UNESCO. (2021). UNESCO science report: *The race against time for smarter development*. UNESCO. https://en.unesco.org/unesco/sciencereport

Wang, M., Callaghan, V., Bernhardt, J., White, K., & Peña-Ríos, A. (2018). Augmented reality in education and training: Pedagogical approaches and illustrative case studies. *Journal of Ambient Intelligence and Humanized Computing, 9*(5), 1391-1402. https://doi.org/10.1007/s12652-017-0547-8

Wang, P., Zhang, S., Billinghurst, M., Bai, X., He, W., Wang, S., Sun, M., & Zhang, X. (2020). A comprehensive survey of AR/MR-based co-design in manufacturing. *Engineering with Computers*, 36*(4), 1715-1738. https://doi.org/10.1007/s00369-019-0799-3

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education, 62*, 41-49. https://doi.org/10.1016/j.jcompedu.2012.10.024

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gourneau, F. (2019). Systematic review of research on artificial intelligence applications in higher education - where are the educators? *International Journal of Educational Technology in Higher Education, 16*(1), 39. https://doi.org/10.1186/s41239-019-0171-0

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