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# Impacts of the Application of Virtual and Augmented Reality on Teaching-Learning Processes in Engineering Courses:

## A Systematic Literature Review About Learning and Satisfaction on Students

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## ABSTRACT

Cognitive approaches to teaching generate learning through the interaction between the subject and object of study. One of the strategies to create this interaction is related to the application of virtual and augmented reality in the teaching-learning processes. Through a systematic literature review, this work aims to describe the approaches used to measure the impacts on student learning using virtual reality (VR) and augmented reality (AR) in the teaching-learning processes of engineering courses, the impacts on learning, and student satisfaction. The surveys showed that in 70% of research analyzed, students who used virtual reality or augmented reality learned more, and 90% of the research showed that students who used virtual or augmented reality were more satisfied with the new approach than the traditional teaching approach. The conclusion is that there are positive impacts, in the vast majority of cases, on learning and the satisfaction of students who use virtual or augmented reality in the teaching-learning processes applied in engineering courses.

## KEYWORDS

Augmented Reality, Impacts on the Teaching-Learning, Satisfaction of Students, Teaching Environments, Virtual Reality

## INTRODUCTION

Through a systematic literature review, this article discusses the impacts of the application of VR and AR on student satisfaction and learning levels in Engineering Education and discusses pedagogical approaches and analyses the impact of the application of VR and AR. According to Libâneo (1994),

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didactics are the intervention process to generate learning conditions for students. In parallel, Freire (1999) points out that "teaching is not transmitting knowledge, but generating the conditions for that to happen," that is, to create appropriate circumstances to the teaching-learning processes, generating conditions for the learning to occur. With that in mind, Kaliská (2014) shows that students can learn in several ways: practicing, listening, visualizing, and discussing. Accordingly, each teacher varies his teaching methods through discussions, demonstrations, exercises, and lectures. Besides that, didactics need to be committed to cognitive issues and the development of students' thinking, so in the teaching-learning process, it is necessary to train thinking subjects capable of interpreting scenarios, receiving information, and solving problems (Gil, 2010). With that in mind, Kaliská (2014) shows that students can learn in several ways: practicing, listening, visualizing, and discussing. Accordingly, each teacher varies his teaching methods through discussions, demonstrations, exercises, and lectures. Besides that, didactics need to be committed to cognitive issues and the development of students' thinking, so in the teaching-learning process, it is necessary to train thinking subjects capable of interpreting scenarios, receiving information, and solving problems (Gil, 2010).

Gathering this with the pedagogical methodologies, there are five approaches to the teaching process: traditional, behavioral, humanistic, cognitive, and sociocultural (Mizukami, 1992).

One approach that links the student and the teacher is cognitivist in the process of a more significant interaction. According to Gil (2010), learning is a process of reconstructing previous knowledge, in which new learning content is anchored to an existing one. In this context, cognitivism has as its main action to privilege mental processes and cognitive skills. The students' experiences must guide the design of the contents, and the methodologies must be selected to learn by doing. For Santos Santos (2006), the teacher does not assume a central position, but the student must be focused and mobilized to be the center of the learning process, thinking, and building his knowledge.

In the cognitive approach, the student needs to participate actively in his learning by carrying out research, experimentation, group work, challenge stimulation, reasoning development, and constant search for knowledge because the answers are not ready or unique. However, to contemplate this investigative model, the teacher must work with didactic approaches that strengthen the students' investigative role in his preparation to think. The question is how teaching can enhance cognitive activities to improve training and consolidate the theoretical knowledge (Gil, 2010; Libâneo, 1994).

Currently, one of the educational tools used to support cognitive teaching methodologies is the application of virtual reality (VR) and augmented reality (AR), which are multisensory technologies that use multimedia, computer graphics, image processing, and other resources to create total or partially artificial environments (Cardoso et al., 2013; Martins & Guimarães, 2012). Those uses are reinforced by Juanes and Ruisoto (2016) when he explains that the virtual environment brings students closer to the real world, and its results are more effective in training, helping in the qualification of the future professional.

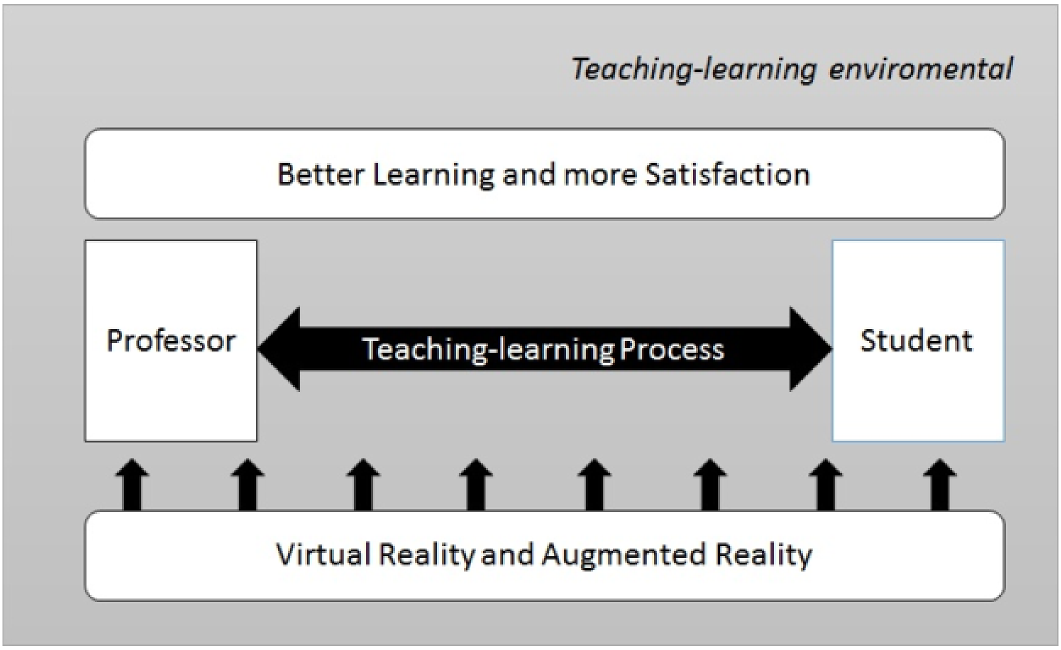
In agreement, Latta and Oberg (1994) show that virtual reality is a process of interaction between man and machine, in which a realistic environment is simulated, creating an opportunity for involvement and interaction between them. According to Raja and Calvo (2017), augmented reality is the projection of virtual devices in a real environment, generating the opportunity for interaction and visualization by man.

Schlemmer and Backes (2015) affirm that VR experiences bring new sensations, and the virtualization of reality generates an environment very close to that of reality. This digital technology contributes to the concepts of presence and immersion, acting directly on students' cognitive issues, enhancing their understanding and interaction with the environment. Those concepts are essential for the learning process to completion. Its applications are a practice increasingly used in teaching-learning processes, as seen in examples of the literature in nursing education (Hanson et al., 2019), primary education (Innocenti et al., 2019), health care (Drewett et al., 2019), the anatomy of the heart (Alfalah et al., 2019), medical studies (Moro et al., 2017) and manufacturing processes (Chen et al., 2019) and others.

When evaluating the application of VR and AR in engineering education, Anjos et al. (2020) presented a systematic literature review with several applications of the theme. Deeply evaluating cited articles, it is perceived superior learning in those who use VR (Perez-Romero et al., 2017; Zulfabli et al., 2019) and AR (Martín-Gutiérrez & Contero, 2011; Sánchez et al., 2015). VR users also have higher satisfaction rates (Ehmann & Wittenberg, 2018; Grodotzki et al., 2018) and AR (Alvarez-Marin et al., 2017; Bazarov et al., 2017).

By understanding the methodologies applied in the teaching-learning process, the importance of applying teaching approaches that address students' cognitive issues, and the application of VR and AR in teaching processes, the conceptual framework presented in Figure 1 was developed.

**Figure 1. Conceptual research framework. Source: Elaborated by the authors**



According to Figure 1, two approaches currently used to generate cognitive support for students' teaching-learning environment are VR and AR, in which results can reflect in the teaching-learning process. The conceptual framework supposes that VR and AR technology can positively impact the teaching-learning process, providing the students with better learning and more satisfaction with this interactive approach.

After understanding the importance of methods that prioritized cognition and the application of VR and AR technologies in teaching processes in several research areas, research questions arise:

RQ1: How are the impacts of VR and AR applications measured in the teaching-learning process in an engineering program?
RQ2: Are there differences in the students' learning when comparing application with traditional teaching methodologies and methodologies involving VR or AR?
RQ3: Is there an impact on the satisfaction of students using VR and AR in the teaching-learning processes?

The general objective is to describe which methods are used to measure the performance of VR and AR artifacts in the teaching-learning processes and impacts on the learning of the students, through a systematic literature review, for engineering courses and to understand whether they are generating satisfaction in students who use such technology.

According to Gil (2010), the teaching-learning process must be working on cognitive issues, providing opportunities for interaction between the student and the object being studied. Thus, it is clear that it is necessary to seek teaching processes with cognitive approaches, and from this perspective, the use of VR and AR allows the use of laboratories very close to reality, which offers an ideal environment for the development of learning. Experiences with VR provide opportunities for immersion, interaction, and involvement, acting directly on cognitive issues and creating learning circumstances in an environment very close to that found in the real world (Braga, 2001; Schlemmer & Backes, 2015).

This work is justified because the research results demonstrate an impact on the teaching-learning processes in the different engineering areas in which VR and AR are applied, and the teaching processes are satisfactory for students. This paper has sections of the methodology, results, analysis of results, and conclusions.

## METHODOLOGY

The methodology applied in this research was a systematic literature review. It is fundamental for the execution of scientific research, and its main objectives are to organize the literature and develop theories based on the results found (Dresch et al., 2015; Gough et al., 2012). This systematic literature review aims to find, evaluate, and consolidate concepts that help answer a research question or identify research gaps in the literature based on the analysis of primary studies. To carry out this systematic literature review, we used the model proposed by Dresch et al. (2015), whose steps are:

1 – Defining the questions and conceptual framework
2 – Definition of working team
3 – Search strategy
4 – Search, eligibility, and coding
5 – Quality assessment
6 – Summary of results
7 – Results presentation

The description of step 1 can be found in the introduction section. Steps 2, 3, 4, and 5 can be found in the methodology section and steps, 6 and 7 are in the results section.

In stage 2, the working team's definition, two groups were chosen, composed of two people. The first team was formed by a production engineering student and a professor in the graduate program in production engineering. The second team consisted of a doctoral student in production engineering and a professor in the graduate program in production engineering. Together, these working groups defined the search, inclusion, exclusion, and evaluation criteria for the publications' quality. The search strategy was necessary to define what to look for, where to look, minimize bias, which studies to consider, and the search extension Dresch et al., (2015).

In defining the search terms, the activity was organized in two stages. In the first, publications related to teaching methodologies in engineering that use some VR or AR technology as a teaching-learning strategy were analyzed. The searches were carried out with keywords, titles, and summaries in Scopus and Web of Science databases. The search terms were combined as follows: (teach* and method*) and ("virtual reali*" or "augmented reali*" or "virtual world" or "real virtual*" or "VR" or "AR") and ("engineer*"). The period of investigation employed was from 2004 to 2020. In the results of these searches, the inclusion and exclusion criteria of collected data were applied.

The bases were defined because they have indexation with the largest number of journals with a high impact and relevance factor available on the periodic portal of the Brazilian Third-degree Education Council (CAPES).

The exclusion criteria for the studies found were:

1) Disregard repeated articles due to the collection of literature in more than one database, avoiding the risk of duplicate publications;
2) Exclude articles that did not have at least one of the following terms in their title: students, methodology, method, teaching, learning, VR, AR, virtual world, engineering, simulation virtual, virtual lab, education, digital environment, virtual 3D, 3D, virtual platform, virtual simulator;
3) Discard, after reading the summary, articles that do not address the teaching methodology related to VR or AR;
4) Exclude publications that do not have full texts available on the web;
5) Exclude, after a complete reading of the texts, articles that did not address teaching in engineering areas and have the application of VR and AR.

The publications that were not excluded underwent an evaluation of the quality of the study. In this assessment, the publication needed to present:

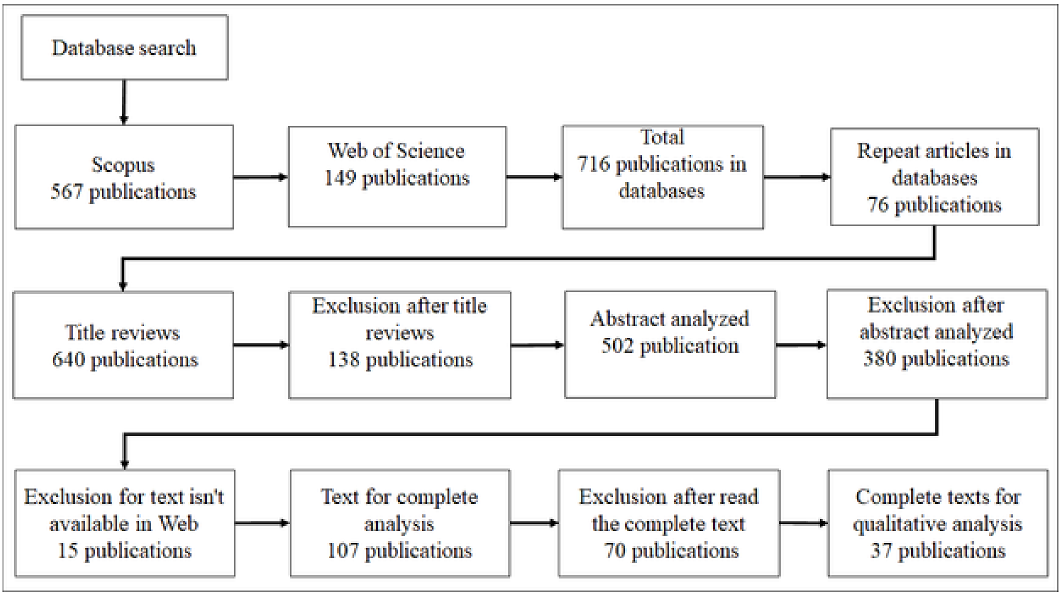
1) which engineering program was the teaching study focused on, for example, having in the text clearly which engineering courses the VR or AR approach supports the teaching-learning processes.
2) description of characteristics of immersion, interaction, and involvement in VR or AR application;
3) some performance or satisfaction metrics regarding the application of VR and AR in the teaching-learning process. This metric can be assessed by knowledge tests acquired after the application of VR or AR. Other options measure satisfaction and motivation levels evaluated in students who used VR or AR applications.

An ecological triangulation approach was carried out to summarize the results in the publications' qualitative evaluation. In the qualitative evaluation of the publications, an ecological triangulation approach was carried out to summarize the results. In this assessment, we tried to understand, from the literature, why the studies generated such results, their reflections upon the human condition, and its development (Barnett-Page & Thomas, 2009). In this triangulation, it was evaluated which application area it relates to (which engineering and subject developed), details of the characteristics of immersion, interaction, and involvement were made and, finally, it was verified how the analyzed sample was organized and which criteria were used to evaluate the results and their impacts on the teaching-learning process.

## RESULTS

Initially, the search and the selection of publications were made in databases - as described in the methodology - on VR and AR applications in the teaching-learning process in engineering. At this stage, 716 publications were selected for analysis, and, after applying the inclusion and exclusion criteria, 37 texts remained for complete qualitative analysis of their content. After applying the inclusion and exclusion criteria, the results of the research are described in Figure 2.

**Figure 2. Search results detailing the inclusion and exclusion criteria. Source: Prepared by the authors**



The next step sought to understand how the authors measured VR or AR's application performance and the sample organization. In the 37 articles analyzed, there were several evaluation ways, of which a summary is shown in Tables 2 and 3.

## Strategies to Measure the Effects of Applying Virtual Reality and Increasing Reality in Teaching-Learning Processes in Engineering Programs

The results shown in Table 2 indicate no specific trend related to the engineering in which the VR artifact is being applied to the model of measuring results in the teaching-learning process. Each research author defined the specification of how the collection was carried out. Some authors organize the sample into a single group to evaluate the results of their research, and other research separates the two groups, normally called experimental and control.

When organized into single groups, student satisfaction or the historical evolution of learning is usually assessed. When the samples are organized into two groups, the level of learning between groups (which used virtual reality and the group that did not) and satisfaction with the application of virtual reality in the teaching-learning environment are usually compared.

The method used to measure the teaching-learning process results in the application of AR is described in Table 3.

The data in Table 3 clarifies that AR's behavior is similar to VR applications separation of groups and data collection strategies. There are analyses of the artifact's performance in the teaching-learning process in single and segregated groups with evaluations through statistical tests, Likert scale, or qualitative analyzes. Notice that, regardless of which engineering program, there is no standard on which type of test to apply to measure the impacts of VR and AR in the teaching-learning processes.

Differences in the students' learning when comparing application with traditional teaching methodologies and methodologies involving VR or AR effects of applying virtual reality and increasing reality in teaching-learning processes in engineering.

In a third step, we sought to understand whether there are differences in the level of learning between traditional teaching methodologies and methodologies using VR or AR. It was possible to evaluate only articles with two working groups, usually called the control group and the experimental

**Table 2. The method used to evaluate the performance of the application of VR in the teaching-learning process**

| **Program** | **Number of publications** | **Sample split** | **Process Analysis** |
|---|---|---|---|
| Civil engineering | **5 publications** | Single group | Questionnaire with Likert scale |
| | | Experimental group and control group | Questionnaire with Likert scale |
| | | Experimental group and control group | ANOVA – Analysis of variance |
| Computer engineering | **3 publications** | Single group | Qualitative questionnaire |
| | | Experimental group and control group | “t student” – pre-test and post test |
| Computer engineering and agroindustrial production engineering | **1 publication** | Single group | Questionnaire with Likert scale |
| Production engineering | **1 publication** | Experimental group and control group | Qualitative test - pre-test, post-test and retention test |
| Miscellaneous engineering | **4 publications** | Experimental group and control group | “t-student” |
| | | Single group | Questionnaire with Likert scale |
| | | Experimental group and control group | Pre-test - Kolmogorov-Smirnov; post-test - “t *student”* and ANOVA |
| Manufacturing and electrical engineering | **1 publication** | Single group | Questionnaire with Likert scale |
| Mechanical engineering | **8 publications** | Single group | Questionnaire with Likert scale |
| | | Single group | Qualitative questionnaire |
| | | Single group | Qualitative testing and historical evolution |
| | | Single group | Questionnaire with Likert scale |
| | | Experimental group and control group | Satisfaction with the Likert scale and t-test - pre-test and post-test |
| | | Experimental group and control group | “t-student” pre-test and post test |
| Industrial mechanical engineering | **2 publications** | Experimental group and control group | Questionnaire with Likert scale |
| | | Experimental group and control group | “t student” pre-test and post test |

**Table 3. The method used to evaluate the performance of the application of AR in the teaching-learning process**

| Program | Qty of publication | Sample split | Process Analysis |
|---|---|---|---|
| Civil engineering | **4 publications** | Experimental group and control group | Qualitative test - pre-test, post-test and retention test |
| | | Experimental group and control group | "t-student" – pre-test and post test |
| | | Experimental group and control group | Qualitative questionnaire |
| Electrical engineering | **1publication** | Single group | Questionnaire with Likert scale |
| Industrial engineering | **1 publication** | Single group | Questionnaire with Likert scale |
| Mechanical engineering | **6 publications** | Single group | Qualitative questionnaire |
| | | Single group | Questionnaire with Likert scale |
| | | Experimental group and control group | Kolmogorov-Smirnov; "t student" and Likert scale |
| | | Single group | Qualitative testing and historical evolution |

group, in which some type of test was performed to measure the differences between them. At that time, 20 articles were evaluated, whose analyzes are described in Table 4.

Analyzing the results described in Table 4, 70% of the evaluated publications reported positive impacts, with higher performance in the teaching-learning process using the VR or AR tool than traditional teaching methods. However, in the application of VR, which was specifically evaluated, just 60% of the articles demonstrated a significant impact on the teaching-learning process, and in the rest of the publications, this impact is not perceived compared to the groups. However, when analyzing AR, all articles reported a positive impact on the teaching-learning process compared to the traditional approach.

Analyzing the published papers, we noticed that the application of VR as a method for teaching-learning processes is usually measured through the composition of groups of students: a control group and an experimental group. These groups were formed of various sizes, gender-mixed (female and male), and organized according to the respondents' interests, not showing any tendency or relationship between the publications. From these, six publications among fifteen articles evaluated did not show notable differences between groups.

The statistical tests to assess the difference between the groups (experimental and control) were four, namely: the "t-student" test, Shapiro-Wilk, ANOVA, and Kolmogorov-Smirnov. The Shapiro-Wilk test had the function of verifying the normality of the data. The other tests had the task of assessing whether there is a difference between the groups evaluated. i.e., interpreting whether there is a difference between the control and the experimental group.

Among the studies, three publications that use AR were examined because the papers by Martín-Gutiérrez (2011) and Martín-Gutiérrez and Contero (2011) have the same databases and analyzes. The same occurs with Redondo et al. (2013) and Sanchez et al. (2015). It is also noteworthy that some non-parametric test was applied (t-student, Mann-Whitney, Kolmogorov-Smirnov) to compare the learning difference between the groups.

In the engineering programs that apply AR and VR, most of the publications that measure the impacts in the teaching-learning process are mechanical, civil, and miscellaneous engineering areas, respectively, with seven, four, and four papers. In mechanical engineering, 50% of the papers have no

**Table 4. Evaluation of the impacts of the application of VR and AR in the teaching-learning process**

| Program | Author | AR / VR | Impacted? | Sample Size | Impacts on the teaching-learning process |
|---|---|---|---|---|---|
| **Civil engineering** | Redondo et al. (2013) | AR | Yes | 146 | Pre-tests were very similar in both groups. When student training ended, they were scored. The results showed that the experimental group improved its results, after training, with 0.24 points above the control group's average. |
| | Sánchez et al. (2015) | AR | Yes | 146 | Pre-tests were very similar in both groups. When student training ended, they were scored. The results showed that the experimental group improved after training, with 0.24 points above the control group's average. |
| | Shirazi and Behzadan (2015b) | AR | Yes | 60 | The null hypothesis that the test group has values greater than the control group cannot be rejected. The values obtained indicated a statistically significant difference between the percentages of improvement in the group that used AR. |
| | Perez-Romero et al. (2017) | VR | Yes | 84 | The TPS group, which worked with physical theoretical class, models physics, and virtual environments, passed the assessment with a score higher than 5 points (considered the minimum desirable score) and was statistically different from the rest of the experimental units. The VPS (just theoretical class and virtual environments) CPS (just theoretical class) groups showed no statistical differences and were unable to pass the assessment of the analyzed skill. |
| **Computer engineering** | Inayat et al. (2016) | VR | Yes | 36 | The T-test value of the experimental group (6.83) is higher than that of the control group (3.01), which shows different learning levels between the two groups. The best result was in the group that used VR, which has positively impacted the teaching-learning process. |
| | Akbulut et al. (2018) | VR | Yes | 36 | According to the test results, students who used the VR system achieved 12% more success on average than students in the control group. When the "t-student" test was performed, the statistical difference between the two groups was confirmed. |
| **Computer and agroindustry production engineering** | Beltran Sierra et al. (2012) | VR | No | 180 | Although the students considered that the realization of a percentage of their classes in a virtual way facilitated their learning process, the final averages, which intended to measure such a process, did not reflect a significant change for the subjects contemplated in this study. |
| **Production engineering** | Laseinde et al. (2016) | VR | Yes | 55 | With students who took a class by the traditional method, 25% of the knowledge acquired had been retained three weeks after the class, whereas, compared to VR applications, the knowledge retention rate was 80%. |
| **Miscellaneous engineering** | Zhu et al. (2009) | VR | No | 58 | It could not be concluded that there are differences between the groups; it is not possible to state that those who used VR learned more than those who used the traditional teaching method. |
| | Zhu et al.(2010) | VR | Yes | 58 | The results indicate that the winning scores of the Haptics Group (experimental) are better than those of the Graphics Group (control). These results confirm that the feedback from the haptic force helps the retention of concepts by the students, positively impacting the teaching-learning process. |
| | Seabra and Santos (2013) | VR | No | 91 | There were no differences between the three groups in the pre-test of the three groups using the Kolmogorov-Smirnov test. After the three tests, the group was divided into low, medium, and high ability. With these groups, the ANOVA test was used, but there was no difference between them. It was noticed that the three groups evolved, but none of them showed differences in knowledge, not generating relevant impacts with the use of VR in the teaching-learning process when applying the "t-student" test, for a simple average. |
| | Hu et al. (2017) | VR | Yes | 153 | The difference between the marks of pre-test and post-test shows that the project provides an immense benefit for the students and helps them better understand practices. |

***continued on next page***

**Table 4. Continued**

| Program | Author | AR / VR | Impacted? | Sample Size | Impacts on the teaching-learning process |
|---|---|---|---|---|---|
| **Mechanical engineering** | Chaturvedi et al. (2010) | VR | No | 61 | The tests applied to students of solid mechanics did not show any significant difference between the groups. However, those performed with students of fluid mechanics showed a significant difference between the groups, demonstrating that the application of VR in this course impacted the teaching-learning process. |
| | Martín-Gutiérrez (2011) | AR | Yes | 47 | The average grades obtained were 5.84, with a standard deviation of 0.31 for the experimental group. The control group had a mean of 4.5 and a standard deviation of 0.39. The null hypothesis was rejected, and students who use AR material had a 99% probability of learning more than those who did not use it. The Kolmogorov-Smirnov test points out that, with 95% certainty, the means obtained by the two groups are statistically different. |
| | Martín-Gutiérrez and Contero (2011) | AR | Yes | 47 | The average grades obtained were 5.84, with a standard deviation of 0.31 for the experimental group. The control group had a mean of 4.5 and a standard deviation of 0.39. The null hypothesis was rejected, and students who use AR material had a 99% probability of learning more than those who do not use it. The Kolmogorov-Smirnov test points out that, with 95% certainty, the means obtained by the two groups are statistically different. |
| | Skarka et al. (2015) | VR | Yes | 66 | The group that used VR as a teaching methodology achieved better grades than the group that used traditional methodology, positively impacting the teaching-learning process. |
| | Zulfabli et al. (2019) | VR | No | 48 | It was not possible to perceive a difference between groups after the experiment. |
| | Hee and Shvetsova (2019) | VR | No | 62 | As a result of the hypotheses, we obtained:<br>1) Different teaching methods have different effects on the development of skills in the engineering teaching process.<br>2) Hypothesis 1, "The VR class improves and develops essential skills in a basic engineering course better than in the regular class," was not proven by this study.<br>3) Hypothesis 2, "The VR class does not improve or develop essential skills in a basic engineering course better than in the regular class," was not proven by this study.<br>4) Hypothesis 3, "The VR class improves and develops only a specific scope of skills in a basic. |
| | Chen et al. (2019) | VR | Yes | 40 | After classes, the experimental group's averages were higher than the control group in the three operations. The results of the "t-student" test support the results that indicate differences between the groups. |
| **Industrial Mechanical engineering** | Jiménez. et al. (2010) | VR | Yes | 274 | In the pre-test, the groups were similar. The results achieved: 1) the evaluation process gave similar results in the two control groups, GC1, and GC2, so the system can be considered reliable; 2) similar results were observed in groups of experiments GE1 and GE2, using the same evaluation method, to consider the learning process homogeneous; 3) statistically significant differences were observed between the degrees of progress of the experiment groups concerning the control groups. The most significant differences were observed at the level I (deficient), much greater in the control groups and at level III (good), notably higher in the experimental groups. |

relevant impact and statistical results in the teaching-learning processes compared to the traditional teaching method. Civil engineering showed, the same relation in showed mechanical engineering, i.e., 50% of the papers show some relevant impact and statistical results in the teaching-learning. Miscellaneous engineering has the best results, i.e., 75% of the papers show relevant impact and statistical results in the teaching-learning process.

## Impact on The Satisfaction of Students Using VR And AR In the Teaching-Learning Processes

**Table 5. Evaluation of student's satisfaction after application of VR and AR artifacts compared to traditional teaching methods**

| Technology used | Was there an impact on satisfaction? | |
|---|---|---|
| | Yes | No |
| VR | 10 | 2 |
| AR | 8 | NA |

The impact of user satisfaction with VR and AR applications on the teaching-learning process was also analyzed compared to traditional teaching methods. For this purpose, 20 articles were evaluated, the results of which are summarized in Table 5.

In 18 publications, a positive acceptance by users was reported. The authors used questionnaires that compared responses from students who used the traditional teaching method and those who used VR or AR. The papers in which no impact was identified on user satisfaction emphasize that the application of VR needs many improvements to bring it closer to reality and better usability. Continuing the study was verified the satisfaction of students who used VR and AR in the teaching-learning processes about engineering concepts. The analysis data are available in Table 6.

The data available in Table 6 show that, in general, students who used VR and AR artifacts in the teaching-learning processes were satisfied. During the systematic literature review, some terms used in the papers were noticed: ease of use, improvement in the teaching process, satisfaction, sense of realism, engagement, motivation, and ease of understanding the content, different experience to learn, greater interest in the studied subject and belief in superior academic performance when used in the classroom. Some contrary points are mentioned, such as handling difficulties, characteristics, and better functionalities of the artifact. From these terms, it was possible to understand that the application of VR and/or AR in the teaching-learning processes creates a different environment with positive and relevant points, generating student satisfaction.

## Analysis Of Results

We noticed that the researchers separated students in two ways in the analyzed studies, in single or two groups. When students were organized in a single group, everyone used VR in the learning process, basically using the Likert scale method and qualitative tests to verify the effectiveness of the VR application. The latter assessed the historical evolution of student learning. Differently, when students were organized into two groups (control and experimental), the control group had a class with a traditional teaching method focused on the teacher. The experimental group, in addition to the traditional class, used virtual reality application. In that case, tests were applied before and after classes.

In the pre-test and the post-test, the comparison between the groups was usually made from statistical tests to measure differences between the groups. The statistical tests used were the analysis of variance (ANOVA), the "t-student" test, and the Kolmogorov-Smirnov test. The exception was

**Table 6. Results of student's satisfaction with the application of VR and AR in the teaching-learning process**

| Author | AR / VR | Sample Size | Impacts |
|---|---|---|---|
| **Fiorentino et al. (2009)** | AR | 20 | 90% of the students answered that it had increased the ease of learning and understanding the studied subject. |
| **(Cherner et al., 2010)** | VR | 10 | 92% of students answered that they strongly agreed or agreed (61% in the first option, and 31% in the second option) that VR supported the teaching-learning process. |
| **Chaturvedi et al. (2010)** | VR | 61 | The students responded according to the Likert scale, composed of grades 1 to 5. The average reached by the respondents was 4.4, showing satisfaction with the applied model. |
| **Andujar et al. (2011)** | AR | 46 | The results presented were:<br>1) A greater sense of realism;<br>2) The same configurations as the physical laboratory can be used for different experiments;<br>3) Verification and generation of easier experiments because, besides offering other possibilities, the experiments can be the same as those traditionally performed when physically in the laboratory. |
| **Gómez et al. (2011)** | VR | 60 | The group that used VR experienced greater satisfaction and engagement with the new method proposed. |
| **Gouveia et al. (2011)** | VR | 50 | Most students agree that technology supports the learning process and stimulates interest in the subject studied. |
| **Martín-Gutiérrez(2011)** | AR | 47 | When applying the Likert scale from 1 to 5, the experimental and control groups average 3.94 and 1.76, respectively, showing higher satisfaction and adherence from students concerning AR. |
| **Chen et al. (2011)** | AR | 36 | More than 90% of participants understand that the AR model helps gain spatial capacity and increase interest in the subject. Approximately 75% of participants agree that the AR model can expand their interest in learning and contribute to a diverse curriculum. |
| **Martín-Gutiérrez and Contero (2011)** | AR | 47 | Regarding efficiency and satisfaction, all aspects have positive values. All students (100%) believe that the technology used is interesting, and most believe it helps them have superior academic performance. |
| **Beltran Sierra et al. (2012)** | VR | 180 | There is considerable growth in the motivational aspect because traditional class patterns are broken through animated computer objects. People can follow a class from anywhere and access much content in real-time. The interaction with teachers and classmates has not undergone significant changes compared to a traditional class but has been significantly enriched because it offers multichannel communication media, such as forums, chat, Wiki, and video chat. |
| **Duckworth et al. (2012)** | VR | 26 | Most students were indifferent to the application of VR. The responses support the development of improvements in the application of VR. |
| **Sampaio and Martins (2014)** | VR | 26 | The introduction of the VR model as a new teaching resource was well accepted. Some difficulty in manipulating the model was brought to light. New technological materials, namely educational resources based on interactive 3D / 4D models, are important in a modern class environment. |
| **Villagrasa et al. (2014)** | VR | 65 | The model's points were perceived to be improved to meet educators' and students' expectations. |
| **Shirazi and Behzadan (2015a)** | AR | 166 | After the experiment, it was found that the students in the experimental group had a very positive view of the use of AR mobile applications, reinforcing the learning of abstract and difficult-to-understand topics. |
| **(Fonseca Escudero et al., 2016)** | VR | 35 | It was demonstrated a direct relationship between the motivation for use and the results of the user experience applicating VR. The results showed that the application of technology in teaching improved the student's space capacity. |
| **Bazarov et al. (2017)** | AR | 24 | The analysis of the results shows that the majority of students expressed a positive attitude towards AR. Their motivation increased as their satisfaction with the learning process. |
| **Hu et al. (2017)** | VR | 153 | The satisfaction questionnaires' application generated an average of 4.56 (maximum 5.0), demonstrating the high level of user satisfaction concerning teaching methods with VR. |

*continued on next page*

**Table 6. Continued**

| Author | AR / VR | Sample Size | Impacts |
|---|---|---|---|
| **Alvarez-Marin et al. (2017)** | AR | 61 | For all its characteristics, the general evaluation is very satisfactory and has obtained an average of 4.3 (on a scale of 1 to 5). The best-classified characteristics were: "the AR image logically connected to the text, plays a didactic role in my learning" and "the AR image that accompanies the text attracts attention and does not go unnoticed," both with 4.5, followed by the characteristics "The text/image relationship of AR facilitate for a better understanding of the content" (4.4), "In general, I feel that the image of AR as a visual strategy positively affects my learning" (4.4), "The way the contents in AR are represented facilitates the understanding and learning of the contents "(4,4)," The AR image manages to support, synthesize and complement the text, facilitating the learning of the contents "(4,2) and" The way how the contents in AR are represented generates a notorious thinking process in me for the construction of new knowledge "(4.0). |
| **Grodotzki et al. (2018)** | VR | 150 | Students understand that VR's application creates a relevant learning opportunity and promotes a differential in the teaching-learning process. Observing the six-year history, it is clear that the students increase their level of satisfaction regarding the use of a VR environment each year. |
| **Ehmann and Wittenberg (2018)** | VR | 25 | Participants were asked about the degree of difficulty when using VR. 69.57% stated that this procedure is easy, 26.09% answered that it is almost easy, and 4.35% considered it moderate. None of the participants perceived the VR application as almost difficult or difficult. Approximately 80% agreed that visualizing systems in VR is very good or good for systems analysis. |

**Table 7. Evaluation of student's learning after application of VR and AR artifacts compared to traditional teaching methods**

| Technology used | Was there an impact on learning? | |
|---|---|---|
| | Yes | No |
| VR | 9 | 6 |
| AR | 5 | NA |

two articles: Hee Lee and Shvetsova (2019), which used a qualitative test to measure the difference between groups, and Villagrasa et al. (2014), which used the Likert scale to understand what needed to be improved in the application of VR.

In AR's application, the groups had the same form of segregation (single group or two groups called experimental and control groups). The evolution of knowledge was performed using statistical tests ("t-student" test and the Kolmogorov-Smirnov test) to analyze the difference between groups or qualitative tests of the evolution of the acquired knowledge. Finally, questionnaires with a Likert scale were used to analyze user satisfaction.

The strategies of segregating groups to analyze are related to the research objective. For example, when a single group is applied using VR or AR, factors such as a differentiated learning environment (Freire, 1999), cognitive teaching approach (Mizukami, 1992), and an approximation of the real world through the virtual world (Juanes & Ruisoto, 2016) contribute to developing some metrics that can be evaluated. The segregation of groups, into experimental and control, performed by other researchers aims to run the experiment and understand if this created environment (using VR or AR) generates higher learning or level of satisfaction for students when compared to other groups, enabling the demonstration of the effectiveness of the method. About the results in learning and student satisfaction, table 7 presents a summary of the results presented.

The research shows that there was a positive impact in all cases with the use of AR. Students who in the experimental group obtained more knowledge than students who were in the control group when comparing the control group and the experimental group in the post-tests (tests performed after the traditional class or the class using VR and/or AR). When VR is applied, only 60% of the experimental groups show statistically significant higher learning results.

It is possible to understand which VR and AR applications in most of the cases have positively impacted the teaching-learning processes in most analyzed articles when evaluating the data displayed in Table 7 and create a cognitive environment to teaching-learning process through this technology can impact positivity in the learning and satisfaction of the students. Different didactic approaches helped the students' learning process, making the experimental group's performance superior in most cases. These positive impacts on teaching-learning processes can be justified by the formation of the cognitive environment (Gil, 2010) and the ability to approach the virtual world with the real world and the possibility of immersion (only for VR), interaction, and involvement with the environment (Braga, 2001; Schlemmer & Backes, 2015).

Some research did not obtain these differences between the experimental and the control group. Even without the publications discussing the reasons for that, the cause must be related to the developed VR artifact. Dresch et al. (2015) explain that the artifact proposed needs to be well designed, developed, and evaluated, and these requisites need to be applied to the artifact of VR and AR. The environmental characteristics in which the project is used and its internal and external relationships need to be considered as, in development, all operating characteristics and tests must be performed. Finally, the artifact must be evaluated, in which it is sought to confirm whether it achieves the expected results in its proposal (Anjos et al., 2021).

In the papers that do not point out differences between the experimental and control groups, possibly, the design, development, or evaluation stages were not executed with the necessary strict, offering the artifact a result inferior to other similar research. The importance of a strict development of the VR or AR artifact is emphasized, from its design to its evaluation, before applying it to a teaching-learning process.

When evaluating users' satisfaction with the application of the VR or AR artifact, it is noted that 90% (table 5) of the publications obtained an increase in student satisfaction. The articles that contradicted this trend reported many artifacts' problems, needing many improvements, making it unfeasible for use.

This satisfaction can be related to Schlemmer and Backes (2015) mention that this type of application brings new sensations, generating an environment closer to reality. This digital technology contributes to the concepts of presence and immersion, acting directly on students' cognitive issues and enhancing their understanding and interaction with the environment, being such concepts essential for learning. It can be interpreted that the cognitive conditions generated in the teaching-learning environment that apply VR and/or AR generate a more satisfactory environment due to its characteristics of interaction and involvement with the artifact.

About the impacts obtained in the teaching-learning process, it appears that, from the segregation of students into control and experimental groups, it was sought to know if the experimental groups had better results than the control groups through statistical tests for assessing whether there were differences between the means obtained by the groups. So it is clear that the use of VR and AR generated higher learning in the students in question, but unrelated characteristics in these publications are decisive for this impact. That is why the importance of developing a VR or AR artifact in a planned way is highlighted, with simulations and impact validation before applying it, on a large scale, in a teaching environment.

## CONCLUSION

After the papers on this study were selected and analyzed, answering the first research question, it was found that the publications that dealt with the application of VR and AR in the teaching-learning processes in engineering presented impacts measured through statistical tests that measure the difference between groups, usually called the control and experimental group. The statistical tests used to assess the difference between groups were: T-test, Kolmogorov-Smirnov test, and Analysis of Variance (ANOVA), as, for the analysis of users' satisfaction, the models performed were qualitative questionnaires that use the Likert scale, in which they position the understanding of the application of VR and/or AR in the teaching processes.

When evaluating the second research question, it was identified that groups of students who used AR in the teaching-learning processes, in all cases, have obtained more significant learning when compared to the group that did not use AR. In the group that used VR in the teaching-learning processes, 60% presented the experimental group with higher learning results than the control group. In 40% of the studies, the groups that used VR did not present knowledge significantly differently from those that did not use VR. When we evaluate the third research question, it is clear that the application of VR or AR in the teaching-learning processes impacts the students' satisfaction in 96% of the cases. It was also noticed that, for some reason not explicitly stated in the research, in some cases, higher learning is not obtained in groups that used VR. Therefore, before being applied in the teaching environment on a large scale, any artifact of VR or AR must be evaluated and validated to certify its impacts with superior learning results for students.

In general, it is noticed that engineering students learn more and are more satisfied when they use VR and AR in the teaching-learning processes of production engineering and that systematic literature review generated the opportunity to structure the results of VR and AR applications in engineering courses. The limitations of the research are not to identify discussions in all the papers evaluated about the reasons why the results were below expectations, in which engineering students did not learn more or were not more satisfied when they used VR and AR when compared to students who took classes only by the traditional method of teaching.

Finally, there are some opportunities for news research using VR and AR to build factories and production departments for applying manufacturing process simulations, such as extruding or injecting polymers, casting, and forming. Other opportunities are for industrial engineering, for example, set-up simulations, material handling, production flows, and materials. Another possibility is the operations of machines and ergonomic analyses at the workplace.

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