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Evaluating an Immersive Virtual Classroom as an Augmented Reality Platform in Synchronous Remote Learning †

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Abstract: Previous research has explored different models of synchronous remote learning environments supported by videoconferencing and virtual reality platforms. However, few studies have evaluated the preference and acceptance of synchronous remote learning in a course streamed in an immersive or augmented reality platform. This case study uses ANOVA analysis to examine engineering students' preferences for receiving instruction during the COVID-19 pandemic in three classroom types: face-to-face, conventional virtual (mediated by videoconferencing) and an immersive virtual classroom (IVC). Likewise, structural equation modeling was used to analyze the acceptance of the IVC perceived by students, this includes four latent factors: ease of receiving a class, perceived usefulness, attitude towards IVC and IVC use. The findings showed that the IVC used in synchronous remote learning has a similar level of preference to the face-to-face classroom and a higher level than the conventional virtual one. Despite the high preference for receiving remote instruction in IVC, aspects such as audio delays that affect interaction still need to be resolved. On the other hand, a key aspect for a good performance of these environments is the dynamics associated with the teaching–learning processes and the instructor′ qualities.

Keywords: augmented reality; immersive virtual classroom; synchronous remote learning

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1. Introduction

Over the past two decades, research on instructional video has grown and matured, identifying what works and what does not work with this type of technology in terms of learning outcomes are the challenges that still need to be addressed. This research focus is relevant because of the popularity of asynchronous learning through massive open online courses (MOOCs). MOOCs reach millions of students worldwide, but these courses have the highest dropout rates [1]. The popularity is partly due to two new trends in online learning: the flipped classroom [2] and the synchronous hybrid classroom [3]. In both trends, students can rely on instructional videos to prepare asynchronously for the course material before engaging in synchronous learning activities with their instructor. In the second trend, when students and instructor meet, they could be organized in different remote groups, fully online, or some face to face (F2F) while others remain online.; these modalities present technical and instructional challenges in developing synchronous online learning activities.

Instructional video has been and continues to be extensively researched in asynchronous online learning, whereas research on streaming video in synchronous online learning is relatively scarce.

There are several research trends in instructional videos for asynchronous learning. Koning et al. [4] identified three categories: (1) extend "traditional" instructional video design principles (e.g., segmentation and transience effect, pacing principle, signaling principle, etc.), (2) examine the effectiveness of "new" design principles (e.g., camera viewpoint or perspective, video modeling or instructor presence, learning from instructional animations and video-practice conditions) and (3) incorporate learner characteristics into the study of learning with the instructional video (e.g., learner gender, learner spatial ability and video model gender).

In the same area, Fiorella and Meyer [5] comment on what works and what does not work with instructional videos: (a) two techniques that seem to improve learning outcomes are mixed perspective (first and third person camera) and video segmentation and (b) some features that do not seem to work are matching the instructor's gender to the learner's gender, inserting pauses into the video, adding practice without feedback and showing the instructor's face in the instructional video. Meanwhile, Bétrancourt and Benetos [6] provide some directions for the future research on instructional videos: (a) the type of content being communicated in the dynamic visualization and the relevance of video to communicate that content, (b) how design factors interact with learner strategies and behaviors, (c) design of rigorous experimental studies that guarantee homogeneity of conditions, except for the variables to be evaluated and their ecological validity and (d) move from the study of mere instructor presence to specific instructor behaviors expected to influence cognitive processing [5]. In both studies, the commentators agree that instructor presence is not associated with improved learning outcomes, although it does not worsen them.

In the systematic review by Henderson and Schroeder [7], the authors also evaluated instructor presence in instructional videos, finding that the results were not consistent in determining whether instructor presence helps improve the learning process, although it does improve student motivation. Similarly ambiguous results regarding instructor presence and learning outcomes were found by Polat [8] and Wang et al. [9]. In the latter [9], the authors identify two other research topics in instructional videos besides instructor presence: instructor characteristics and content presentation, as recommended in [5]. Among the various "instructor characteristics" mentioned, it is emphasized that instructors' pointing and stress gestures can direct learners' attention and help them achieve better learning performance [10–12]. In "content presentation", it is emphasized that learners will have better learning performance if instructors draw graphics on blackboards [13]. Both subjects are of particular interest because they imply that educational video technology should allow the instructor to interact in "real time" with the material being taught, with all the attendant benefits of pointing gestures, gaze tracking, eye contact and increased social presence.

Two recent styles of real-time instructional video (which do not require a large investment in post-production) are transparent whiteboards [14] and instructor behind slides [15]. This last style is a variant of transparent whiteboard lessons where the slides are displayed in front of instructor, who does not write or draw but can point and gesture with their body without obstructing the material taught [15]. As Lubrick et al. [14] points out, more research should be conducted on instructional videos with transparent whiteboards. The first formal study was conducted by Stull et al. [16], whose finding shows that students who watched lessons with transparent whiteboards performed better on immediate post-tests. However, the benefits of learning from transparent whiteboards did not persist on a delayed post-test. Recent studies demonstrate the ability of the transparent whiteboard to enhance instructor characteristics such as eye contact [17], dynamic drawing [17,18] and gaze guidance [19] that produce better learning outcomes. These are instructor characteristics included in the five ways to increase the effectiveness of instructional video by Mayer et al. [20].

There are also research trends in synchronous learning. Raes et al. [3] identified three categories related to the learning setting of the synchronous hybrid learning environment: (a) hybrid virtual classroom connecting on-site participants with remote individuals, (b) remote classroom connecting groups, (c) remote and hybrid virtual classroom. According to the findings of Raes et al. [3], most of the studies (between 2013 and 2019) were case studies (28 in total), five studies took a comparative approach to study the effectiveness of different modes of delivery and one experimental study was found. For Raes et al. [3], synchronous hybrid learning presents both benefits and challenges that each fall into two categories: (1) organizational benefits related to educational access and instructional efficiency: increase recruitment rates, offer more elective or specialized courses, more easily consulting outside experts, not teach the same course twice to different classes and flexibility and (2) instructional benefits related to the quality of learning: making new contacts around the world, providing equal learning opportunities, ensuring continuity of instruction, promoting student retention and giving students more control over their learning; and (1) instructional challenges: require a variety of teaching methods as well as activating learning activities, require more coordination from instructor, design and implement both instructional strategies and technological systems that enable comparable learning experiences (co-presence), require more self-discipline from students following remotely or online and (2) technological challenges: maximize the social presence of remote students; ensure that remote students receive the same audio quality as F2F students; address the minor usability issues caused by constant updates of innovative technologies that can confuse, delay or hinder students' learning processes.

Similarly, in the studies of synchronous video lectures reviewed by Belt and Lowenthal [21], the authors identified advantages, disadvantages, text-based chatting and participation signals. Regarding the advantages they found, these this tightly aligned with F2F instruction, promoted interactivity, helped build community and provided ways to reach students in different locations; knowledge and use of videoconferencing application features and visual presence supported student engagement and flexibility. The disadvantages were balancing the instructor as an authority figure to create community and foster better student performance, the frequency of technical problems with videoconferencing applications (e.g., unstable Internet connection, delayed video, unclear audio) and the requirement to meet virtually online at the same time can be problematic for geographically dispersed courses. With respect to text-based chatting, they found that perceptions of text-based chat during video lectures were mixed; however, researchers seem to agree that a clear advantage of text-based chat is the ability to provide immediate feedback, so having a colleague or even a specific student manage the chats during a lecture can make it more manageable. The participation signals found were raising hands and voting functions, which organized interaction and encouraged participation; turning on a webcam or muting indicated intent to participate.

The video used in asynchronous and synchronous discussions analyzed by Belt and Lowenthal [21] revealed that instructor social presence and teaching presence, whether recorded or streamed, are essential to academic discourse. However, research on asynchronous and synchronous video communication in online and blended courses still is limited. The studies of Belt and Lowenthal [21] provide substantive precedents for the future research on prompting discussion with video and hosting discussions via videoconferencing. Finally, according to Belt and Lowenthal [21], three areas in need of further research are virtual backgrounds, features and uses of synchronous communication technology (e.g., polling, chat, screen sharing and presenter rights) and synchronous assessments and feedback. Both aforementioned studies emphasize the importance of the instructor's social and instructional presence for these synchronous hybrid learning environments to be beneficial, as well as the instructor's technical competence and willingness. This finding is consistent with results of other authors [22–24].

During the COVID-19 pandemic, the leading role of the instructor combined with technological factors was evident [25,26]. In this sense, it is relevant to highlight observations and practical recommendations from the experience of the authors of [27], where they invite people to integrate aspects of successful video game design that are relevant to online synchronous learning environments: (a) measuring and motivating performance, (b) allowing users to interact directly with creators, (c) capturing and maintaining user engagement, (d) building community and (e) curating content.

Accordingly, both types of learning (asynchronous and synchronous) share elements related to the importance of the instructor's social and instructional presence, instructor characteristics and content presentation. These factors are mediated by the asynchronous and synchronous video communication technology used. In this area, asynchronous and synchronous learning challenges with instructional videos can be extrapolated to synchronous learning with web video conferencing and live streaming platforms. It is, therefore, essential to research new styles of instructional video and live streaming, such as those supported by augmented reality [15,16], that enhance the instructor's social presence and can be used for both synchronous and asynchronous learning.

Thus, this paper evaluates the perception of an immersive virtual classroom (IVC) used as an augmented reality live streaming platform for the instructor and its preference compared with a video conferencing platform and the F2F classroom. To the best of our knowledge, studies of the perception of augmented reality videoconferencing platforms in synchronous remote classrooms are scarce.

2. Background

Warden et al. [28] conducted, for the first time, a nine-year action research study on synchronous distributed learning environments supported by videoconferencing technology up to immersive virtual reality environments. Regarding the experience with limited videoconferencing technologies in the first decade of this century, Warden et al. [28] emphasize the audio factor (the main issue is audio feedback) on video quality and the need to integrate different support tools when lecturing (such as chat, mute, hand raising and presentation synchronization). Regarding the experience in immersive virtual reality environments for a large online class to participate with effective instructional delivery, Warden et al. [28] highlighted findings that need to be addressed, such as:

- As with videoconferencing technology, the audio feedback problem persists, compounded by the fact that distance between the avatars changes the audio intensity and makes it difficult to identify open-mic problems in large classes.
- Students' unwanted manipulation of the space can be controlled with program restrictions, and engagement can be increased with more interesting designs and a richer virtual world. However, designing complex locations and buildings close together can be counterproductive, as this invites exploration. Glass walls and open spaces are preferable so that all avatars can see each other.
- Objects within the virtual space require strong management to prevent accidental manipulation by an individual student and the widespread confusion that can result. Another control issue arises because the instructor cannot be sure that students are following instructions or even arriving at designated locations, so the instructor may be overwhelmed by the complexity of the virtual space when managing the class.

A decade after this first research work, videoconferencing technology and virtual world control have improved. However, the pitfalls and promises of learning in immersive virtual reality (IVR) that Mayer et al. mentioned in [29] are still prevalent. A 3D virtual environment with a head-mounted display implies a high degree of immersion, whereas a 2D virtual environment delivered on a computer screen implies low immersion. According to the cognitive theory of multimedia learning [30,31], IVR promises to increase the motivation to learn, which in turn increases generative processing (anchoring learning by relating it to prior knowledge). However, the pitfall of IVR is increasing learner distraction due to the richness and novelty of the 3D virtual environment, which decreases essential processing (representing what is being taught in their working memory), as the learner focuses on extraneous processing (which does not support the instructional goal) when exploring the "highly" immersive virtual reality [29]. In contrast, the promise of conventional media (instructional videos, desktop and slideshow) is that they present less extraneous processing, freeing up capacity for the learner's essential and generative processing. In addition, if the lesson is well designed, it will focus on the essential material, resulting in better essential processing. The pitfall, however, is that the learner may need to be more motivated to engage with the material being taught and will, therefore, show less generative processing [29].

According to Mayer et al. [29], the challenge for instructional designers using IVR is to minimize extraneous processing while maintaining appropriate levels of generative and essential processing, whereas the challenge for designers using conventional media is to foster a high level of generative processing while maintaining the presentation of a well-organized lesson. To meet this challenge, Mayer et al. [29], in their own experience of 13 comparative experiments on learning outcomes achieved with conventional media versus IVR, concluded that these 13 comparisons did not provide "strong" evidence for the effectiveness of learning academic content in IVR compared with learning with conventional media. One reason is that learning in IVRs can distract students, an observation made previously by Warden et al. [28]. Finally, Mayer et al. [29] concluded that the effectiveness of academic-content-related lessons presented in IVR can be improved by adapting instructional design principles (such as modality, personalization and pre-training principles) and by incorporating generative learning activities (such as summarizing, responding and enacting).

This indicates that learning with both conventional media and IVR could benefit from the good use of both internal factors (instructional design principles) and external factors (generative learning activities). This suggestion could be extrapolated to synchronous learning with videoconferencing platforms. However, although the experience with videoconferencing platforms is much more friendly today, there are more tools unified to videoconferencing (such as surveys, interactive boards, grouping, etc.), the video at both ends is still not high resolution and specific audio problems persist. Therefore, it is necessary to propose to study the perception that this would have on synchronous learning, not the use of a limited videoconferencing platform but the use of live streaming platform supported in augmented reality as an intermediate solution for the low immersion (involves a 2D virtual environment delivered on a computer screen) between current videoconferencing technologies and IVR.

This paper evaluates the perception of three online synchronous classroom models: (a) F2F classroom, (b) conventional virtual classroom and (c) immersive virtual classroom, used during the COVID-19 pandemic by undergraduate students at the Universidad of Cauca, Colombia. The conventional virtual classroom mainly uses a videoconferencing platform, whereas the F2F classroom is the place that students and faculty wanted to return to after the pandemic.

2.1. Immersive Virtual Classroom—IVC

IVC is a streaming platform that incorporates an augmented reality component into the materials used in synchronous learning and allows the production of engaging audiovisual educational resources as instructional videos. It requires no post-production time and was developed during the COVID-19 pandemic at the University of Cauca [32]. IVC performs a live composition of audiovisual material (type slides) with video of the instructor, allowing an online interaction between the instructor and their slides while the interlocutors watch in a live transmission in full HD quality (1920 × 1080 pixels) and interact with the instructor via audio using a conventional videoconferencing platform.

Four features determine the functionality of IVC in online synchronous classrooms between an instructor and their students: (a) interactions, (b) IVC modes, (c) streaming type and (d) augmented reality type.

2.1.1. Interactions in IVC

Student–instructor and student–student interactions occur more often in a F2F classroom than in a synchronous online learning environment. However, the outcome of these interactions is highly dependent on class dynamics and the freedoms that an instructor applies during class [33]. During a synchronous class in IVC, as in blended courses, student–instructor, instructor–content and student–student interactions can occur according to the instructor's teaching–learning dynamics [34]. However, in an IVC, an instructor can perform real-time augmented reality instructor–content (material taught on slides) interaction during the synchronous class. This real-time interaction allows the instructor to perform pointing gestures, eye contact and gaze orientation, thereby enhancing his or her social presence.

2.1.2. IVC Modes

An IVC uses an automated streaming studio that generates the necessary lighting conditions and audiovisual feedback to create an augmented reality environment for the instructor (see Figure 1a). In the studio, the instructor is positioned behind a dark curtain and lit from three points. As the instructor's video is composited in real time with video of the slides, the instructor can perform two types of interactions. The first is with the material being taught, thanks to a clicker and visual feedback provided by a composite video monitor. The second level of interaction is with the students via audio, thanks to a traditional videoconferencing platform (see Figure 1a).

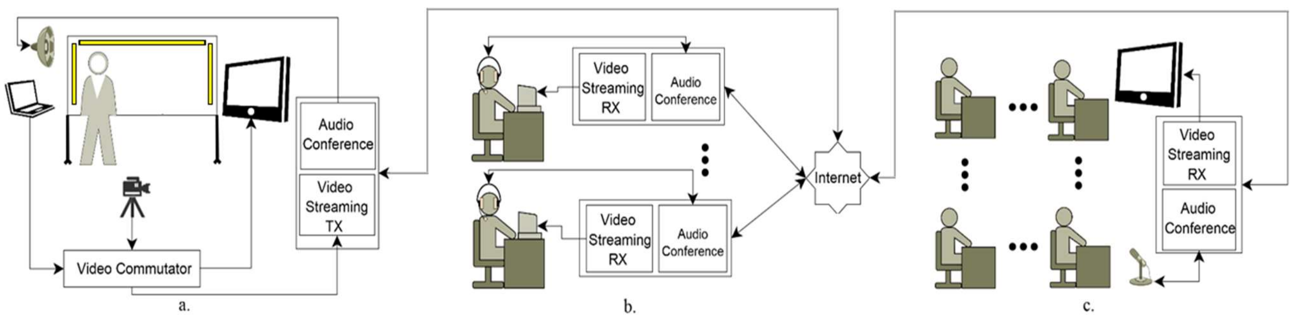


Figure 1. IVC modes: (**a**) immersive virtual classroom study and modes according to student location, (**b**) distributed, (**c**) concentrated and (**b**,**c**) hybrid.

Students have three types of locations in the IVC: (a) distributed: students are geographically dispersed, each connected from a device with an Internet connection, preferably using a hands-free system (see Figure 1b), (b) concentrated: students are in a classroom with an Internet connection and a mic to allow audio interaction with the instructor (see Figure 1c) and (c) hybrid: this case involves both concentrated and geographically dispersed students in the same session. In all three modes, it is possible to have feedback from the students' video webcam or from the classroom to the instructor via a second monitor.

2.1.3. Streaming Type in IVCs

IVCs have four types of live streaming, depending on combinations with or without video server mediation and one-to-many or one-to-one:

1. Type 1: The traditional video server—one-to-many. This is how commercial video streaming platforms work. The instructor produces the audiovisual material, transmits it to the cloud and a commercial video server distributes it to the student consumers with a certain quality and delay. Depending on the type of configuration used in the streaming platform from the producer's side, there can be delays of 2–5 s at the consumer side. Type 1 is associated with distributed and hybrid IVC modes (see Figure 2a).
2. Type 2: Video server—one-to-one. This occurs when the consumer is unique or all students are confined to a single location. Delays of 2–5 s or less also occur, depending on the type of configuration used in the streaming platform. Type 2 is associated with concentrated IVC mode (see Figure 2b).

3. Type 3: Simple peer-to-peer only requires an initial server to connect the IP addresses of the video producer's computer to the video consumer's computer; once connected, no additional servers are required and a high-quality bi-directional connection is established. Delays are in the millisecond range. Type 3 is associated with the concentrated IVC mode (see Figure 2c).
4. Type 4: Multiple peer-to-peer requires an initial server to connect the IP addresses of the video producer's computer to the computers of a small number of video consumers. Once the link is established, no further servers are required and a one-to-many connection is established, the quality of which depends on the hardware capabilities of the producer's computer. Delays are in the order of milliseconds. Type 4 is associated with distributed and hybrid IVC modes (see Figure 2d).

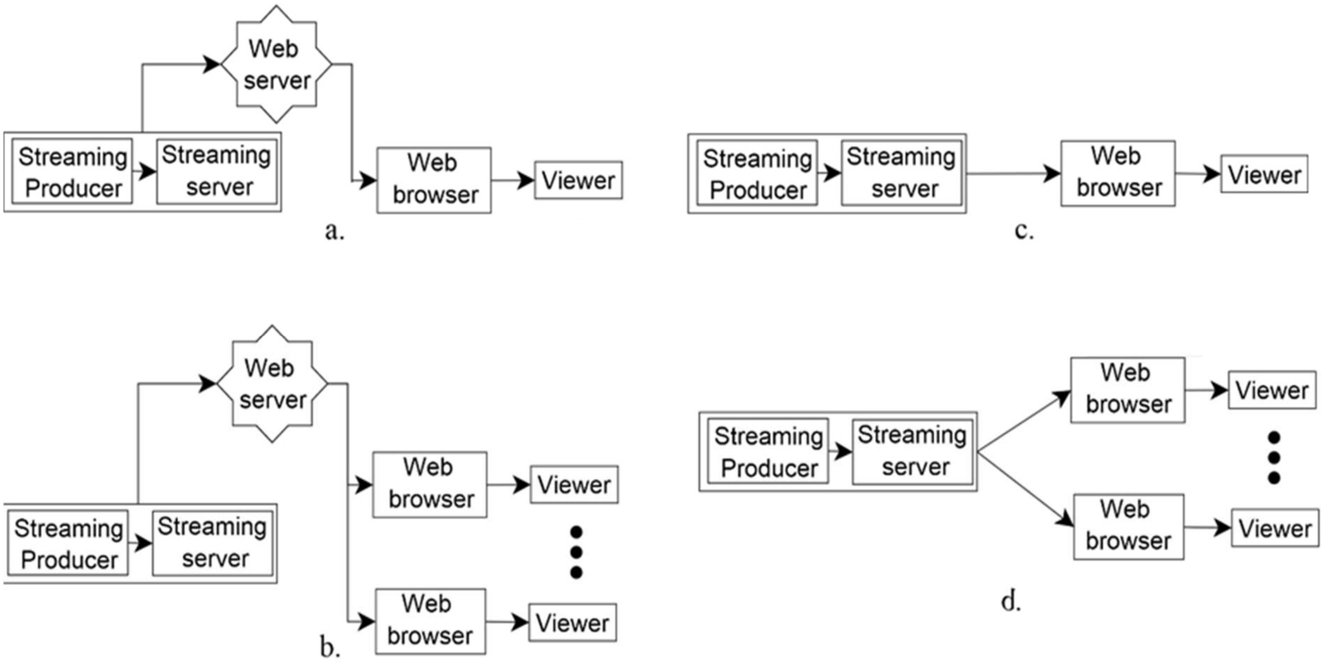


Figure 2. IVC Streaming type: (**a**) type 1 one-to-one video server, (**b**) type 2 one-to-many video server, (**c**) type 3 single peer-to-peer and (**d**) type 4 multiple peer-to-peer.

2.1.4. Type of Augmented Reality in IVCs

The IVC allows three types of augmented reality in the audiovisual material generated for both synchronous and asynchronous learning.

- Type 1. The first type combines the audiovisual material prepared for the lesson with the instructor's video against a black background. In this type of augmented reality, the student observes how the instructor interacts with the audiovisual material through pointing gestures, eye contact and gaze orientation. This interaction takes place thanks to the visual feedback the instructor receives through a monitor (see Figure 3a).
- Type 2. The second type of augmented reality is generated by simply drawing and writing the prepared lesson material with fluorescent markers on a transparent board and horizontally inverting the video before recording or streaming it (see Figure 3b).
- Type 3. The third type combines the previous two types of augmented reality. This third option takes advantage of the ease of preparing visually appealing material with the ability to write on a transparent board with fluorescent markers. The IVC combines the two videos in real time and provides visual feedback to the instructor, allowing them to interact with the audiovisual material and the writing on the board (see Figure 3c).

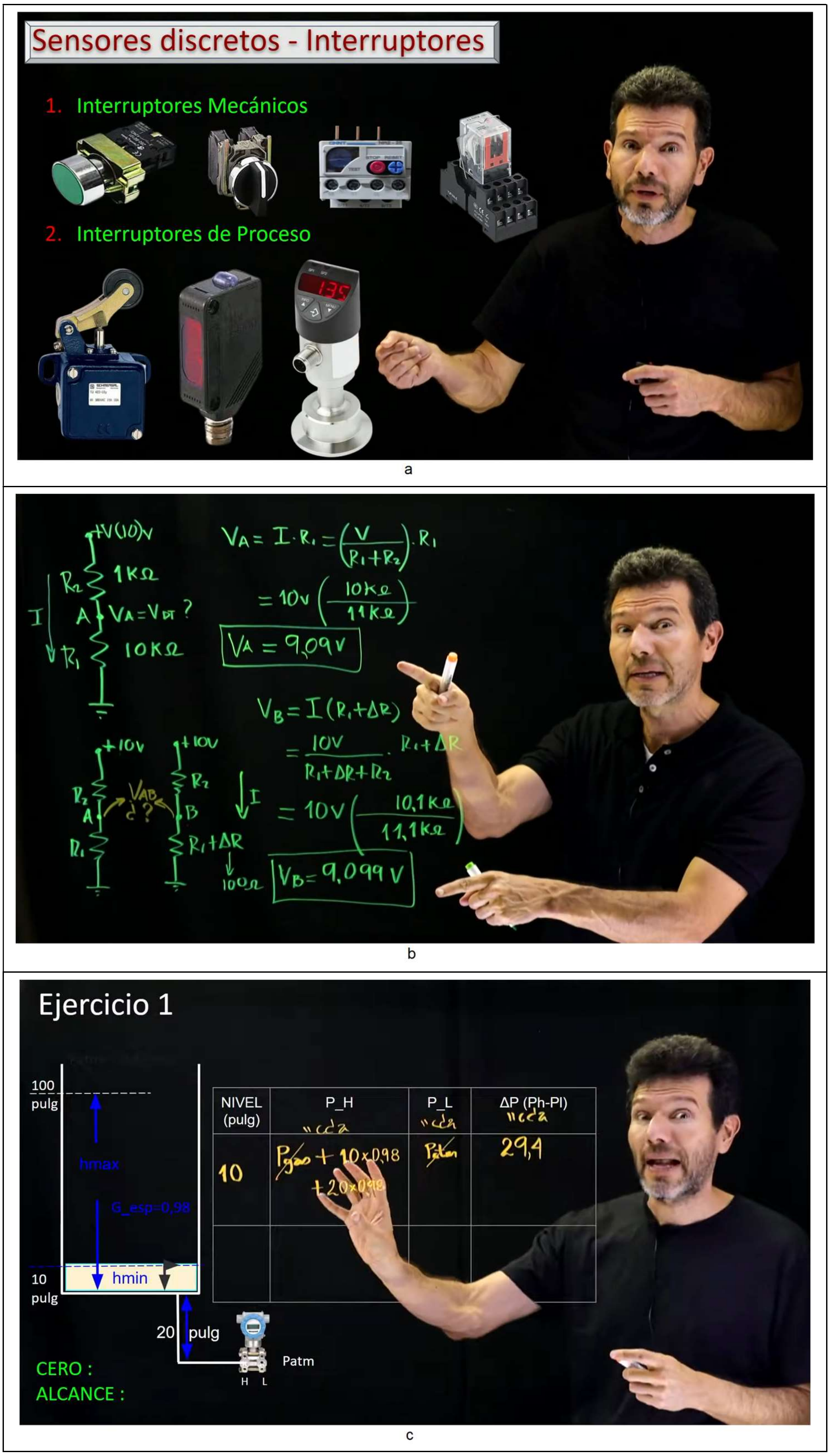


Figure 3. Three types of augmented reality generated with the IVC.

3. Materials and Methods

Two courses conducted in the IVC environment during the COVID-19 pandemic were evaluated by inviting participants to complete a questionnaire at the end of the semester. A mixed-methods approach was used to collect quantitative and qualitative data to analyze the impact and perception of IVC compared with the F2F classroom and the virtual classroom with videoconferencing, latent factors influencing the perception of the IVC and personal observations about the three types of classrooms.

3.1. Participants

The participants were students on two courses of Industrial Instrumentation in the Industrial Automation Engineering Program of the Faculty of Electronics and Telecommunications Engineering of the University of Cauca (Colombia). The two participating courses were oriented under a virtual inverted classroom model in IVC during the second semester of 2021. Participation in the survey was voluntary for the students. Demographic data were collected (see Table 1), such as age and gender. The average age of the students was 22.2 (standard deviation 3.6) years, 29.0% were female and 71.0% are male; the students were in their fourth to ninth semester. The students had previous experience with F2F teaching and had used videoconferencing platforms in their other courses. There were 33 participants between the two courses, with 31 students responding to the questionnaire.

Table 1. Demographic data for the participants in the perception of the IVC.

Demographic Data	Range	Quantity	Average	Standard Deviation
Gender	Female	9	-	-
	Male	22		
Age	19–24	26	22.2	3.6
	25–30	3		
	31–35	2		
Semester	4	3	5.8	1.3
	5	14		
	6	3		
	7	8		
	8	2		
	9	1		
Device used	Desktop computer	4	-	-
	Laptop computer	24		
	Smartphone	3		

3.2. Procedure and Questionnaire

The instructor used a flipped classroom model throughout the second semester of 2021, where students were required to prepare weekly class material on a collaborative annotation platform prior to the synchronous sessions. The weekly class material consisted of 5 to 7 videos created in an IVC (using Google slides with slides designed with a black background) that averaged 10 min in length. The instructional videos were recorded according to Mayer's multimedia design principles [13], including signaling while explaining and periodic eye contact with the camera (see Figure 3). In the synchronous IVC sessions, an intervention protocol was defined for the students. In this protocol, each student was recommended to watch the live streaming on a computer/laptop with a good-sized screen/monitor, to use a hands-free device, to ask questions freely during class, to keep their webcam turned off and not to leave their microphone open during class. During the synchronous sessions, the instructor used an extensive repertoire of verbal and nonverbal immediacy responses with his students [35], including addressing each student by name. The synchronous IVC sessions involved explaining exercises, solving team problems and other collaborative activities. At the end of the second semester of 2021, the instructor emailed students a link to an online survey. Each recipient could individually decide whether to participate in the survey, resulting in an average response rate of 93.9%. Students were not pressured to complete the survey to avoid negative consequences for biased responses. The questionnaire began with an informed consent form. It then asked what type of device they used to access and view the IVC lesson, which showed 77.4% used a laptop, 12.9% used a desktop, 0.0% used a smart TV and 9.7% used a smartphone.

We used an instrument validated by Nagy [36] for analyzing IVC acceptance based on the quantitative data collected in this study. The proposed structural equation model assesses, through four cores of questions, the perceived usefulness of the IVC by students, the ease of receiving the class in the IVC, students' attitude towards the IVC and the use of the IVC by students. Each core has two or three Likert-scale-type questions recorded on a survey adapted from Nagy [36]. The main core of analysis is the use of IVC by students (see Table 2). A 7-point Likert scale (1—Totally Disagree, 2—Significantly Disagree, 3—Disagree, 4—Neutral, 5—Agree, 6—Significantly Agree, 7—Totally Agree) was used to answer each of the ten items.

Table 2. Questions associated with the four cores of the proposed structural equation model.

Core	Associated Questions
Ease of receiving the class (E)	E1: The audio and video quality of the synchronized classes in the IVC is good. E2: I think the interaction protocol established in IVC is adequate.
Student Perceived Usefulness (U)	U1: During classes at IVC, there is good student-teacher interaction. U2: I think there are advantages to IVC over other virtual classrooms used in other courses. U3: I think there are advantages of IVC over the real classroom.
Students' attitude towards IVC (At)	At1: I attend all synchronous and asynchronous classes in the course. At2: The knowledge imparted by the teacher in the IVC is useful. At3: In general, I had technical problems receiving the virtual classes.
Use of the immersive virtual classroom (Vc)	Vc1: During the synchronous classes in IVC, I felt as close to the teacher as in a face-to-face class. Vc2: The IVC has positively influenced my knowledge of the course.

In addition, the questionnaire included four open-ended questions about the perceived benefits of the IVC over the traditional virtual classroom and F2F classroom.

3.3. Data Analysis

The two virtual courses in the IVC conducted during the restriction period due to the COVID-19 pandemic allow us the possible combinations of the four IVC features; conventional values were set according to the pandemic situation and the student's geographical dispersion during this period (distributed) (see Table 3). For example, at the Universidad of Cauca, students were not required to turn on their webcams due to problems with limited bandwidth on student connections.

Table 3. Characteristics configured to use IVC in both courses.

IVC Characteristics	Value
Interaction	Instructor–Content, Instructor–Student, Student–Student
IVC mode	Distributed (webcams turn off)
Streaming type	Video server—one-to-many
Type of augmented reality	All types (1, 2 and 3)

The support platforms used in the IVC with the two courses were YouTube for streaming, Google Meets for traditional video conferencing and Google Forms for the survey.

In addition to demographic data, the questionnaire included three quantitative questions about preferences for receiving instruction in each classroom, ten quantitative questions related to the four cores (see Table 2) and four questions of qualitative information (responses to open-ended questions). The survey was designed to answer two research hypotheses:

- There is a difference between the IVC and the traditional virtual classroom regarding student preference.
- There is a difference between the IVC and face-to-face instruction regarding student preference.

The quantitative data related to the four cores were analyzed using a proposed structural equation model [37] (see Figure 4). In this model, the factor IVC use (Vc) is highlighted to determine its perception in its interrelation with the factors: attitude towards IVC (At), perceived usefulness (U) and ease of receiving a class (E). Qualitative data from the questionnaires were analyzed using thematic analysis by identifying similarities and inductively creating word clouds. Thirty-one responses with qualitative data were collected in addition to the questionnaire items. The structural equation model (see Figure 4) proposes to investigate and analyze the following hypotheses in the IVC:

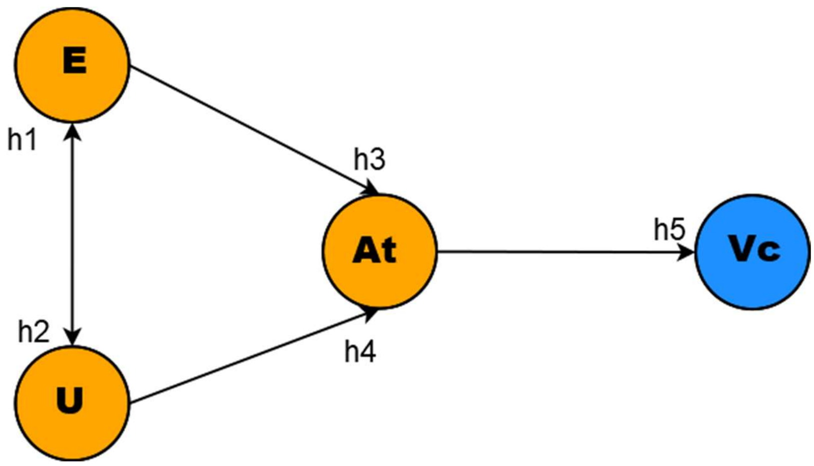


Figure 4. Proposed IVC structural model.

h1. The ease of receiving a class in the IVC (E) is influenced by students' perceived usefulness of the IVC (U).

h2. Students' perceived usefulness of the IVC (U) is influenced by the ease of receiving the class (E).

h3. Students' attitude toward the IVC (At) is influenced by the ease of receiving the class (E).

h4. Students' attitude towards the IVC (At) is influenced by students' perceived usefulness of the IVC (U).

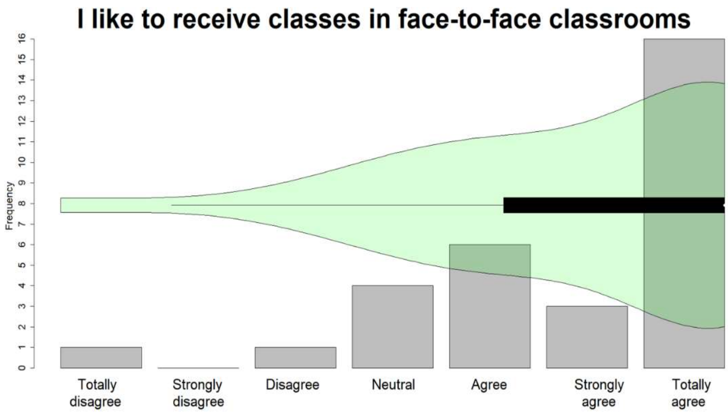
h5. Use of the IVC (Vc) is influenced by the attitude towards the IVC (At).

The two research hypotheses were tested with an ANOVA analysis of the student preference scale regarding the IVC vs. conventional virtual and F2F classrooms. In the IVC vs. conventional virtual classroom comparison, the goal is a p-value below α to accept the hypothesis. In the IVC vs. F2F classroom comparison, the goal is a p-value above α to reject the hypothesis. The software used for statistical processing and graphical presentation was R. The graphs used were bar graphs to quantify each level of the Likert scale used and violin plots to visualize the concentration of data with respect to the Likert scale used. The statistical processing builds the structural model to support the hypotheses, whereas the word clouds provide a graphical summary of the responses to the open-ended questions.

4. Results

4.1. Preference for Each Classroom

The study analyzed the students' preference for receiving classes in F2F classrooms, in conventional virtual classrooms, and in IVCs (see Figure 5). According to the students' responses, there is a high acceptance for F2F classes. On the other hand, the students show a neutral tendency to receive classes in conventional virtual classrooms. In the case of the IVC, most students prefer to receive classes with this type of augmented reality technology.



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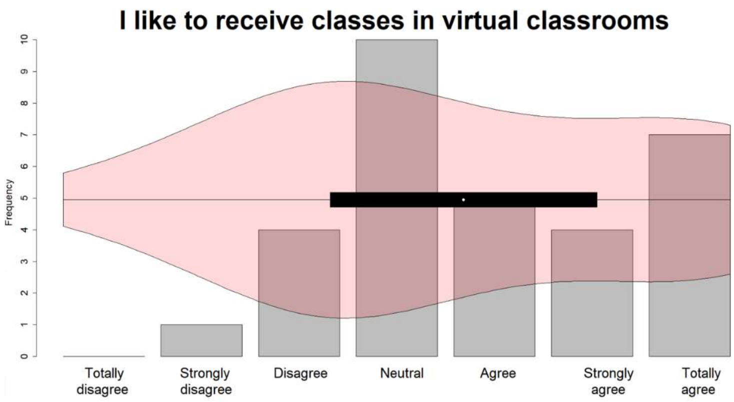

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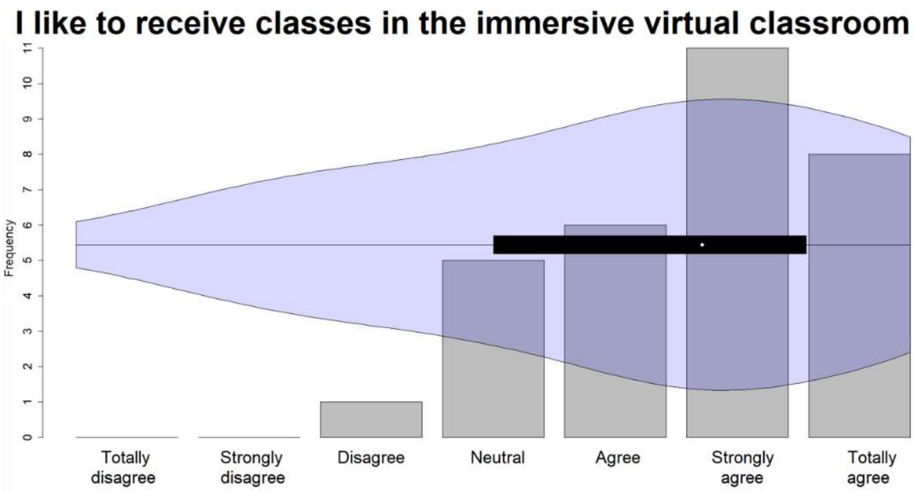

(**c**)

Figure 5. Violin plots of Student preference for classroom model: (**a**) F2F classroom (green), (**b**) conventional virtual (pink) and (**c**) IVC (blue).

4.1.1. IVC and Conventional Virtual Classroom

The first research hypothesis contrasts the students' perceptions of preference between the IVC and the conventional virtual classroom. Through an ANOVA analysis with an α of 0.05, the result is a *p*-value of 0.0317, accepting the hypothesis that there is a difference between a conventional virtual classroom and an IVC. From the trends of the students' preferences (see Figure 5b,c), we can see that the difference is positive for the IVC.

4.1.2. IVC and F2F Classroom

The second research hypothesis compares students' perceptions of their preference for receiving instruction in the IVC versus the F2F classroom. Using an ANOVA analysis with an α of 0.05, the result is a *p*-value of 0.641, rejecting the hypothesis of a difference between the F2F classroom and the IVC. The student preference trends (see Figure 5a,c) indicate a high acceptance of being taught in both classroom types.

4.2. IVC Acceptance Model

The set of 10 closed-ended responses has a Cronbach's alpha coefficient of 0.815, indicating a high reliability for the data provided by the students. Statistical data analysis and verification of the stated hypotheses used data resampling by bootstrapping 500 samples. The arc weights obtained from the proposed structural model and the *p*-value obtained for each hypothesis (see Table 4), with an alpha of 0.05, indicate that all the hypotheses of the structural equation model are valid and positively influenced.

Table 4. Arc weights for the hypotheses.

Path	Estimate	Std. Error	t-Stat.	*p*-Value	Confidence Interval Percentile 95%
E~U	0.7145	0.0468	15.2533	<0.0001	[0.3656; 0.4875]
U~E	0.7145	0.0468	15.2533	<0.0001	[0.3656; 0.4875]
At~F	0.6173	0.0865	7.1372	<0.0001	[0.2781; 0.5047]
At~U	0.7813	0.0783	9.9835	<0.0001	[0.5798; 0.7608]
Vc~At	0.4950	0.1010	4.9003	<0.0001	[0.6247; 0.8711]

According to the results (see Table 4), in the factor of students' attitudes towards the IVC, there is a significant positive effect of the perceived usefulness of the IVC (h4, $\beta = 0.7813$) and the ease of receiving instruction (h3, $\beta = 0.6173$). Hypotheses h1 ($\beta = 0.7145$) and h2 ($\beta = 0.7145$) confirm a high perceived mutual relationship between the perceived usefulness and the ease of receiving class. Finally, IVC use (h5, $\beta = 0.4950$) presented a medium but positive influence on the student's attitudes towards IVCs.

4.3. Qualitative Analysis of Open-Ended Questions

Four open-ended questions provided a broader analysis of students' preferences and perceptions, and the word clouds summarize students' responses (see Figure 6).

A total of 31 students answered the question "If you feel that IVC has advantages over other virtual classrooms, what are these?" Among them, 64.5% indicated that the increased interaction and didactic support. Although some students said they liked the overall quality of the live streaming, others said they liked the professor and his teaching style. The coding results indicated that the students liked IVC over other virtual classrooms because of four main elements (see Table 5).

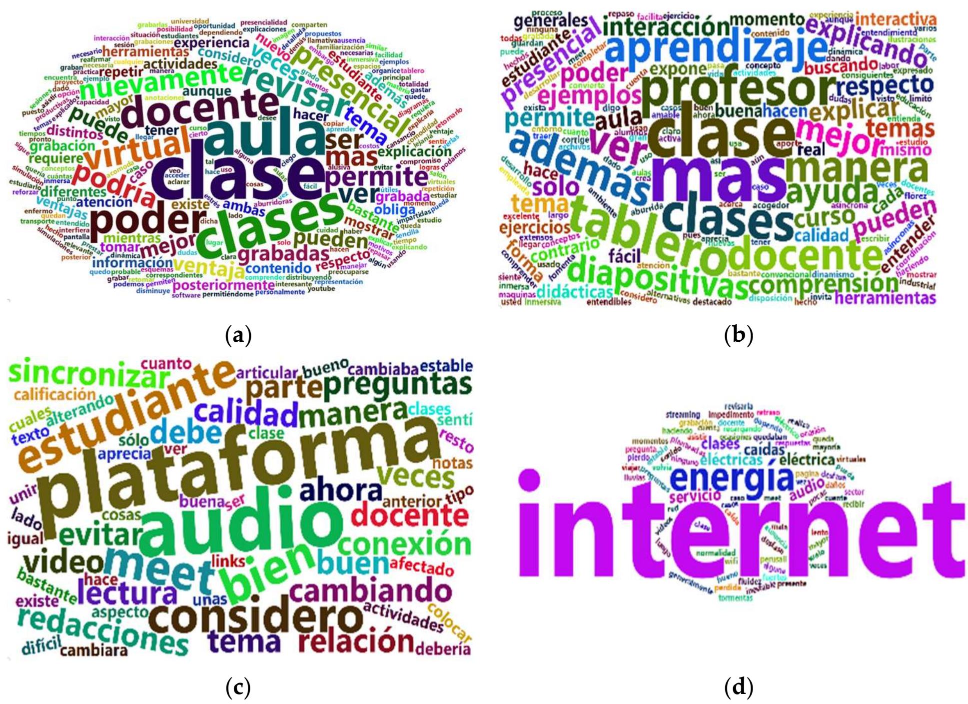

Figure 6. Word clouds associated with the answers to the four open-ended questions on IVC. (**a**) If you feel that there are advantages to IVC over F2F classrooms, what are these? (**b**) If you feel that IVC has advantages over other virtual classrooms, what are these? (**c**) What aspects of the IVC can be improved? (**d**) If you have had any technical problems with the virtual classes, what have they been?

Table 5. If you feel that IVC has advantages over other virtual classrooms, what are these?

Label	**%**	**Explanation**	**Illustrative Comment (Translated from the Original Response in Spanish Language)**
Increased interaction and didactic support	64.5	IVC enables a more significant interaction between teacher and student, enhancing the learning process.	*It is more active because it is closer to what would be observed when the teacher is explaining in a classroom setting, and the presentation of topics in terms of content and illustrations helps to understand the topics and helps the teacher to be more explanatory.*
Streaming quality	12.9	The quality of the streaming video and the videos recorded in Full HD allow students a clear visualization of the material taught.	*Quality, it creates a more welcoming learning environment, further encourages understanding and helps to maintain attention.*
Professor	12.9	Students emphasized that in addition to DVI, the way the course is taught and the methodology of the course are essential in the learning process.	*I believe that more than the advantages of the immersive virtual classroom compared to other virtual classrooms, it is the methodology used by the teacher, the dynamism with which he presents the topics and the disposition of the students.*
Recorded lectures and other audio-visual aids	12.9	The availability of recorded classes to review topics. Additionally, integrating video and other SW tools into the classroom.	*Multimedia files and the implementation of new alternative topics for education, such as the software shown during the course.*

A total of 31 students answered the question “If you feel that there are advantages to IVC over F2F classrooms, what are they?” Among them, 58.1% indicated that they recorded classes. Some students said they liked the more significant interaction and didactic support;

others said the lectures being virtual was an advantage. The coding results show that students liked the IVC over the F2F classroom because of three main elements (see Table 6).

Table 6. If you feel that there are advantages to IVC over F2F classrooms, what are they?

Label	%	Explanation	Illustrative Comment (Translated from the Original Response in Spanish Language)
Recorded lectures	58.1	The chance to view all recorded classes for revisiting topics that may not have been completely comprehended during the live sessions.	*The possibility to review the class after it has been recorded* .
Increased interaction and didactic support	25.8	IVC allows more interaction between teacher and students, supporting their learning process.	*The use of tools that allow a more detailed and practical explanation for the teacher.*
Virtual lectures	22.6	Virtual classes allow students to attend synchronous sessions from different geographic locations, saving time, reducing transportation costs and even being in class when the student is sick.	*One of them is to be able to take the class when he is sick, the interaction with the teacher is similar because he is explaining and using the board* .

A total of 31 students responded to the question "What aspects of the IVC can be improved?" Among them, 64.5% answered that the live streaming was excellent and that no changes were needed. Some students said the audio delay could be improved, whereas others stated that the connection stability could be improved. The coding summarizes the three main changes suggested by the students (see Table 7).

Table 7. What aspects of IVC can be improved?

Label	%	Explanation	Illustrative Comment (Translated from the Original Response in Spanish Language)
None	64.5	Students believe there is no need for enhancing the IVC	*I do not believe that they.*
Audio delay	22.6	The delay in audio synchronization between students and instructors among Google Meet and YouTube unveil some problems for an effective communication during synchronous instruction.	*Suddenly in the part of linking the platforms or synchronizing to avoid delays when the student wants to intervene to ask a question or answer.*
Connection stability	9.7	The Internet connection from students and instructors determined how well the class ran. In most cases, students need a stable Internet connection.	*Avoid lags that occur between Meet and YouTube when generating questions, I do not know if it is possible because it would be a connection problem, on the other hand also the issue of reading times, as often the connection is not stable then this reading time can be affected.*

A total of 31 students answered the question "If you have had any technical problems with the virtual classes, what have they been?". Among them, 71.0% indicated that the Internet was an issue. Some students said failures with the power grid. The coding results indicate that the students experimented with two types of technical problems during the virtual classes (see Table 8).

Table 8. If you have had any technical problems with the virtual classes, what have they been?

Label	%	Explanation	Illustrative Comment (Translated from the Original Response in Spanish Language)
Internet	71.0	Students had problems connecting to the Internet due to bandwidth, network damage, weather conditions or lack of coverage where they were located.	*The problems are the fall of the Internet network, damage to the electrical section, making it impossible to attend classes, but the recording remains for later review.*
None	22.6	Students had no technical problems in synchronous virtual classes	*I have not had any problems.*
Electrical faults	19.6	Absence of electricity	*Power failures.*

5. Discussion

This research aims to contribute to the body of knowledge in online and blended learning, specifically synchronous online instructor-led learning. Whereas much of the existing research focuses on asynchronous learning mediated by videoconferencing, we focused on extending the body of knowledge in synchronous online learning using an augmented-reality-supported instructor video streaming platform that can be used for both asynchronous and synchronous learning.

5.1. Preference of Students for Each Classroom

During the virtual classes forced by the COVID-19 pandemic, the generalized result of the different studies was the technological and instructional shock in the online teaching processes of students [26]. There were many reasons for the previous result, among which we can mention the short time to update the teaching–learning practices of instructors [38,39], the lack of technological preparation by instructors and the gaps in Internet coverage in many places of the world [38]. Although the Internet was identified in the present study as the main technical failure experienced by students, the IVC model prevailed over the virtual classroom model supported by videoconferencing technology as a tool to continue with online classes, with a trend of preference similar to that of receiving classes in an F2F classroom. This means that our first research hypothesis (There is a difference between IVC and the traditional virtual classroom regarding student preference) is accepted and our second research hypothesis (There is a difference between IVC and face-to-face instruction regarding student preference) is rejected. There may be several reasons for the above findings. However, the present study raises for discussion the limited social presence of the instructor mediated by the videoconferencing platform used in virtual classrooms and outdated teaching–learning practices for both the F2F classroom and synchronous online environments. Previous studies have shown that instructor social presence is a motivating factor in increasing student satisfaction and perceptions of learning [40,41].

Many of the ambiguous results in measuring the impact of instructor presence on learning outcomes with instructional videos found by Henderson and Schroeder [7] and by Polat [8] are likely due to the poor design used (picture-in-picture videos), the technological limitations of the platform used to produce the instructional video or both, which drastically limited both the social and instructional presence of the instructor. For example, in our analysis of the 12 papers reported in the study by Henderson and Schroeder [7], we found that:

1. Pi and Hong, Hong et al. and Homer et al. [42–44] did not specify the video style, nor was there any interaction with the material taught; they do not provide further details of the video style nor place supporting images.
2. Wang et al., Ng and Przybylek and Kizilcec et al. [45–47] used half of the instructor's body in the lower right corner, with no interaction with the material taught.
3. Wang et al. and Wang et al. [48,49] used half of the instructor's body is in the lower right corner, interacting with the material taught using a tablet.

4. Yu, Zhang et al. and van Wermeskerken et al. [50–52] used half of the body of the instructor in large format located on the right side of the slide, without interaction with the taught material.
5. Colliot and Jamet [53] used half the instructor's body is in the upper left corner, without interaction with the material being taught.

For the preceding, none of the studies were found, according to the criteria of Henderson and Schroeder [7], to include transparent whiteboards and the instructor behind the slides (another reason is that this technology is still novel), which allows for a more significant social presence and physical interaction with the material being taught. The same result was found in the Polat's systematic review [8], where picture-in-picture accounted for the highest percentage of video styles used the in studies. In the present study, it is assumed that the conclusion that the instructor's face (talking head) does not seem to work in the instructional videos that is reported by Fiorella and Mayer [5] and Bétrancourt and Benetos [6] is due to this same fact: the limited social as well as instructional presence of the instructors in this video style. Regarding synchronous learning, in the present study, it is assumed that a "possible" common aspect in the study conducted by Raes et al. [3] was that the synchronous video communication technology was a video conferencing platform (talking head), which may explain why it is a technological challenge to improve the social presence of the student. It can be "assumed" that the instructor's social presence was limited too. The same reason could explain the ambiguous results on the level of engagement reported between the VIRI system and the F2F classroom in the study [54].

It is necessary to take advantage of the preferrable attitude towards IVCs perceived by students (H4, $\beta = 0.7813$), as well as the excellent perceived mutual relationship between perceived usefulness H2 ($\beta = 0.7145$) and ease of receiving instruction H1 ($\beta = 0.7145$) in the structural equation model obtained for the IVC to propose the importance of aligning instructional methods with appropriate learning strategies [18,20].

5.2. Student Comments

In the thematic analysis of the student's comments in the present study, the advantage of the IVC over both the virtual classroom (64.5%) and the F2F classroom (25.8%) was highlighted as "more interaction and didactic support", which is not directly related to the augmented reality technology of IVC but rather to the teaching–learning strategy used by the instructor. The relevance of the teaching–learning strategy is also related to the identified advantage of the IVC over the virtual classroom (12.9%): "instructor and teaching style". This result confirms other findings about the importance of the instructor in video instruction [24] and synchronous learning [22].

Some advantages of IVC technology over both the F2F classroom (58.1%) and the virtual classroom (12.9%) were "the overall quality of live streaming" and "recorded classes"; these factors are related to the presentation of content in augmented reality and Full HD transmission, which allows the production of high-quality videos. On the subject of the proposed improvements for the IVC, it is clear that "audio delay" (22.6%) and "connection stability" (9.7%) are associated with the IVC mode (distributed) forced by the COVID-19 pandemic and the type of IVC transmission used: video server (one-to-many), which implies a delay in the video streaming concerning the audio communication of the videoconferencing platform. This audio delay problem is critical and needs to be addressed, as other authors have pointed out [28,55]. An interesting result of the thematic analysis is that a large proportion of students (64.5%) perceived that there was no need to improve IVC, probably due to the novelty effect introduced by the IVC.

Considering the high cost of producing high-quality instructional videos, which are the most preferred and interesting for students [21], and the low post-production cost of transparent whiteboards [14] and instructor behind the slides [15], as well as the benefits already mentioned, it is necessary to research these augmented reality styles as low immersion balancing current web videoconferencing and immersive virtual reality technologies [29].

Our quantitative results confirm that there is a difference between the IVC and the traditional virtual classroom mediated by videoconferencing, with a preference to continue receiving distance instruction in the IVC over the conventional virtual classroom. According to structural equation modeling, this is due to the fact that in the factor of students' attitudes toward IVCs, there is a significant positive effect of the perceived usefulness of IVCs and the ease of receiving instruction. Here, it is confirmed that there is a high perceived mutual relationship between perceived usefulness and ease of receiving instruction in the IVC. According to the qualitative analysis of the students' comments, our quantitative findings may be due to two facts. First, students emphasize the "overall quality of the live streaming" and "recorded classes" of the IVC as opposed to both the F2F classroom and the virtual classroom, which is related to the presentation of content in augmented reality and Full HD streaming, which allows for the production of high-quality videos in IVCs. However, the qualitative analysis also shows that the platform tested in the present configuration has audio problems that hinder instructor–student interactions. Therefore, it is proposed as a second fact that when students highlighted "more interaction and didactic support", this was not directly related to the IVC augmented reality technology but rather to the teaching–learning strategy used by the instructor. The relevance of the teaching–learning strategy is also related to the identified advantage of the IVC over the virtual classroom: "instructor and teaching style".

6. Conclusions, Limitations and Further Work

The IVC is a virtual classroom model that allows both synchronous online classes and the generation of audiovisual educational resources in the form of instructional videos with augmented reality elements that is more engaging and has a low level of post-production. The COVID-19 pandemic has made it possible to experiment and improve virtual classroom models supported by videoconferencing and evaluate teaching–learning models for F2F, blended and online environments. Given the current limitations of videoconferencing platforms and the need for further research in instructional videos on how to integrate aspects such as instructor characteristics and content presentation, it is recommended to experiment with transparent whiteboard and instructor behind-the-slides video styles in both asynchronous and synchronous learning, thus taking advantage of both the social and instructional presence of the instructor by producing audiovisual material without high post-production costs.

A practical contribution of our work is for synchronous learning researchers to experiment with new live streaming technologies and integrate video styles such as transparent whiteboards and instructor behind the slides into synchronous distance learning. These have been shown to increase learner satisfaction [15]. However, this must go hand in hand with aligning teaching methods with appropriate learning strategies [18,20]. Without an instructor who is adequately prepared to carry out an optimal teaching–learning process [22], the benefits of social presence and physical interaction with the material being taught, which allows for the visual presence of the instructor that characterizes an IVC, are lost. In this regard, Ou et al.'s [56] seven-principles model for video lesson design and development, extrapolated to synchronous learning, could serve as a guide. In the same way, we recommend not only assessing the perception but also the potential impact on learning outcomes that this would have on synchronous learning, not the use of a limited videoconferencing platform but the use of a live streaming platform supported in augmented reality as an intermediate solution of low immersion (involves a 2D virtual environment delivered on a computer screen or a smart TV) between current videoconferencing technologies and immersive virtual reality.

Despite students' preferences for the IVC over the virtual classroom supported by video conferencing, the life experience and other benefits of what happens in an F2F classroom cannot be easily replaced. However, there is a need for the instructor to integrate into the classroom (regardless of type) technological tools to support instruction (e.g., simulation software, design software, game software, assessment software and lecture and video management software, etc.), alternative instructional models and even other assessment mechanisms that together can enhance any of the three classroom models (F2F, virtual and IVC).

A valuable lesson learned from the COVID-19 pandemic virtual classrooms is that one should not return to F2F classrooms with the same pre-pandemic teaching–learning practices [57]. We recommend use of a blended approach because it encourages pre-preparation of course material (e.g., providing IVC-type instructional videos: encouraging essential processing) by students and using the classroom (virtual or F2F) to conduct dynamic activities that encourage generative processing, resulting in enhanced student learning.

This study has several limitations. First, the study examined student preference for an IVC over a virtual classroom (videoconferencing) and a F2F classroom in the same group of students. The researchers in this study developed the technology during the COVID-19 pandemic and assessed the preferences based on feedback from students in an engineering program. However, the technology has yet to be evaluated by experts outside the Universidad of Cauca. Second, the students belong to two courses in the same engineering semester. Third, the main method of the study was survey research. The novelty effect of the IVC may have increased the likelihood that student responses would be a helpful outcome variable in this study. However, we evaluated the external validity with other similar studies that showed consistency with our results.

Given the importance that online synchronous learning has been given, future work in IVCs is proposed, first, to conduct a study of instructor's social presence mediated by the IVC in a synchronous online class and, second, to evaluate IVCs not only in their perceived favorability but also in the impact on learning outcomes in other configurations of IVC modes, such as concentrated and hybrid.

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