Development and Assessment of a Learning Object based on Virtual Reality and Augmented Reality for Technical Drawing Teaching

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Abstract
For a long time, graphic representation was taught only on paper, however, with the advent of new digital technologies, more innovative and interactive teaching methods and strategies are emerging. Virtual Reality (VR) and Augmented Reality (AR) are 3D visualization technologies used in different areas of education. In this context, a Learning Object (LO) called DT3D, based on VR and RA, was developed to be combined with the method traditionally used for Technical Drawing teaching. This paper aims to present the development and the assessment of the DT3D Learning Object in a Technical Drawing discipline of undergraduate courses. The quality of the LO was assessed through a questionnaire that was answered by the students after one semester of use. The results demonstrate that the DT3D Learning Object has satisfactory quality. Searching for alternatives that make it possible to improve the criteria with the lowest rating can provide subsidies for future improvements of the system. These data indicate that the development of teaching resources associated with VR and AR can aid the teaching-learning of Technical Design content.

Keywords: learning objects; higher education; virtual reality; augmented reality; technical drawing.

1 Introduction

The learning process is always in constant transformation. For a long time, graphic representation was taught only on paper, however, the emergence of new digital technologies have provided more innovative and interactive teaching methods and strategies. The generation of mechanisms or tools that allow 3D visualization by adding movements and sensations are interesting alternatives that can be used to facilitate the learning process. These tools can be of great value particularly with regard to disciplines that involve visual and spatial perceptions, such as Technical Drawing.

The textbook and the classroom board are still widely employed for educational instruction. However, these materials no longer capture students' attention, since they are considered tedious and boring and do not provide an adequate interaction. Another issue to consider is the lack of a balanced cognitive development among students. It is known that there is disparity in the assimilation of contents by students due to their different capacity of abstraction (Silva, 2012). Cunha et al. (2009) reported that there is a growing interest of young people in computers, games and the Internet, concomitant with a lack of motivation for traditional disciplines. Motivation is one of the key factors for the student to learn certain contents. When individuals are motivated, their mental states, including attention and perception, are activated, contributing to the learning process (Silva, 2012). Increasing motivation, attention, concentration and satisfaction are mental benefits that can be encouraged by 3D visualization technologies (Diegmann et al., 2015).

3D visualization technologies that have been increasingly applied in different areas of education are Virtual Reality (VR) and Augmented Reality (AR). In most cases, the use VR and AR aims to improve learning, to provide greater involvement and engagement as well as to help learners construct knowledge (Gargrish; Mantri & Kaur, 2020; Hu-Au & Lee, 2017; Diegmann et al., 2015). The evaluation studies conducted by Virvou & Katsionis (2008); Wright (2014); Ohley (2016) reported that the use of these tools must be done with scientific rigor or else they could negatively affect the learning process

In this context, a learning object called DT3D was developed with the application of VR and AR to the method traditionally used for teaching the contents of Technical Drawing. Taking into consideration the digital technologies that have been implemented in the educational context, this article aims to present the development of learning objects (LO), as well as to evaluate the DT3D Learning Object for a discipline of Technical Drawing in undergraduate courses.

2 Educational informatics in the education context

Traditional learning methods are constantly evolving and with the development of the first personal computer in the 1980s, humans experienced a technological revolution. In 1990, personal computers became an essential part of our lives (Paraskevopoulou-Kollia et al., 2018). Since then, computational technologies have been implemented in different areas, including educational informatics, which can be used to facilitate the learning process. According to Levy et al. (2003), the term Educational Informatics refers to "the study of the application of digital technologies and techniques to the use and communication of information in learning and education".

Educational informatics comprises the disciplines of information science, education, and computer science. It focuses on the relationship between people, information and communication technologies, learning and professional practice at the level of individual and social action, and on numerous organizational and institutional environments. The disciplines investigated in educational informatics seek to know the effects on humanity of the use of digital media and their rights of use, as well as to understand learning aided by information technologies (Artikis & Artikis, 2009; Ford, 2004; Levy et al., 2003).

Informatics and visualization technologies promote an interesting method of contemporary learning, and if the users are familiar with these technologies, they will adopt it faster, making the learning experience more current and interesting (Rankin & Brown, 2016). In technical, or even invasive, disciplines, the visualization technologies contribute to improve confidence and competence of students in a more accessible way and also due to the replicability of method in virtual environments (Fealy et al., 2019).

Among the 3D visualization technologies, Virtual Reality (VR) and Augmented Reality (AR) can be highlighted. VR simulates a computer-generated environment or virtual objects in 3D that allow users to interact with them in a very realistic or physical way. VR is a simulation of a 3D real or imaginary world, which provides the illusion of reality (Milgram & Kishino, 1994). Conversely, AR is characterized by the combination of a system of virtual elements with the real environment, interactivity, real-time processing and 3D design. In addition, AR enhances the user's perception of an interaction with the real world (Azuma, 1997).

VR and AR are being applied in different educational areas, such as: Health (Alhonkoski et al., 2021; Downer; Gray & Andersen, 2020; WANG et al., 2020; Fealy et al., 2019; Aebersold et al., 2018); Biology (Zhou et al., 2020; Jenkinson, 2018); Chemistry (Xiao et al., 2020; Macariu; Iftene & Gîfu, 2020; García-Hernández & Kranzlmüller, 2019), Physical Education (Soltani & Morice, 2020), early childhood and middle school education (Oranç & Küntay, 2019; Sannikov et al., 2015), Architecture (Delgado et al., 2020; Yildirim & Yavuz, 2012), Technical Drawing (Gargrish, Mantri & Kaur, 2020; Pohlmann & Silva, 2019), Cultural Heritage (Carvajal; Morita & Bilmes, 2020; Bozzelli et al., 2019), Engineering (Harun; Tuli & Mantri, 2020; Scaravetti; Doroszewski 2019; Uva et al., 2010), Design (Shen; Ong & Nee, 2010), and Forensic Science (Mayne & Green, 2020).

VR helps students engage more deeply with the lesson contents. When used as an educational tool, VR provides the development of constructivist learning, improves the learning experience, and empowers students with creativity. VR visualizations have also the potential to help students to visualize geometries or models concretely, since these patterns are often invisible or inaccessible. Its application is directly related to virtual interfaces, without merging into the real world, that is, an immersion in a designed environment (Hu-Au & Lee, 2017). The advantage of this technology is that it meets the interests of young students due to the characteristics of the computerized lifestyle (Wadhera, 2016). In addition, it allows the student to access content from various parts of the world using the internet. The negative aspects include internet connectivity, hardware and software performance issues, which may interfere with the user’s experience (Hu-Au & Lee, 2017).

In their review on AR in education, Yuen; Yaoyuneyong; Johnson (2011) highlighted the potential of this technology in learning by identifying five directions for implementing AR in the classroom: AR books, AR gaming, discovery-based learning, objects modeling and skills training. The authors also described that AR blends the real world and computer-generated content and its usage can be incorporated in teaching materials. AR in education can be beneficial in terms of engagement, stimulation and motivation for students to explore different perspectives. AR may improve collaboration between students and instructors, stimulate creativity and imagination, help students take control of their learning, and create an environment suitable for different learning methods. Furthermore, AR can make learning of disciplines more meaningful to students by using real-world examples. The disadvantages of AR include software and hardware problems that can interfere with the learning environment when not used properly.

In general, these visualization technologies can be applied as tools to improve teaching methods. In addition, they can be used as strategies to promote interaction between students and the content, contribute to reduce the learning gap between students and to be applied in Distance Learning (DL). With regard to the psychological aspects, visualization technologies can improve motivation and help reduce stress of students who are burdened by the demands to achieve specific academic goals (Cavalcante; Bonizzia & Gomes, 2009; Ranjbartabar et al. 2018).

AR and VR technologies are being used in geometric and graphical representations to enhance conceptual understanding of 2D or 3D shapes, given the difficulties encountered by some students. Moreover, VR and AR can help learners to improve their spatial skills to better understand these objects. The adoption of both technologies has been the focus of many empirical studies (Gargrish; Mantri & Kaur, 2020; González, 2015; Coimbra; Cardoso & Mateus, 2015; Kaufmann & Schmalstieg, 2002).

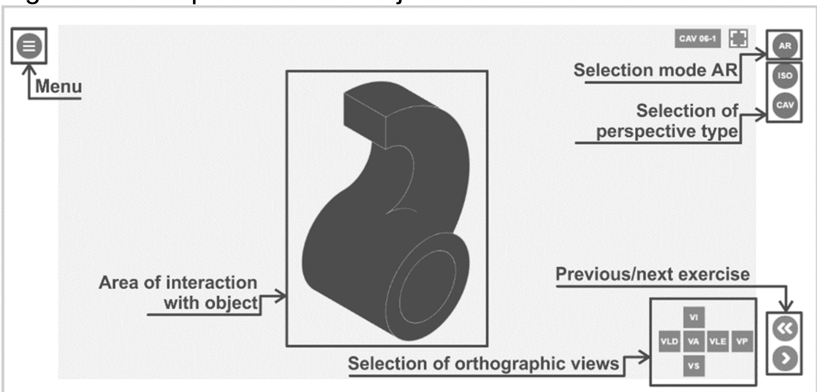
Visual representation is essential for teaching technical drawing. For Alhonkoski et al. (2021), students need three-dimensional models, virtual or real, to understand the geometry of an object before representing them in 2D. Simple physical models are widely used in the classroom, however, as the class content progresses, more complex objects are exhibited and their physical models are not always available. Thus, to meet this demand, educational computing, particularly the 3D visualization technology, can be a helpful teaching tool.

3 Development of the DT3D Learning Object

The development of the didactic model was based on a bibliographic review, a state-of-the-art survey on the research topics, as well as on the meetings with the research team. With that in mind, the model was defined as an online Learning Object (LO) using VR and AR technologies to give students access to 3D contents. To this end, the generation of the LO was entirely based on open source software for internet application. Therefore, 3D contents could be displayed directly in the web browser, in any platform, without the need to install extensions or plug-ins.

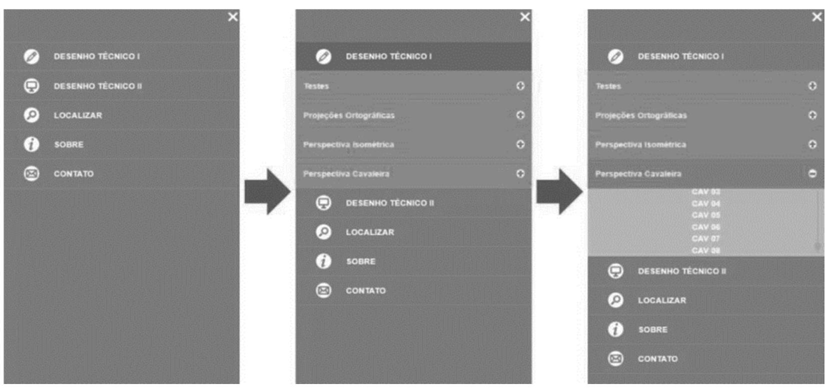
The main focus was on the disciplines of Freehand Technical Drawing of the Federal University of Rio Grande do Sul (UFRGS), Brazil, where the study was conducted. The content was adapted from the workbook developed by Bornancini; Petzold & Orlandi Júnior (1987). Some 3D solid objects were modeled and others were available in SketchUp format. These 3D solid objects were exported to OBJ (Wavefront Object) format in Blender to meet the characteristics of the project. For the representation of the visible edges in orthographic views, each modeled (or imported) solid was duplicated and in one of them, the wireframe modifier was applied to create the edge thickness to facilitate visualization. To represent the hidden edges, it was necessary to duplicate the original solid and to position lines in front of the solid. Each resulting 3D model file was stored on a server to be loaded when requested. Thus, when the solid is requested, it is loaded from the server and the textures (materials) with different colors are applied to the edges and faces. The hidden edges and boundaries are displayed as the orthographic views are selected. Following the definition of the concept, the design of the layout for the development of the LO was performed. The types of material, color palette and fonts were defined in order to offer an intuitive navigation to users (Figure 1).

Figure1: Example of a solid object.



For online and multiplatform displays, the content was developed in HTML5 (Hypertext Markup Language) combined with CSS (Cascading Style Sheets). The CSS language was also used in short animations in order to obtain greater fluidity of transitions of the visual elements, such as: opening or closing the menu (animated with a transition screen) and accordion effect (Figure 2) for its items. Content information, areas, and assignments are dynamically recovered from a database server (MySQL), making it easier to add new items to the menu.

Figure 2: Menu with accordion effect for the selection of exercises.



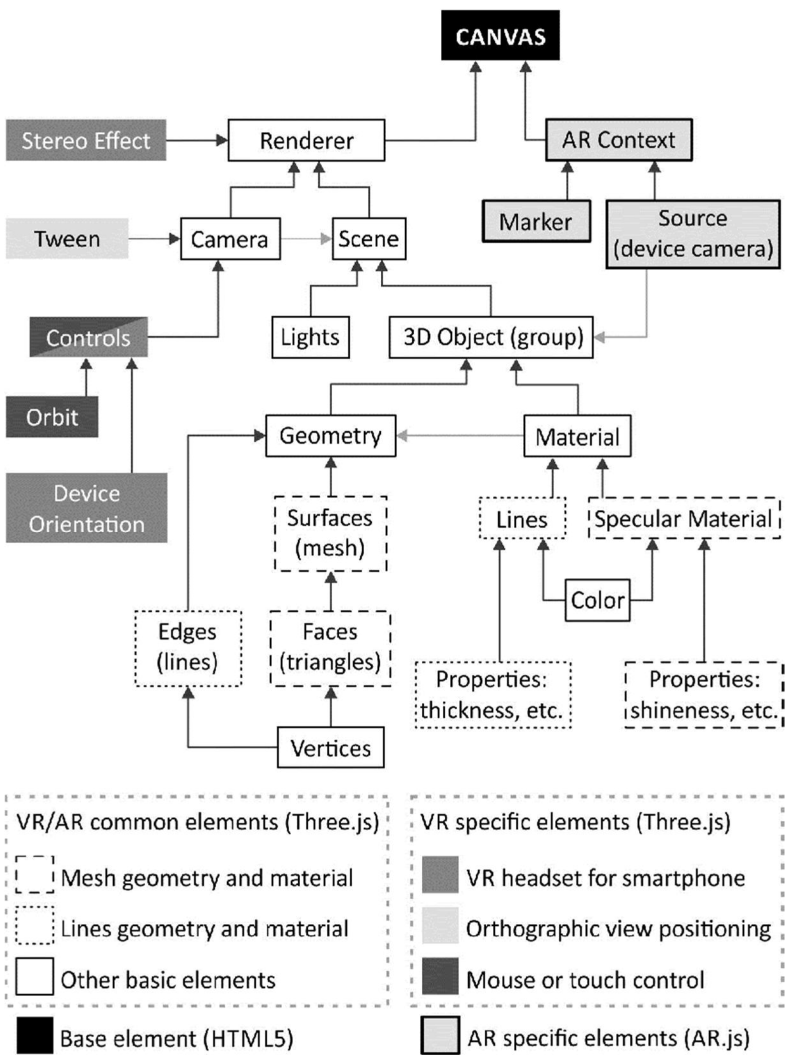
The development of a LO was based on open source software for internet applications using WebGL (Web Graphics Library). WebGL is a graphics application programming interface (API), i.e. a library, a set of subroutines and patterns created for use in web applications. Specifically, the WebGL is an API intended to generate low-level 3D graphics with JavaScript. In turn, JavaScript is commonly used as a client side scripting language. This language programming enables interaction with the user without having to wait for the server to react. Therefore, the browser can be controlled and the content can be changed in real time. The adopted tools allowed the 3D content to be displayed directly in the web browser, without the need to install extensions or plug-ins. For the purpose of achieving independence from specific browsers or operating systems, all codes were developed using the World Wide Web Consortium (W3C), which is an international community that work together to develop Web standards. It is worth mentioning that the Web Graphics Library (WebGL) is maintained by the Khronos Group. Major browser venders including Apple (Safari), Google (Chrome), Microsoft (Edge) and Mozilla (Firefox) are members of the WebGL Working Group, maximizing its compatibility.

As previously explained, the VR features were executed using the JavaScript language since it is widely applied in web development, in addition to providing the tools needed to create the LO environment. To do so, the present study used the Three.js library (https://threejs.org), which is a JavaScript framework for displaying 3D content on the web. An example of this is the user's interaction with the web page when the orthographic views or perspectives are selected. Following the programming, a series of frames is generated at a rate of 30 frames per second, giving the illusion of movement. The selected 3D object has its proportions, materials and edges in the programming. Thus, animations, such as the rotation of the 3D model in the scene, can be done using mouse (computers) or touch (mobile devices).

Likewise, in JavaScript, the AR features were performed using the AR.js library (https://github.com/jeromeetienne/AR.js), which makes use of Three.js and works well on mobile devices from different operating systems. When the AR option is activated, the image from the camera of a mobile device is analyzed by the library and the 3D object designed via programming is projected on a physical marker. The smartphone camera records the moving images and the menu remains open with all the settings available to users.

The display of the 3D model on the web page is created using the HTML5 Canvas element, which is a container to draw graphics via JavaScript. The flowchart for the project implementation (Figure 3) was based on the study previously published by the authors (Pohlmann & Silva, 2019), which presents all the steps of development and the hierarchical organization of the elements used in the programming.

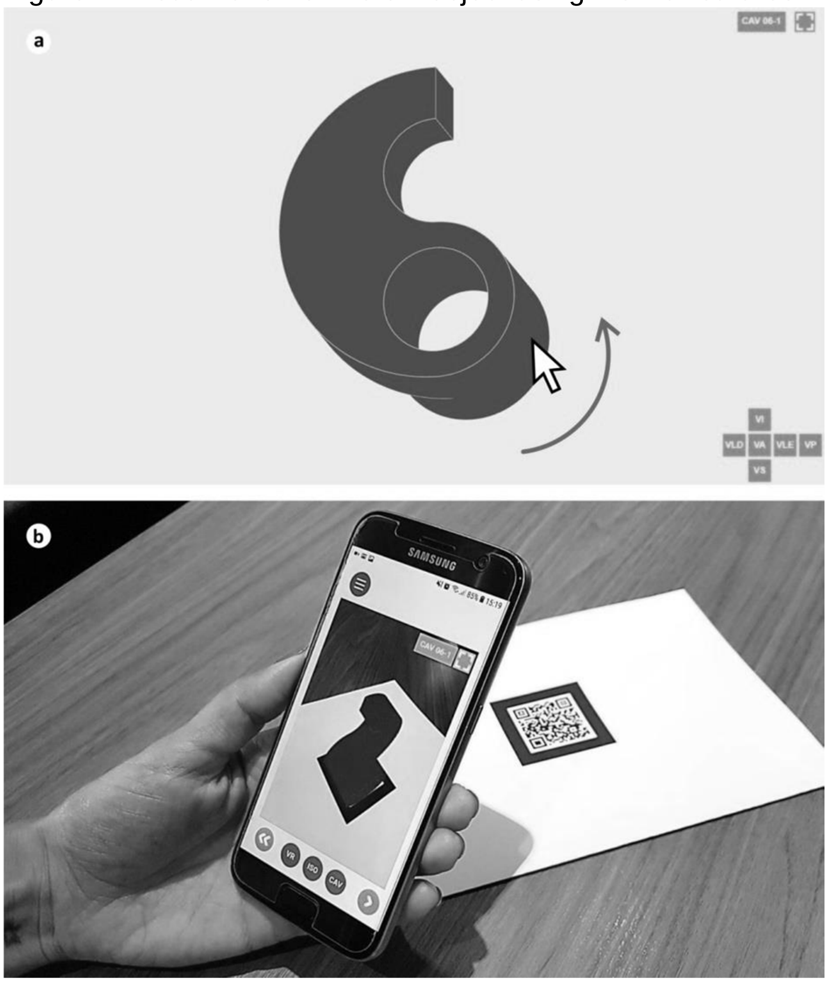
Figure 3: Flowchart for project implementation using HTML5 and JavaScript.



Pohlmann & Silva (2019).

Figure 4A illustrates the interaction with a 3D model in the DT3D learning object interface. Figure 4B shows the use of the AR feature when pointing a mobile phone camera at a marker.

Figure 4: Visualization of the 3D object using the LO features.



4 Assessment of the DT3D learning object

The Learning Object Review Instrument – LORI, developed by Belfer; Nesbit & Leacock (2009), is used to evaluate the quality of the e-learning resources. In the format of a questionnaire, the LORI assesses the quality perceived by users according to the nine criteria (Nesbit; Belfer & Leacock, 2009; Braga, 2014) presented in Table 1.

Table 1: Criteria evaluated using the LORI.

#	Criteria	Description
1	Content quality	Accuracy, balanced presentation of ideas, appropriate level of detail, and reusability in varied contexts
2	Learning Goal Alignment	Alignment among learning goals, activities, assessments, and learner characteristics
3	Feedback and adaptation	Adaptive content or feedback driven by differential learner input or learner modeling

4	Motivation	Ability to motivate and interest an identified population of learners
5	Presentation design	Design of visual and auditory information for enhanced learning and efficient mental processing
6	Interaction Usability	Ease of navigation, predictability of the user interface, and quality of the interface help features
7	Accessibility	Design of controls and presentation formats to accommodate disabled and mobile learners
8	Reusability	Ability to port between different courses or learning contexts without modification
9	Standards compliance	Adherence to international standards and operability on commonly used technical platforms

Source: Adapted from Nesbit; Belfer & Leacock (2009).

Thus, the questionnaire used to assess the quality of the DT3D Learning Object was elaborated according to the nine criteria mentioned above. The criteria were scored using a Likert-style five point response scale with the items ranging from low (1) to high (5). Some questions on the user and the type of device used were added, as well as a space for comments, criticisms and suggestions.

The DT3D Learning Object was made available for use in a class of 40 students of Technical Drawing discipline in the Design undergraduate course at the UFRGS. Following the research ethics approval, the questionnaire was applied in the last face-to-face class of the discipline. The questionnaire was completed by those students who used the DT3D Learning Object during the semester.

5 Results and discussion

A total of 26 questionnaires were answered by students with a mean age of 22.5 years and standard deviation of 5.9 (18 to 39 years). Among these, 6 students were repeating the course. A small part of the students used only the computer (4) or the mobile phone (6), while the majority used both devices (14) to access the content of the DT3D Learning Object. It can be noted that only 8 students (approximately 1/3 of the respondents) had wireless internet access. This is an issue to be observed with regard to content access, since students may not have a data pack on their smartphones.

With the Likert scale scores (1 to 5) obtained by the respondents, the mean and standard deviation for each criterion were calculated (Table 2). It was established that scores closer to 5 indicated that the criterion was fully met, while those closer to 1 revealed that the criterion was not met.

Table 2: Means and standard deviation determined for each criterion.

Criterion	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Mean	4.69	4.54	4.25	4.27	4.62	4.65	4.50	3.76	4.64
Standard deviation	0.62	0.76	0.85	0.87	0.57	0.69	0.96	1.27	0.64

The results obtained showed that the mean scores for criteria 1, 2, 5, 6, 7 and 9 (respectively: content quality; learning goal alignment; presentation design; interaction usability;

accessibility; and compliance with standards) were equal to or above 4.5 and, therefore, were fully achieved. The lowest means for criteria 3 and 4 (respectively: feedback and adaptation and motivation) were approximately 4.26, and for criterion 8 (reusability), the mean score was 3.76. It should be noted that participants gave many different responses to criterion 8, which is evidenced by the high SD value (1.27). This observation can be attributed to certain confusion on how the DT3D Learning Object would be introduced in other disciplines, considering that this is a question to be answered by teachers instead, since they elaborate the contents.

To improve the evaluation of feedback and adaptation, audio features and layout options, such as those that change the color scheme to increase contrast and consequently convey the underlying data accurately, should be included to benefit students with visual disability. With regard to increasing motivation, challenges, such as quizzes and exercises on topics that the students are searching on the DT3D Learning Object. The evaluation of the reusability criterion could be improved if the LO included resources in other related courses, such as Descriptive Geometry.

In the space left for comments, some students have reported that the LO “facilitates understanding and gives you more confidence" and also that it “saves time in class with questions and visualizations that can be made by the student himself”. These comments allowed us to infer that the class time could be optimized to solve doubts and even to deepen the content. Moreover, some students have suggested that more contents should be added to the discipline, such as hatching.

The aspects listed in the students' comments, as well as those identified through the LORI instrument, should be the focus of future studies to optimize the system. In general, the students, who participated in the study, declared that the DT3D Learning Object has helped them better understand the content of the discipline. It is worth mentioning that the final mean score of the responding students (6.3) was higher compared to that obtained by the students of the previous semester (5.8). However, in order to obtain more consistent data in this regard, it is necessary to continue using LO for the upcoming academic semesters.

6 Conclusion

In the present study, the Virtual Reality and Augmented Reality technologies were used to develop the DT3D Learning Object. Combined tools from the areas of Design and Educational Informatics enabled the online exhibition, regardless of the platforms, allowing the application of LO and providing access to contents via different devices (computers, smartphones and tablets).

The evaluation carried out by the graduate students in the Technical Drawing discipline has shown that the DT3D Learning Object has satisfactory quality, since the overall mean was 4.44 (maximum score of 5). Searching for alternatives to improve the criteria with the lowest rating can provide subsidies for future improvements of the system. These data indicate that the development of teaching resources associated with Virtual Reality and Augmented Reality can aid the teaching-learning of Technical Design contents. Moreover, the proposed 3D visualization system may be disseminated to other areas and institutions.

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