IMPLEMENTATION OF A VIRTUAL LEARNING ENVIRONMENT FOR IMMERSIVE TEACHING OF THE OPERATION OF HIGH-RISK EQUIPMENT IN ARCHITECTURE AND INDUSTRIAL DESIGN WORKSHOPS

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ABSTRACT
Learning the use of machinery for the transformation of materials, such as wood and metal, continues to be an important part of the architecture and industrial design students training, due to the manufacture of models and prototypes. The teaching-learning process of this type of equipment has always been face-to-face, with minimal interaction and attention from the students, to learn the sequence of operation and security measures.
On the other hand, and due to the return to 100% face-to-face classes for more than a year (due to the drop in COVID 19 infections), the development and implementation of learning activities with the support of virtual reality technologies is increasingly used in the training of design and engineering students at a professional level. It is for this reason that a virtual environment was developed to support the learning process of the most dangerous machines for the transformation of wood and metal. This environment, installed in the VR Zone at Tecnologico de Monterrey, Campus Queretaro, Mexico, has allowed greater immersion, interaction, and feedback in learning the aspects of use and safety of the mentioned machines. The objective of this virtual environment is to be an effective complement to face-to-face training, allowing learning in a more participatory and safe way. This work presents the implementation of this virtual environment, carried out in the February-June 2022 semester.

Keywords: Virtual reality, professional education, higher education, educational innovation

1 INTRODUCTION
The manufacture of scale models and prototypes is an essential part of the work of architecture and industrial design professionals. Due to this, training in the use of machinery for the transformation of wood, plastics, metal, and other materials is of the utmost relevance and importance.
On the other hand, the machines used to cut these materials are usually of medium and high danger, so training regarding their operation and security measures is equally important and relevant to maintain the physical integrity of students. Freshman receives training in person and with the support of an expert supervisor, who explains the security measures and the details of the operation. A problem is that students have little interaction with the machinery and are limited to watching and listening. This makes the training not entirely effective. The proposed innovation considers the use of virtual reality technologies to learn about the operation and safety measures of workshop machinery. VR environments are widely used for educational and training purposes [1] since they assure safe, immersive, and interactive spaces for learning [2]. When VR is used, students and trainees learn under a constructivist model, which enriches learning [3]. Thus, virtual reality is recognized as a strategic tool in education [4]. Regarding our interest, an increasing number of researchers have started to implement VR technologies for education and training in the Architecture, Engineering and Construction (AEC) industry [5], especially for construction safety education [6] and assembly machines training [7].

2 METHODOLOGIES

2.1 Description of the innovation

The innovation proposal consists of the design and implementation of an interactive and multimodal virtual reality environment, which is an effective complement to the traditional face-to-face training. This VR platform provides knowledge of the safety and operation measures of five medium- and high-risk machines for cutting metal and wood materials. The platform has two operation modes: tutorial and evaluation mode, and a recording system that keeps track of the activity and progress of each student. Upon entering the platform, each student must register and freely select the machine with which he or she wishes to start with. The student can, as well, review the status of her training evaluation. The detail of each of the modes of this environment can be consulted in a previous paper [8]. This virtual learning platform is installed in the VR Zone at Tecnologico de Monterrey, Campus Queretaro. It is important to mention that this platform is not exclusive to architects and designers, it can be used by any student on campus.

2.2 VR platform design and implementation process

The virtual platform development process lasted just over two years, largely due to the COVID-19 pandemic. Figure 1 shows an infographic that summarizes the entire development process of the virtual environment and the visualization of use of the metal cutter in the virtual environment.

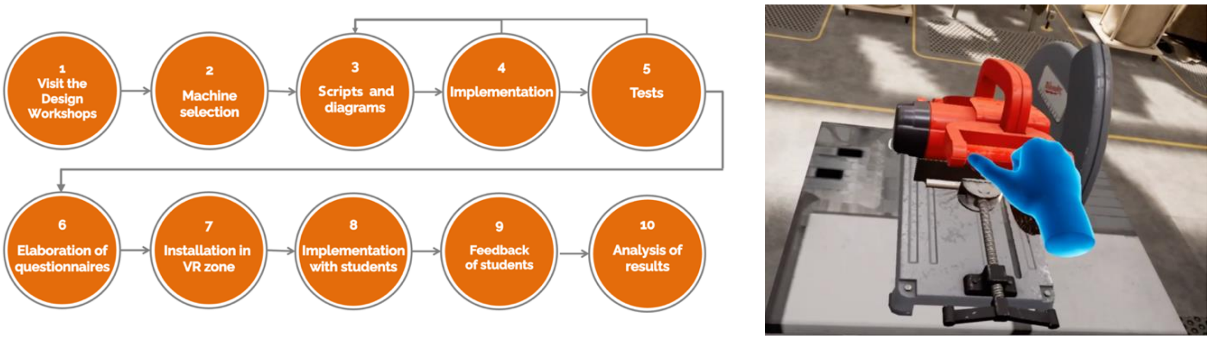

Figure 1. VR platform design process and the use of the metal cutter

All the details of the design and development process of the VR platform, as well as the adjustments made after the first implementation tests, can be consulted in a previous paper [8].

3 IMPLEMENTATION AND INITIAL RESULTS

3.1 Implementation

This innovation was implemented at Tecnologico de Monterrey, Campus Queretaro during the February-June 2022 semester in three Tec21 blocks [9]:

1. Formal representational space (Groups 101, 201 and 202)
2. Introduction to 3D (Groups 501 and 502)
3. Thought and creative process (Groups 101 and 102)

In Formal representation of space block, second semester students of the Creative Studies entrance are enrolled, while Introduction to 3D is taken only by fourth semester Digital Art students. In both cases, the students had never used the machines in the Design Workshop, nor had they received training. In the Thought and creative process block sixth semester Industrial Design students are enrolled. This last group had already taken face-to-face training in a previous semester (before the pandemic) and had some experience with machinery.

All the students, at the beginning of the corresponding block, were given general information about the project, they were explained what the experiment would consist of, and they were invited to participate. Those who accepted the invitation signed an informed consent letter. Once informed, the students participated in the experiment freely. Table 1 shows the number of students who received training without having previous experience in the use of the machines. In total, 12 students were trained in person and 25 using the virtual environment.

Table 1. Face-to-face training and in the VR environment for groups without previous experience in the machines

Block	Group	Number of students trained on the VR platform	Number of students who received face-to-face training
Formal representational space	101	5	12
	201	11	0
	202	1	0
Introduction to 3D	501	5	0
	502	3	0

Table 2 shows the number of students who tested the platform with previous experience using some of the machines. In total there were 28.

Table 2. Face-to-face training and in the VR environment for groups with previous experience in the machines

Block	Group	Number of students trained on the VR platform	Number of students who received face-to-face training
Thought and Creative Process	101	13	All in previous semesters
	102	15	All in previous semesters

Since participation was not mandatory, nor did it have a weight in their final grade, it was difficult to get students to participate consistently throughout the experiment. Not all completed the pre- and post-training questionnaires. As shown in Tables 3 and 4, the number of students who answered the post-training questionnaire is significantly lower than the number of students who started the experiment and who participated in some type of training.

Table 3. Participation in questionnaire before and after face-to-face training

Block	Group	Number of students who answered the previous questionnaire	Number of students who received face-to-face training	Number of students who answered the post-questionnaire
Formal representation of space	101	13	12	4

Table 4. Participation in the pre- and post-training questionnaire on the virtual platform

Block	Group	Number of students who answered the previous questionnaire	Number of students who were trained on the VR platform	Number of students who answered the post-questionnaire
Formal representation of space	101	9	5	4
	201	16	11	3
	202	3	1	0
Introduction to 3D	501	5	5	2
	502	3	3	3
Thought and Creative Process	101	14	13	8
	102	17	15	9

3.2 Results

To arrive at the following results, the students were divided into 2 categories: a) those who had not received training before and had no experience in handling the machines in the Design Workshop and b) those who had already received training in a previous semester. and they had some experience in using the machines.

Both categories of trainees answered a pre-training and a post-training questionnaire that included general questions about their experience with the cutting machines and specific knowledge of the machines.

3.2.1 Students without previous training or experience in the operation of machines

In this category, 4 students with face-to-face training and 12 students with training in the virtual environment completed the entire process, that is, the pre-questionnaire, training, and post-test.

In the questionnaire on specific knowledge of safety measures and cutting machines, the students with face-to-face training had an average of 5.75 correct questions out of 22 in the previous questionnaire and 7.25 correct questions in the subsequent questionnaire. There is an increase of 6.8% in questions answered correctly after face-to-face training, however the results in both cases are low.

In the same questionnaires, students trained in the virtual environment had an average of 6 correct questions out of 22 in the pre-questionnaire and 7.08 correct questions in the post-questionnaire. There is a 4.9% increase in questions answered correctly after training in the virtual environment, but, again, the results are low and similar. There is no significant difference between the two types of training. The increase in correct answers is because the answers to the questions that have to do with security measures improved, but not specific knowledge of the machines was gained.

The students who took face-to-face training pointed out as advantages 1) the possibility of asking questions and solving doubts, 2) becoming familiar with the space and seeing up close how the real machines work. The students who were trained with the VR platform said that the main advantage is 1) the possibility of making mistakes without fear, 2) the exercises can be repeated as many times as necessary without wasting material and without risk, 3) interacting with the machines to understand how they work and what are they for.

In terms of disadvantages, the students of the face-to-face training indicated that they could not use the machines themselves and that it is a long and overwhelming session, while the students of the VR platform training pointed out that there are limitations of movement in space and that the interaction with the VR controls is not always the same as it would be with the real machine.

The main change that the students suggested for the face-to-face training was to let students test the machines under the supervision of the workshop personnel. The students who used the VR environment suggested to 1) add a pause button so that the execution of the tutorial and evaluation could be paused at any time, 2) add audio instructions and not only written instructions in the evaluation mode, and 3) add a skip button so that the security module could be skipped after it was seen one time. They also suggested that, in the evaluation mode, only the fragment of the exercise that was not performed correctly could be repeated, not the whole exercise.

3.2.2 Students with previous training and some experience in the operation of machines

In this category, 17 students completed the entire process, that is, pre-questionnaire, training, and post-questionnaire. In the questionnaire on specific knowledge of safety measures and cutting machines, the students had an average of 6.41 correct questions out of 22 in the pre-questionnaire and 7.24 correct questions in the post-questionnaire. There is an increase of 3.77% in questions answered correctly after training in the virtual environment, however, the results are low. There is no significant difference between the results obtained by students with and without experience in machinery.

The advantages that the students pointed out have to do with 1) the possibility of practicing and making mistakes without risk, 2) learning on their own in their free time, 3) interacting with the machines and 4) the tutorial mode.

Regarding disadvantages, the students included 1) the discomfort and fatigue of using the VR glasses, and 2) not being able to feel what you are touching. The improvements they suggested include 1) not repeating the security module instructions more than once, 2) making the instructions clearer in evaluation mode, 3) adding more machines, not just cutting machines, and 4) checking that all user movements are detected correctly.

3.2.3 Focus groups

At the end of each block, focus groups were held to receive feedback from the students. In total there were 3 focus groups. In the first one, corresponding to the block of Formal Representation of the space, 2 students participated, one who received face-to-face training and the other in the virtual environment. In the second, the two complete groups of Thinking and Creative Process were present (even students

who did not test the platform). In the third session of focus group, in Introduction to 3D, most of the students who tested the virtual platform were present.
In these focus groups the attitude towards the VR platform was very positive. Everyone saw a value and usefulness in this educational innovation; however, they did not consider that this could replace face-to-face training, but rather complement it. They did not agree on the order in which the training sessions should be taken, but they all agreed that the ideal would be to get to know the machines live, even if only in a general and passive way, and learn to operate them on the VR platform.
Among other comments, the trainees stated that their results were not significantly better on the post-training quiz partly because they did not identify the machines by name. They suggested including photos of the machines to distinguish them more clearly.
Finally, in all the focus groups, a specific machine was pointed out, the band saw, which was the most complex to implement. It seems that with certain movements it gets stuck or does not give the expected result.

3.2.4 VR platform database

In addition to the results from the questionnaires and focus groups, we have information provided directly by the VR platform (Figure 2). The VR platform database stores the student ID, academic programme, and the last time they entered the VR environment.

Figure 2. Student ID, academic programme and last session in the VR environment

It also stores the number of times they have followed the tutorial of each machine and the number of times they have completed the evaluation exercises, as well as whether they have passed each one of them.
The information generated from the platform was emptied into Excel sheets with the intention of having a clearer visualization regarding the machines that were more difficult for students. The failed exercises were marked in red, those that were approved in green, and those that were not performed in white. Figure 3 shows results from students with no previous experience. A clear pattern is observed, three exercises were failed by almost half of the students. These three sections of the VR environment must be examined to assure instructions are clear enough and the programme is running without errors.

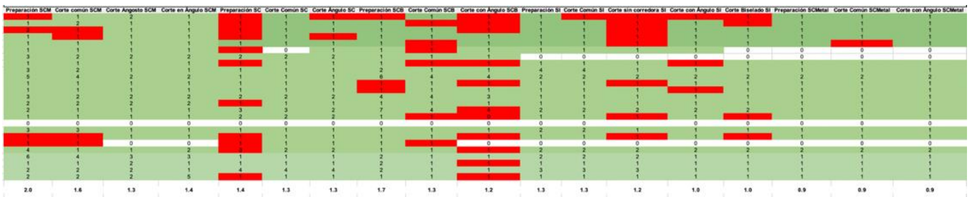

Figure 3. Excel table with the repetitions of each of the exercises for the 5 machines

4 DISCUSSIONS

The general attitude towards the virtual platform is positive. Most of students confirm that the tool helps to learn the security measures of the workshop, reduces the fear of using the machines and contributes to learning the steps to operate the different cutting machines.
All students, with or without experience using the cutting machines, agree that the main advantages of using a virtual environment for training is the possibility of making mistakes without fear or danger, repeating the tutorials and/or evaluations as many times as they need them and have free time.

There were almost no remarks about the tutorial mode. The only thing that they pointed out on several occasions is that they would like the security module not to be repeated every time the training starts on a machine. In focus groups they said that the audio instructions were precise and clear.

The evaluation module does require some changes:

a) Add, in addition to the written instructions, an audio that makes it very clear what must be done.

b) When failing, make it clearer which step was carried out wrong and make the students repeat only the wrong section.

On the other hand, one of the machines, the band saw, which was the most complex to implement, has programming errors. It seems that with certain movements it gets stuck or does not give the expected result.

Regarding the acquisition of specific knowledge about the machines, good results are not being obtained with any type of training, with or without previous experience, which indicates that perhaps there are other factors that are influencing the questionnaires, such as not recognizing or remember the machines by name or the number of days that have passed between training and answering the questionnaires.

Finally, almost all students stated that training in the VR environment should complement face-to-face training and not replace it. In the future, the intention is that 100% of the users of the Design and Architecture workshops pass the evaluation of each machine within the virtual platform to have the right to use the real machines. Consequently, it is expected to reduce accidents in the use of cutting machines and the demand for help from workshop supervisors.

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