DESIGN PROCESS 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

This document explains the objectives, characteristics, and design process of a virtual learning environment for the immersive teaching of high-risk equipment operation in Design and Architecture workshops. This proposal aims, through a tutorial and assessment mode, to substantially improve the training processes in cutting machinery in the Design and Architecture workshops for students enrolled in Creative Studies. The project has a special emphasis on safety and equipment operation aspects, with the possibility to register and document the training process of each student. At this moment, the educational innovation project shows an 80% progress, expecting to have the first implementation tests in March 2022. The main aspects of the research methodology to be carried out during 2022, once the virtual environment is finished, are explained in the document. This project has the support of the Novus Fund for Educational Innovation, Institute for the Future of Education, Tecnologico de Monterrey, Mexico.

Keywords: Virtual reality, interactive learning environments, higher education, simulation, educational innovation

1 INTRODUCTION

Training in the use of machinery for wood and metal (cutting, roughing, drilling, and sanding) is essential in Industrial Design and Architecture careers since students build models and prototypes using these machines. Because this equipment is of medium and high danger, training in its use is of the utmost importance and relevance, especially to maintain the physical integrity of the students.

To avoid accidents, general regulations have been published for each workshop and safety certificates have been placed on each machine. The training for first-semester students has always been carried out in person and with the support of a supervisor. The person in charge of the training gives the explanation of each machine and manipulates it, while the students limit themselves to listening and observing.

The proposed innovation, applying virtual reality technologies for training, implies a radical change in the way in which this first approach to machinery is carried out, given that each student will be able to interact with the virtual machines as many times as necessary without any risk while learning the procedures and safety measures of each piece of equipment.

2 METHODOLOGIES

2.1 Theoretical framework

In the Oxford Dictionary the term "virtual reality" is defined as "A set of computer techniques that allow the creation of simulated images and spaces in which a person, through a visual device, has the sensation of being and being able to function within them" [1]. Three essential concepts linked to virtual reality emerge from this definition: immersion, interaction, and feedback. The concept of immersion refers to the perception of being physically present in a world that is not physical and occurs when the user feels that the simulated environment and objects are perceptually convincing, authentic, or real [2]. In these spaces, users can interact with objects using different physical interfaces and obtain responses to this interaction. Thanks to these characteristics, virtual reality has been used extensively for specific educational or training purposes and can be considered as one of the natural evolutions of computer-based training [3].

Virtual reality allows, among other things, to increase learning through the manipulation of objects on a real scale. This physical exploration of objects helps students to understand and memorize them better, allowing teaching under the approach of learning by doing, especially when there are restrictions that prevent the use of objects or the real environment [2]. Students can experiment under a constructivist learning scheme, resulting in an experience that improves learning [4].

Active interaction and participation is naturally promoted if the user sees and hears the result of his actions immediately [3]. Through devices such as viewers, headphones and controls, the user can obtain feedback that, in the field of education, is vital. Additionally, information that is not available in the real world can be provided improving the learning of a task [5]. In many cases, there are multiple opportunities to access resources and a greater amount of time to complete specific activities, allowing for repetition and modification, fostering deeper learning [6].

Regarding the perception that students have about virtual reality, two decades ago [7] stated that students had a favourable attitude towards virtual reality in the educational process. Ten years later, Pantelidis reaffirmed that students find it exciting and challenging to walk through a three-dimensional environment and interact with it [3]. Jensen reviewed 21 research papers published from 2013 to 2017 that describe experimental studies of the use of HMDs (Head Mounted Displays) [8]. In these studies, he found again that virtual experiences are perceived as useful and interesting. According to Martin-Gutierrez virtual technologies increase student motivation to a certain extent because they feel like protagonists while they live immersive experiences [4].

It is not only about the attitude and perception of the students, simulations, games, and virtual environments have been found to have a significant positive impact on learning outcomes [9], [10], [11]. In a review of 56 papers (post 2005) related to empirical research, the findings suggest that the levels of learning achieved are the same or better in non-traditional laboratories (virtual and remote), compared to traditional laboratories in all levels of learning: knowledge and understanding, practical, analytical and research skills, as well as social and scientific communication [12]. Jensen identifies several situations where HMDs are useful for skill acquisition [7]. This includes cognitive skills related to information retention and comprehension, spatial and visual knowledge, as well as psychomotor skills related to head movement.

Among the motivations for using virtual environments, the one that stands out is the fact that they provide the opportunity for training in safe environments, avoiding potential real risks [2] [9]. Pantelidis suggests using virtual reality when real training is dangerous or when mistakes made by the student using the real object can be devastating or harmful to both the student and the equipment [3].

In the specific case of virtual laboratories, savings, flexibility, multiple access, the possibility of changing configurations and resistance to damage are also important motivations, according to Potkonjak [13].

It has been widely accepted that these types of systems are the desirable initial step in teaching science, technology, engineering, and design, recognizing that more advanced students still require hands-on experience with real equipment. However, with the fast advancement of technology, the gap between what can be done in the real world and what can be done in a virtual world is shrinking [13]. Today virtual reality is recognized as a strategic and well-defined tool in education [14].

2.2 Description of the innovation

The innovation that is presented in this paper consists of designing and implementing a multi-modal and interactive virtual reality platform that provides knowledge and active training in the use of the main wood and metal cutting machines in design workshops. The platform has a main menu where you can choose the machine you want to train on, two modes of use: tutorial and assessment, and a progress record per student.

In the tutorial mode there is a guide that provides information on the general safety equipment that must be worn, the additional safety measures to be considered, the type of materials that can be used and the steps to follow to operate the selected machine. According to the meta-analysis carried out by Lee [14], students perform better if some type of guide is provided and if the sequence of activities is controlled

by the computer [10], [11]. For this reason, the assistant designed for this environment guides the student at each step and provides the necessary visual and auditory feedback to promote understanding and retention of information.
In the assessment mode students must complete certain tasks following specific instructions. They are told what to do, but not how to do it. If all steps are completed successfully, training on that specific machine is passed. Virtual reality has great potential as an assessment tool since it allows accurate monitoring of student's activity within the virtual environment [16].
The environment is flexible because it allows students to enter when they have any free time, stay if they want to and repeat the guided training and assessment sessions as many times as needed.
This virtual learning environment will be installed in the space known as the VR Zone, which has virtual reality capable machines and headsets. All students on campus have access to this area.

2.3 Innovation implementation process

2.3.1 Platform design process

The platform design process has consisted of several stages:

Stage 1 - Visit to the Design and Architecture workshops

At the beginning of the project, several visits were made to the Design and Architecture workshops to learn about the security measures and the steps to follow in the operation of the different machines. Figure 1 shows Camerino Ávila, coordinator of the DICI workshops, explaining the operation of one of the machines.

Figure 1. Visit to the Design and Architecture Workshop

Stage 2 - Selection of machines

After these visits, five of the most dangerous and commonly used wood and metal cutting machines were selected: band saw, circular table saw, mitre saw, bench jig saw, and metal cutter, because these are the machines that students frequently use to complete their design or architecture projects and the ones that can cause accidents. In the same way, the main use cases of each of the machines were selected: common or straight cut, narrow and angled cut.

Stage 3 - Preparation of the script, flow, and state diagrams

For each of the machines and use cases, flow and state diagrams were prepared to clearly show the order and conditions to be fulfilled in the operation of the equipment. The flow charts included the scripts that were professionally recorded for the tutorial mode. Figure 2 shows the states through which the mitre saw passes when performing a straight cut.

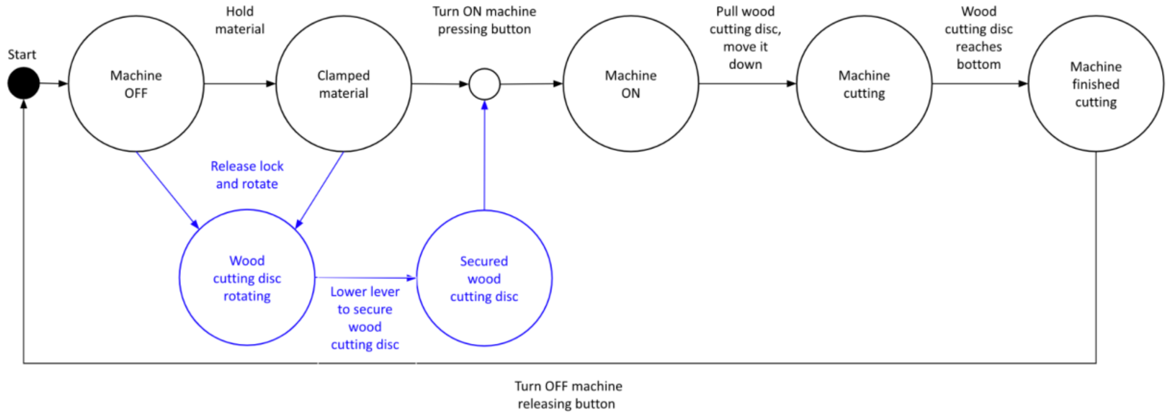

Figure 2. State diagram of the mitre saw

Stage 4 - Implementation of the tutorial and assessment mode

Once the flow diagrams were ready, the five machines and the space that simulates the workshop where the equipment is physically located, were modelled and textured in 3D, see Figure 3. Subsequently, the sequence of actions, operation and interaction with the virtual machines were programmed in a modular way, first in the tutorial mode and then in the assessment mode. For flexibility and to reduce the complexity of the system, a series of modules were created (security, material selection, common cut, narrow cut, angled cut modules). Some modules are dependent on others, while some are independent. All of them can be repeated as many times as needed to practice and pass the training.

Figure 3. Jigsaw and Table Saw 3D Models

Stage 5 - Preparation of questionnaires

Parallel to the implementation of the virtual environment, the questionnaires that will be applied to the students before and after the training (whether traditional or virtual) were developed. The objective of these questionnaires is to evaluate the experience of the students in the use of the virtual machines, knowledge about their operation and, above all, knowledge about the safety measures that must be taken in general to enter the design workshop.

2.3.2 Implementation plans

This innovation is planned to be implemented at the Tecnologico de Monterrey campus Querétaro during the February-June 2022 semester. The courses in which the virtual environment will be tested are *Specification of Products and Services*, a course offered during the first semester of the Creative Studies entry, and *Specification of Products and Services*, offered during the fourth semester of the Design programme.

It is expected to have a sample with 24 students from the Digital Art, Design and Architecture programmes with no experience in the use of cutting machines, and 40 students from the Design programme with some experience in this area.

A quantitative approach will be used to research the level of learning of the safety measures and general operation of the machines, while qualitative methods and techniques will be used to explore the experience of students while using the simulator and the real machines. The instruments that will be used for data collection are the automatic records of the virtual environment, questionnaires in which the level of knowledge about the safety measures and operation of the machines are evaluated, and finally, focus groups at the end of the semester.

2.4 Innovation design assessment

The first tests of the virtual environment were carried out with staff from the Design and Architecture workshops, to ensure that the correct terms and procedures were being used, as well as adequate interaction and feedback. Online sessions were also held to review and correct the tutorial and assessment mode scripts. Based on these tests and reviews, various adjustments and changes have been made related to the information provided by the platform and the correct order of the steps in the operation. Figure 4 shows two photographs of the tests carried out on January 29, 2020. Figure 5 shows three examples of user interaction with three different machines within the virtual environment.

Figure 4. Interaction tests

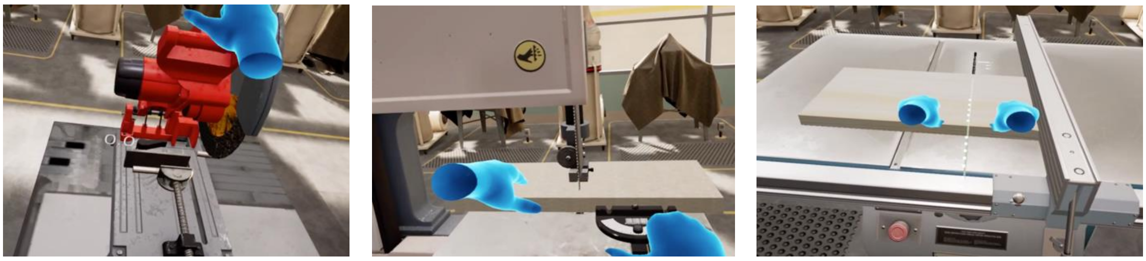

Figure 5. User interacting with the machines within the virtual environment

3 CONCLUSIONS

The development of the platform is complete, but, unfortunately, the confinement derived from the COVID19 pandemic has delayed the implementation of the innovation in the different courses. The tests with students imply the physical presence on campus, in addition to the use of the virtual reality headsets. Once face-to-face classes are restored, the platform will be used to substantially improve the understanding, retention and compliance with the safety measures and operation of the machines in the design workshops. It is also expected to increase the number of students trained in their use. The goal is to have all users of the Design and Architecture workshops pass the assessment mode of each machine within the virtual platform before they have the right to use the real machines.

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