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Enhancing Autonomous Learning in Maker Spaces: The Impact of Augmented Reality Tutorials at the Innovaction Gym

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Abstract*— The current century has seen a growing interest in applying Augmented Reality (AR) to create innovative learning tools. The integration of Augmented Reality (AR) in educational settings has shown promise in enhancing interactive learning experiences. This study reports the findings from applying AR to facilitate autonomous learning for students using various quick prototyping machines at the Innovaction Gym at Tecnológico de Monterrey. The initiative's primary goal is to enable students from all disciplines to operate complex equipment independently, fostering self-reliance and confidence. By diminishing reliance on administrative guidance, the program aims to streamline the learning process and enhance operational efficiency within a university lab such as a maker space. Custom AR tutorials were developed for each piece of equipment, providing intuitive, step-by-step visual instructions. The effectiveness of these AR guides was assessed through usage analytics and qualitative feedback from students, focusing on ease of learning and the reduction in administrative intervention. The introduction of AR tutorials has led to a marked improvement in students' self-directed learning, with a notable decrease in the need for staff-led demonstrations. The success of AR implementation in the educational context has also sparked interest in its potential applicability in industrial settings, indicating a wider scope of influence and utility.

***Keywords*—Augmented Reality Tutorials, Maker Spaces, Autonomous Learning, Educational Innovation, Higher Education.**

I. Introduction

This project is looking at enhancing autonomous learning in a Maker Space (MS), specifically at the one within the Innovaction Gym at Tecnológico de Monterrey, Campus Monterrey. The Innovaction Gym belongs to the School of Engineering and Sciences and has the goal to promote innovation from a technological perspective, to do so, it has several programs and spaces, one of them is its maker space, a maker lab where students can spend time learning to use the different tools and Computer Numerical Control (CNC) machines and experimenting with them to create fast prototypes for their classes or personal projects.

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Some of the CNC machines the MS has are 3D printers, laser cutters, plotters, and routers, which are used on average by 130 students per week. The MS operates under a Do it Yourself (DIY) policy because its main purpose is that each student learns how to operate the machines to build their own prototypes. The way the lab is operated is through a booking system where each student selects the CNC machine they need.

The typical users of the MS are undergrad students from different engineering fields. Most of them arrive to the lab without knowing how to use the CNC machines and tools, to train them and allow them to freely use the equipment, the lab admin offers two different courses each week on how to use a specific machine, each course has a duration of two hours and in them, they get an explanation on the technology and the practical use of each machine. After the students have taken the course, they should be ready to operate the machines by themselves, however, most of the time that is not the case. It has been noticed by the lab admin that frequently, students need help with operating the machines because they skip steps of the process, or they forget one, or several of them. When this happens with several students at the same time, some of them will have to wait their turn until the lab admin finishes helping the others, and a lot of time is wasted. Because of all this, the main goal for this project is to enable students from all disciplines to operate complex equipment independently, fostering self-reliance and confidence, through the implementation of Augmented Reality tutorials to enhance an autonomous experience at the MS in the Innovaction Gym. Because a large part of the project involves design elements, several methodologies will be used, mainly Bruno Munari's project methodology.

II. Augmented Reality

A. Antecedents

Augmented Reality (AR) is defined as a technology that allows the blending of virtual and physical objects in real-time through technological devices. Reference [1] states that AR allows reality to be completed without replacing it, unlike virtual reality which immerses the individual in a world that is not real, AR allows the users to see what surrounds them. AR is understood as the combination of real environments, in which information is incorporated in digital format to expand what the senses capture about real situations, this can be displayed on the screen of a mobile device where reality, captured by a camera (in real-time), and virtual information previously created and synchronized through marks (e.g. cards with pictures or black and white diagrams) are mixed, or by geographic positioning (linked to internet use). In very simple terms, AR works as it follows: a camera focuses on the real environment, where the user has one or more marks, which are programmed to be associated with certain images, static or animated in 2D/3D, documents, phone numbers, videos, sounds, music, etc., successively, other markers can be associated with other media. Reference [2] establishes that in this way, when the user aligns markers in front of a camera, it recognizes them and translates them, displaying the associated media.

This mixed integration of physical and digital reality can be carried out at different levels, ranging from the use of QR codes, the use of images, the use of 3D objects, the mobilization of coordinates using GPS, to thermal traces, as said by ref. [3]. On the other hand, AR systems can be classified based on their location or based on images.

Reference [4] said that the concept of AR can be confused with a related term that is Virtual Reality (VR), both refer to different levels of immersion of users in a virtual environment where the real and the virtual coexist. According to reference [5], the difference that distinguishes these technologies is that AR combines virtual elements within real environments, while virtual reality completely replaces a real environment with a virtual one, that is, an artificial world. AR was chosen for this project because, while VR completely immerses the user in a digital environment, AR superimposes digital information on the real world, allowing a more direct interaction with the physical environment. The choice of AR was based on its ability to enrich the educational experience without completely disconnecting the student from their physical environment, due to the type of machinery the students will be handling. AR offers a dynamic and interactive solution, where students can view relevant information directly while using the machines, creating a more immersive and contextualized experience. By using the camera on their mobile devices, such as smartphones, students can access visual guides, step-by-step tutorials, and additional data without losing sight of the equipment they are working with. This integration between the physical and the digital enhances the understanding and retention of knowledge.

The choice of AR aligns with the avant-garde vision of Tecnológico de Monterrey, which constantly seeks to innovate in its educational methods. The institution recognizes the importance of preparing students for an increasingly digitalized world, where the ability to interact effectively with advanced technologies is essential.

B. AR in Education

Certain technologies emerge experimentally, restricted to environments of research specialists, but that over time become more accessible, both for content producers and developers and for consumers. One of these technologies is AR, there is a lot of talk and writing about it and, because of that, marks a trend, and will probably continue to be used in new studies and proposals. Reference [6] determined that the use of AR facilitates the learning processes and allows you to decide what knowledge you want to expand in each situation, making the content more attractive for the user. In addition, AR allows interaction with real and virtual objects, allowing the object to be appreciated from different perspectives. This allows the learning, despite not being in person, to be of high quality and for users to experience what it would be like physically to be in the environment they are seeing. All of this facilitates the explanation of abstract, complicated and/or difficult-to-access topics, in addition to avoiding physical risks that may arise in some situations [7]. Which makes it easier to learn both in the institution, in industry, and in general in different aspects of life.

Reference [8] said that this technology enables an interaction closer to reality between the student and the content. It can also show enriched environments of a situation in the place of study or expose a distant object in the real space in which it is located. In addition, it implies the active participation of students, who spend more time with the educational material, which improves the experience and enhances the effectiveness of learning.

This project focused on facilitating autonomous learning for students in the use of the Zortrax 3D printers’ models M200, M200 Plus, and M300, and the STM Robotics laser cutting CNC machine, thus expanding their scope and educational potential at the MS in the Innovaction Gym.

a) First Generation of AR in Education

According to ref. [9], AR in education can be categorized into three generations, the first one, from 1995 to 2010, was hardware-based, characterized by expensive and complex AR systems using devices such as head-mounted displays, heads-up displays, and handheld displays. On top of being expensive, these devices needed specialized maintenance of hardware devices and special programming, therefore making it hard for most educational institutions to acquire them. Another major setback was usability, understood as the ease of use of the technology, at this first stage, the AR focused on education was a complicated system that demanded too much effort from the users, making it unpopular within class environments, thus affecting its propagation.

b) Second Generation of AR in Education

The second generation of AR in education was from 2010 to 2020 and is mainly application-based. Reference [10] established that this generation started with an increase in the number of AR applications for education obeying in part to the fact that AR applications could be deployed on mobile devices, which meant that more people could access AR, eliminating the need to purchase expensive devices such as the ones used in the first generation. This also gave people the opportunity to get familiar with technology in more ways than only the educational one and take it from the classroom to their everyday lives. Another breakthrough in this generation was the release of the public version of Google Glass in 2014 and Pokémon Go in 2016. Reference [11] proposed five directions for educational applications: AR books, AR gaming, discovery-based learning, object modeling, and skills training.

c) Third Generation of AR in Education

Finally, the third generation of AR in education, starting from 2020 to date, seems to be one driven by smart glasses and Web-based AR and AI. As this decade progresses, shipments of smart glasses worldwide will rise significantly according to reference [12] which will, in consequence, branch the use of the technology into industry, medicine, tourism, education, entertainment, etc. Web-based solutions will also increase the number of users of AR. Nowadays, people must download a dedicated app onto their smartphones to use the technology, and most of the time, they erase it after using it a few times. WebAR seems to solve that problem by enabling smartphone users, designers, and developers to discover AR technology via the Web, eliminating the installation process [13]. Lastly, the blending of AR and AI is predicted to create solutions to different problems of everyday life by bridging the physical and digital worlds, moving the boundaries of the digital world beyond screens and into the multisensory 3D world. AI will fuel AR, enabling the shift to more realistic and engaging experiences and a more powerful customization of applications [14].

III. METHODOLOGY

This project, despite focusing on engineering, required many design elements therefore, the development was carried out following mainly the design methodology by reference [15]. The figure below shows the methodology the way Munari first presented it, he did it using an analogy of how to cook green rice and described the different steps by following that simile.

Fig. 1. Munari´s design methodology.

Following the same steps of Munari's methodology, below is a description of how these steps were followed to carry out this project:

1) Problem: To create an AR tutorial for using CNC machines.

2) Problem definition: To create an AR tutorial for bachelor's degree students at Tecnologico de Monterrey to autonomously learn how to use the CNC machines at the maker space in the Innovaction Gym.

3) Problem components (elements): CNC machines at the MS in the Innovaction Gym, such as 3D printers and laser cutters. The 3D printer models are Zortrax M200, Zortrax M200 Plus, Zortrax M300, Z-SUITE Software, the laser cutter model is STM-L6090 and RWWORKS V8 software.

4) Data collection: Have a look at the user manuals available at the MS to learn how to use the equipment. Observe and ask the MS staff how are the students learning to use the machines currently? Interviews were conducted with staff members to understand the issues they have when teaching students how to use the machines, and the ones arise when they are not used correctly. Enroll in the courses offered by the MS staff to observe how it is conducted, what are the most common questions, and how the students feel after completing the course. Interview the MS staff regarding the most common issues they have when teaching students to use the CNC machines and what happens when students did not learn how to use them correctly.

5) Data analysis: Currently there are user manuals available with each machine, however, each one has more than 100 pages so students do not read or consult them. Each week, the MS at the Innovaction Gym offers several two-hour courses on how to use each CNC machine, students can book a place and learn with a staff member. After interviews conducted with the MS staff, it was discovered that Five students were selected a day after having the 3D printers course, they were asked to print a file given to them using what they learned the day before, after that, it was analyzed what are the issues they had when using the machines by themselves. The most frequent problems found as a result of students not using the equipment correctly were the following: loss of time in the use of the machines, waste of materials, delays in the bookings made for the use of the machines, damage to the equipment which translates into repair costs, a feeling of frustration in the students for not being able to complete their projects on time. After completing the courses given by the MS staff, the students feel that, for the most part, they understood the entire process of using the machines, however, they also recognize that there are steps that they may not have fully understood, that they lacked time to be able to practice what they learned, or that there are some steps that they would have liked to repeat or reinforce.

6) Creativity: How can technology help students to autonomously learn to use the CNC machines? Take advantage of the AR for tutorials that students can use to retrieve the information they need to learn how to use the CNC machines at their own pace and time.

7) Materials and technology: Deciding which technology will have better results, for example, AR vs VR. It was decided to use AR instead of VR because AR is an added layer of technology deployed in the real world, allowing users to experience and execute what it shows simultaneously on the CNC equipment. On the other hand, for security reasons in the MS, the use of the devices necessary for VR experiences would not be recommended. Research what kind of software to use, for this project, the software used was zapworks designer because, as stated in the website of reference [16], makes it easy to create immersive web-based augmented reality (WebAR) experiences – no apps, no downloads and no coding to produce immersive AR experiences. Design the Information Architecture for the project (decide the roadmap the user will follow, decide if the user will see images, text, videos, etc., and produce all the content).

8) Experimentation: Try different approaches to develop the project, take pictures, and create videos to make prototypes. Experiment using different media such as text, sound, voice-off, illustrations, pictures, etc.

9) Prototyping: Create different prototypes and choose a final one to be tested.

10) Verifying: Using the Guerrilla Usability Testing method by reference [17], five students were asked to try the final prototype, all of them bachelor's degree students, and none of them having any previous knowledge on how to operate a CNC machine. After an initial verification, iterations were made following the comments and data gathered. For example, one of the things that was changed was the voice in off in the videos (from a male voice to a female one), after comments made by the users.

11) Final technical drawings: Minimum viable product ready to be used by students.

12) Solution: A marker next to each CNC machine that triggers an AR tutorial by using a smartphone, each tutorial teaches students how to autonomously learn the correct use of CNC machines such as 3D printers in the MS.

RESULTS

The following figure shows the first action that students must carry out to deploy AR on their Smartphones. As shown in Fig. 2, the first thing would be to download the Zappar app, then scan the code and finally scan the image that is the "Trigger" to deploy the AR tutorial. The idea of this image is that it is posted in the maker laboratory near the equipment, preferably on one side of the computers where the software must be used so that they have these instructions at hand and if their smartphone crashes or they slip out from the application by accident, they can re-enter the tutorial by scanning the code and the image. To make it more student-friendly, the codes will be accompanied by Caster, a small beaver that is the MS mascot.

Fig. 2. Instructions to use the AR tutorial in the 3D printers.

The following image (fig. 3) shows the AR already deployed within the Zappar application, this is the main menu where students can go step by step to carry out the printing process, or in the event that there are students who already know certain parts of the process, but have doubts about certain steps, the interface allows them to choose which step to go to and they can navigate within it as they wish. It is important to mention that in this example, AR was used with the Smartphone held horizontally since that way it has better manipulation and can be better appreciated.

Fig. 3. Instructions to use the AR tutorial in the 3D printers.

As with many other digital interactions, users have the option to go back to the main menu all the time, as well as to go forward to the next video or picture with instructions.

The first verification test that was carried out was to learn if the students who took the two-hour course taught by the MS staff on the use of 3D printers were enough. This test was carried out with the purpose of knowing how necessary the implementation of the AR tool was for the laboratory.

In the test, the students were given a file ready to be uploaded to the printer and the filament of material to print the 3D part, in this case, they did not manipulate anything in the computer software, everything was in the machine to evaluate if the knowledge learned in the course was enough for them to carry out the 3D printing process and manipulate the machine without external help. The five students evaluated took this test one day after taking the MS course, to evaluate them with their recently acquired knowledge.

The points to be evaluated in the group of students in this test were the following:

• Did the student get stuck during the process?

• The time it took to complete the process, or how long it lasted before getting stuck.

• Were there any steps skipped by mistake, and at which point they had to ask the lab instructor for support?

• Result: Whether the part was printed or not.

The results of this test are shown in the following table.

TABLE I. STUDENTS WHO TOOK THE TWO-HOUR COURSE.

Test Results				
Minutes the test lasted	***Doubts during the process***	***Did the student get stuck?***	***Did the student skipped a step and had to ask for help?***	***Result***
7:09	How to upload the material	Yes	Omitted to load the material in the printer command before sending the part to print.	Could not print the part.
4:23	No doubts	Yes	Omitted to load the material in the printer command before sending the part to print.	Could not print the part.
5:44	How to turn on the 3D printer	Yes	You failed to load the filament manually into the printer and failed to load it with the printer command.	Could not print the part.
21:52	Turn on the 3D printer Upload the material Load the material into the printer command.	Yes	When finishing printing the part, the student did not know how to unload the material from the printer.	Printed the part.
6:11	Turn on the 3D printer Load the material into the printer command.	Yes	Omitted to load the material in the printer command before sending the part to print.	Could not print the part.

Once the AR tutorial was ready to be tested, it was decided to invite students to the MS one by one to evaluate the tool, to see if the entire designed structure was functional and had a positive performance as expected. The users who tested the AR were five students of the institution of different ages, and from careers other than engineering or technology, with zero knowledge about topics such as AR, 3D printing, 3D part software and any equipment within the MS. They proved to be very useful because, if students from different majors, unrelated to engineering -or topics related to this field, can manipulate the CNC machines and complete different processes such as 3D printing without external help, only having the AR tool, it can be inferred as a result that the tool works and is functional for any student who wants to try it.

The variables evaluated in this AR prototype were the following:

• The time it takes the user to complete the process.

• Problems during the process.

• Result of the process, whether they were able to print the part or not.

• Usability.

TABLE II. STUDENTS USING THE AR TUTORIAL.

Test Results			
Minutes the test lasted	***Problems during the process***	***Usability***	***Result***
22:33	The material was not loaded correctly.	Excellent.	Printed the part successfully.
16:43	The material got stuck when downloading it.	Good.	Printed the part successfully.
19:23	The material was not loaded correctly.	Very good.	Printed the part successfully.
24:04	The material was not loaded correctly.	Excellent.	Printed the part successfully.
22:23	No problems.	Good.	Printed the part successfully.

As it can be seen in the table above, the five students, without prior knowledge of how to use AR or 3D printing technology, were able to print their pieces successfully.

DISCUSSION

Confirming what was previously established in the document, Web-Based AR technology seems to work very well to ensure that engineering students who come to the Innovaction Gym MS can learn to use CNC machines, or to reinforce the prior knowledge they may have. The tutorials developed and tested have, so far, achieved the goal of allowing students to use the equipment to carry out their projects without the need to wait for staff to help them if they get stuck at any step in the process.

Last year (2023), it was estimated that close to 40% of the budget for maintaining MS equipment was used to repair damage caused by the incorrect use of the equipment, so this is expected to improve. as more students use the AR tutorials. Measurements still must be made in terms of the time of use and the use of equipment in the coming school year, however, the expectation is that delays in bookings for use, waste of materials and waiting times will decrease.

Having done tests with users who do not belong to the engineering areas, it was found that when using the tutorial with AR, and successfully printing their parts, there was a general feeling of satisfaction and empowerment. The tests carried out were not intended to make psychological measurements of user satisfaction beyond the usability of the AR experience, however, it cannot be overlooked that the users who took the course given by the MS one day before taking the test, at not being able to complete the printing of their pieces, -even though they had the knowledge still fresh, expressed feelings of frustration; contrary to test users who used the AR tutorial, who commented that being able to go back steps, and see them in more detail through the images and videos, gave them an added layer of confidence that they were doing it right, and that they were in control of the process. There were also comments that using the application allowed them to lose their fear of technology and equipment that they had never used.

DISCUSSION

Although AR has been used in different ways within the educational field, its use applied to tutorials, so that students can learn independently to use CNC machines in an MS is proving to be successful through the project carried out at the Innovaction Gym. The advantages of using this type of experience are very clear: waste is reduced, waiting times and maintenance costs are reduced, students feel empowered, and it allows students from other disciplines to experiment with technologies that are not familiar to them in a friendly way. This type of tutorial can be created and installed in other laboratories and on other machines where the steps to learn its use are repetitive. Another great benefit that can be observed is that of familiarizing students with technologies that are already being used by the industry to train their personnel.

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