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Competencies Development Strategy Using Augmented Reality for Self-Management of Learning in Manufacturing Laboratories (AR-ManufacturingLab)

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ABSTRACT

Technological tools in education open new learning possibilities. This proposal describes integrating augmented reality and different educational elements to develop engineering competencies, specifically using specialized machinery in the manufacturing laboratory. It is necessary to encourage self-management of learning, where users interact with the devices employing an application that contains significant information about procedures to perform and essential elements to consider when manipulating the machinery. The machines involved include industrial robots, CNC (Computer Numerical Control) lathes and milling machines, and PLCs (Programmable Logic Controls). In a traditional training model, an instructor guides the users in learning how to manipulate the equipment. This proposal intends that the participants use their mobile devices to receive each machine's instruction and the necessary documentation. The participants' learning pace varies. So, the research aimed to reduce the deficit in the disciplinary competencies since, in the traditional methodology, there is no heterogeneity in understanding the contents. We designed a competency development strategy with six laboratory practices, integrating multimedia elements to address the significant learning content of each manufacturing cell device. Each lesson contained information about each device and a practice activity and self-evaluation to ensure learning the content.

1. Introduction

Students' self-management of learning and using engineering laboratory equipment are increasingly relevant when developing different disciplinary competencies. Having adaptable tools that facilitate their pace of study independently is vital for the student to achieve the desired objectives for professional preparation. Most of the learning in the next 20 years will be delivered through flexible and open approaches outside the classroom, supported primarily by mobile apps and devices [1]. The popularity of mobile devices today offers an excellent application platform for augmented reality (AR) technology.

According to Ref. [2], who synthesized various authors' definitions, augmented reality is any system that meets three characteristics: it combines the real and the virtual, is interactive in real-time, and is three-dimensional. Thus, augmented reality involves.

- All cases in which the visualization of a real environment uses virtual objects (computer graphics)

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- Augmentation of natural information to the operator with simulated signals
- Augmentation of the real world by a virtual world to provide additional information.
- Displays in which the image is mainly of a real environment enhanced or augmented with computer-generated images.

Augmented reality has been extensively utilized for diverse purposes to offer an immersive experience to users (students) within a virtual environment to enhance their knowledge, skills, and perceptions. Cabero Almenara & Barroso Osuna [3] introduced this innovation in various educational settings (primary, secondary, preparatory, and professional) as smartphones and tablets are readily available and accessible, thanks to the advantages of mobile technology. The use of augmented reality for educational purposes was examined from 2011 to 2016, analyzing 55 different studies [4]. Augmented reality tools have increased considerably since 2013, strengthening students' involvement and commitment, increasing their positive attitudes, and elevating their perception of enjoyment during the courses. Using this technology, instructors no longer need to be in the laboratories face-to-face for the student to continue their studies; it reduces work overload on the part of the facilitators [5]. One factor that negatively affects the student experience is the lack of faculty mentoring due to two possible factors, the availability and quantity of human capital, teachers, or assistants [6].

Some technologies with promising use in engineering subjects include Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), which are tools that provide the opportunity for engineering students' self-management of training in various specialized fields [7]. Although there are several barriers and challenges to adopting virtual reality worlds in educational settings, AR/VR applications effectively enhance learning and memory by providing immersive multimodal environments enriched by multiple sensory features. There is even strong evidence of significant improvement in students' social and creative skills [8]. Augmented reality relevantly impacts learning skills or disciplinary competencies. The immersive experience provided by augmented reality allows students to focus, understand, and acquire the necessary skills effectively compared to traditional learning through user manuals [7]. Various approaches have included, for example, teaching urbanism and heritage. Joo-Nagata et al. A pedestrian location system was employed to gather information on the cultural heritage of Salamanca, Spain, and Santiago, Chile [9]. Also, Martín-Ramos et al. [10] used AR simulations pedagogically to develop a physics simulator for projectile movements. Calderón & Arbesú [11] presented an application focused on laboratories, where the use of augmented reality for a control laboratory and industrial automation added more profound and comprehensible knowledge of content, which is also the intention of this proposal.

Technology, video games, computer-assisted instruction, and mobile devices are most effective when used to complement traditional instruction and not as a substitute. Therefore, rather than replacing all class time with these techniques, using such technology with other educational strategies could enhance students' learning. Mixing a personalized combination of these techniques into the classic everyday teaching method is practical and convenient. Mobile technology has become an essential and undeniable influence on learners because of the motivation and achievement it brings. Through mobile technology, the classroom can go anywhere. Students can learn at home on a cell phone with all the content sources included and deliverables when needed [12]. In the traditional teaching methodology, which is still teacher-centered, inconvenience and efficiency may arise due to the type of training, the class size, the environment, and the limitation of the maximum number of people who can correctly receive the information simultaneously. AR and VR technologies have essential features that meet the needs of teachers and students through educational applications. They bring unique experiences to learning, allowing the teaching process to be multidirectional, and the students can have all the materials and help when needed [13]. Traditional training delivered in person by a qualified expert in a theoretical and practical course is limited, and although much remains to improve AR-based training, it fulfills its primary purpose: all trainees get to carry out their procedure successfully [14].

Mobile devices have become a necessity for the social life of our students, so we seek to integrate technology into their daily learning [15]. Students must use mobile applications and specialized software in their study subjects to be broadly current with technological trends in this field. Manufacturing laboratories use highly specialized machinery to handle with caution during specific training. Engineers in charge of planning, measuring, improving, and maintaining production lines must be familiar with the machines that perform the processes, which require specific and appropriate training. Virtual training tools reinforce their learning of machine operation in a flexible and versatile way. One problem is the students' deficit of disciplinary competencies, specifically the lack of heterogeneity in the mastery achieved. Naturally, they have diverse rhythms and learning depths. This augmented reality project aimed to bring flexibility to learning by providing students with the necessary virtual tools to learn machine technology at their own pace. The use of study strategies described as guides improves students' academic performance. These effectively organized strategies address the different moments of the learning process and encourage self-study. In this way, the learning process is facilitated topic by topic, promoting self-management of learning [16].

Although teachers are very good mentors, when guiding students in the use of fabrication equipment in the labs, it is important to keep in mind that students have different ways and rhythms of learning, so it is necessary to provide them with different tools to help them in their own learning process.

It is necessary to encourage self-management of learning in students, allowing them to interact with applications that provide them with important information about procedures and elements to consider when manipulating machinery.

The objective of this study is to share the results of a strategy for developing disciplinary competencies comprising six laboratory practices, where integrated multimedia elements address relevant learning contents of each device of the manufacturing cell. Each lesson contains information about each device and a practice activity and self-evaluation to ensure learning the contents.

This work is divided into six sections. Section 2 presents the development of the augmented reality tool called *AR-ManufacturingLab*, including the description of the innovation, as well as the implementation and distribution of content to users. The third section describes the methodology used to measure the impact in two main guidelines, the creation of multimedia elements that make up the platform and the implementation of the augmented reality tool. Section 4 describes the results, including the statistical study with

Cronbach's alpha to validate the internal consistency of the instruments used. The fifth section summarizes the main conclusions of this research, and the last section includes the limitations of this study and recommendations for future research.

2. AR-ManufacturingLab development

This section describes the development process of the educational innovation tool for self-management of learning in manufacturing laboratories, with the presentation of multimedia elements with augmented reality for higher education students.

2.1. Description of the innovation

At an early stage of this project, we proposed and developed augmented reality tools designed to encourage self-management of the learning of the specialized machinery in manufacturing laboratories. The machinery includes industrial robots, CNC lathe and milling machines, and PLCs. Traditionally, an instructor guides the students in using the machinery; however, this work intended that students use their mobile devices to receive instructions from each machine.

The problem to resolve was to reduce the deficiency in the student's disciplinary competencies. In the conventional approach, variations in students' comprehension of the subject matter are not accounted for, as they progress through the curriculum at diverse paces. We observed that some students, fearing and accepting that they do not understand the contents at the pace of others, fall behind and carry doubts that diminish their ability to acquire new skills and knowledge.

Many students request personal advice on using laboratory equipment, which makes teachers invest more time than in the classroom. With this proposed tool, students take charge of their learning by referring to support materials as frequently as needed.

The different operational stages of the machines appear in different lessons on the app, which students can consult when needed. The training stages on any machine are.

1. Technical description.
2. Start-up.
3. Manual operation.
4. Simulation (if the process requires it)
5. Machining considerations.
6. Machining.
7. Post-processing (if required).

Each machine has *triggers* for using augmented reality resources (see Fig. 1), so the students can resort to them when needed.

Once the augmented reality tool has been accepted, a training plan is proposed, consisting of 6 laboratory practices covering important learning content for each element within the manufacturing cell. Each lesson includes information about the specific elements (machinery), practice activities, and self-evaluation components to ensure comprehension of the addressed content.

The purpose of developing this application is to offer students flexibility in self-directed learning and enhance accessibility. Students can learn about the technical knowledge of each element at their own pace, with the added advantage of repeating activities as many times as necessary, without the constraint of having instructor guidance. Fig. 2 displays a series of screenshots from the UNITY-programmed application, illustrating the lessons described in the subsequent section.

2.2. Implementation process for the innovation

It is worth mentioning that the student is free to use the platform as often as needed, opening small "locks" that enable his self-managed training.

The augmented reality tool was utilized with seventh-semester students enrolled in the Industrial and Systems Engineering program. Specifically, those students studying "Integrated Manufacturing Systems" were selected. Fig. 3 presents the triggers employed in

Fig. 1. Example of trigger used by the AR tool.

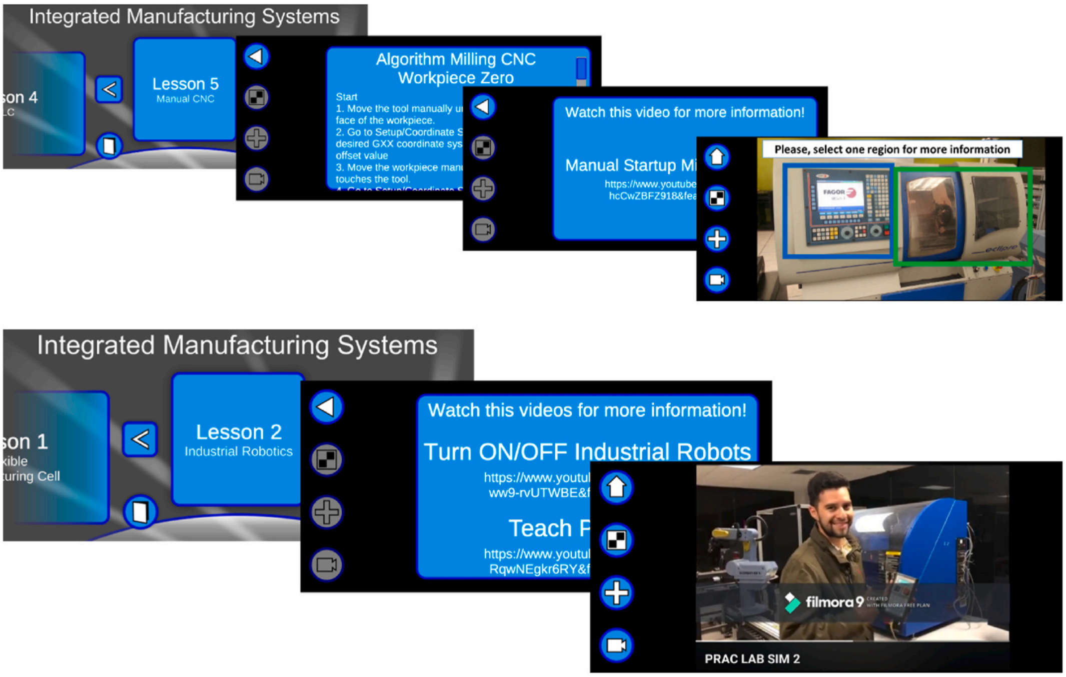

Fig. 2. Screenshots of the AR-ManufacturingLab app.

each of the lessons, which can be summarized as follows.

- **Lesson 1.** Flexible manufacturing cell. This unit introduces the student to the distribution of the elements in the manufacturing cell (layout) and its general description as a system. It describes each workstation, its elements, and its pertinent classification.
- **Lesson 2.** Industrial robots. This unit describes the elements and general operation of an industrial robot. Additionally, links to videos accessible by the students show the elements of the teaching pendant and the procedure of turning on and off the equipment for proper use.
- **Lesson 3.** Programming of industrial robots. This section describes the programming procedure of the ACL (Advanced Control Language) controller for industrial robots and a list of the most used commands as a reference for the student. Additionally, it includes videos with the step-by-step procedure of robot programming.
- **Lesson 4.** PLC (Programmable Logic Controller). This section describes the procedure to program the STEP 7 S controller for PLCs and the basic ladder language symbology for programming routines as a reference for the student. Additionally, videos are tutorials for working with basic programs.

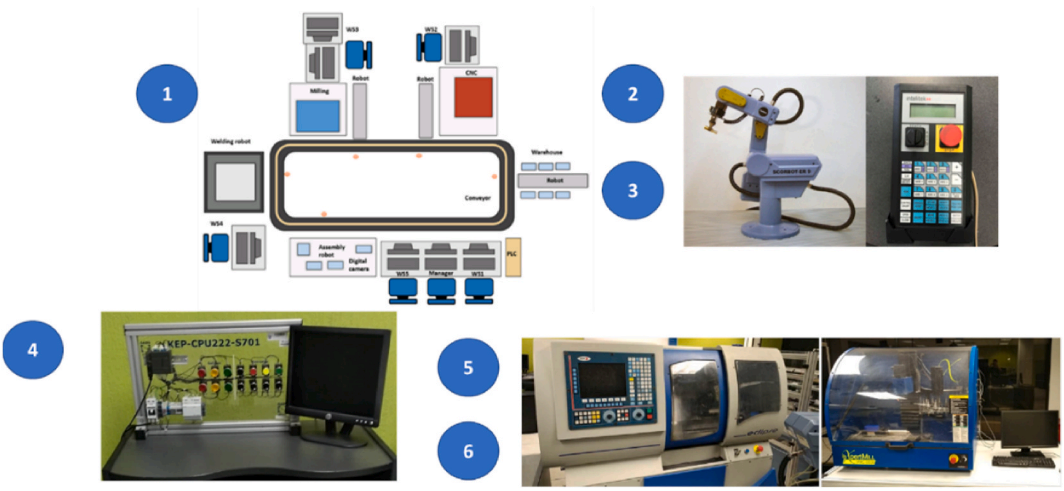

Fig. 3. Triggers implemented in the six learning lessons.

- **Lesson 5.** CNC (Computerized Numerical Control) Manual operation. This unit covers essential concepts such as machine zero, the machining zone, the control panel, and two crucial machine calibrations: tool compensation and part zero definition. An instructional video is also included on how to perform the procedures and manually operate the machine movements.
- **Lesson 6.** CNC Simulation and Machining. This section includes instructions to simulate the part before machining and a list of G-code commands for programming the lathe and milling machine. Additionally, a procedural video is included for performing the simulation and summarizing safety considerations for machining.

The implementation of the Lesson 5 for the CNC lathe is described below as an example. Fig. 1 initiates the augmented reality (AR) components shown in Fig. 4, which display two designated areas of interest for this study: the machining area and the machine controls area. These regions are separated by the displayed regions.

Once students identified the areas of interest, they could examine them separately to obtain more information about the control panel operation (box on the left) or the machining area (box on the right). Clicking on the screen of the device displays the description of each region, enabling individual focus on them. Fig. 5 shows the screens that appear when selected.

These images represent the elements the user should focus on for a more detailed study of the machine or the configuration procedures. The content may take the form of visual aids, signage, descriptions, or instructional videos. Fig. 6 displays the control panel's details, including the functions and buttons of each component.

Machining has high complexity, so its operations and the procedures to configure the machine must be described. For example, in a specific configuration procedure, the zero of a part and zero of the machines must be fully established before proceeding to the initial configuration. Fig. 7 shows the three main configurations for machine calibration.

- Configuration A. No workpiece compensator and no tool compensator (the factory configures it) (Fig. 7a).
- Configuration B. Has a workpiece compensator, no tool compensator (Fig. 7b).
- Configuration C. Has both a workpiece compensator and tool compensator (ready for machining) (Fig. 7c).

Students' use of the tool is unsupervised, providing autonomy in the teaching-learning process. Fig. 8 shows a group of students using the platform.

3. Methodology

The conduct of this experimental study and the ethical implications involving the individuals in this study were regulated and approved by Tecnologico de Monterrey, with the technical support of the Writing Lab of the Institute for the Future of Education, including the express consent of the students involved in this study for research purpose.

To analyze the tool acceptance by the students, we applied a mixed methodology. The qualitative instruments were semi-structured interviews and observation, and two Likert scale questionnaires comprised the quantitative instruments. The Cronbach's alpha reliability test measured the internal consistency of each [17].

The Likert scale, created by psychologist Rensis Likert in 1932, is widely used in survey research. It allows individuals to respond to statements using a scale ranging from positive to negative, effectively describing human attitudes and the factors influencing them [18]. The scale in our study was five-level Likert: (1) strongly disagree, (2) disagree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree.

Cronbach's Alpha coefficient measure reliability and internal consistency in research instruments with multiple items, so it is crucial to calculate and report this coefficient, especially when using Likert-type scales. Cronbach's Alpha coefficient varies between 0.00 and 1.0, where a value of 0.00 indicates a lack of consistency and 1.0 reflects perfect consistency; generally, 0.70 to 0.90 is

Fig. 4. Selection of areas of interest for CNC lathe.

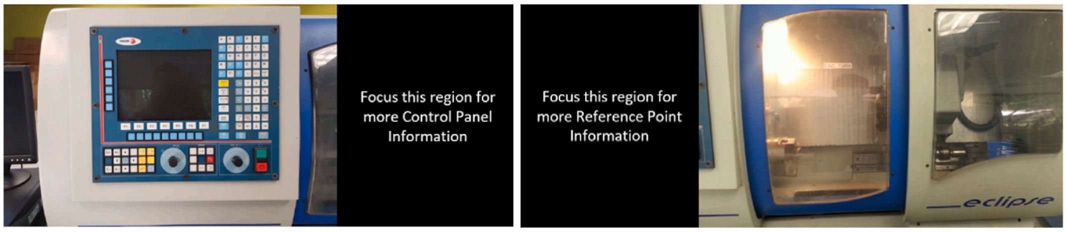

Fig. 5. Areas of interest after selection on the main screen.

Fig. 6. Explanation of the control panel buttons.

considered acceptable [19].

First, the contents added to the augmented reality system were generated by ten of the most advanced students in specific topics under the teacher's supervision, 20 % women (n = 2) and 80 % men (n = 8). At the same time, they were trained to program the applications to make the material more accessible to struggling students. This strategy reinforces the most advanced students' knowledge while they generate teaching material for their peers.

The first Likert scale questionnaire, shown in Table 1, was applied to these students during the development of the tool to detect possible improvements and to observe the user experience during the adoption of this application.

These three questions asked the students about the ease of creating helpful content for laboratory training and the benefits they obtained by developing competencies for their professional lives. The last question affirmed whether they learned better by creating the content for the laboratories, following the popular thought that "the best way to learn is to teach."

The qualitative components supporting the questionnaire results were the observations of the supervisor during the whole tool development process and the semi-structured interviews with three students to determine how they perceived that this strategy could help their learning.

The second Likert scale questionnaire in Table 2 measured *motivation, engagement,* and *usability*. It was given to 55 students in the 6th semester of mechatronic and industrial engineering programs: 29 % were female (n = 16), and 71 % were male (n = 39).

In these five questions, the students identified if they perceived that this strategy effectively improved their disciplinary competencies, enhanced their skills in manufacturing equipment usage, and their level of self-management learning. Additionally, the students evaluated the quality, impact, and ease of use of the AR-ManufacturingLab platform in the laboratory.

The qualitative component supporting the questionnaire results were the supervisor's observations during the whole tool implementation, how the students interacted with the AR–ManufacturingLab platform, and the semi-structured interviews with five students asking how they perceived that this teaching strategy helped their learning.

The following section describes the results from the quantitative and qualitative instruments.

4. Results

To validate the proposal, we applied two surveys to the students, focusing on two critical aspects: content creation and implementation.

Some students served as content designers and could explain the content they had already mastered to their classmates, thus strengthening their learning. Fig. 10 presents the results obtained from the analysis of the survey regarding content creation. The data comes from a sample of 10 students and those who took the implementation survey. The data shows that all designers took part in the educational innovation initiative, demonstrating a participation rate of 100 %. In addition, 80 % of the participants recognized that

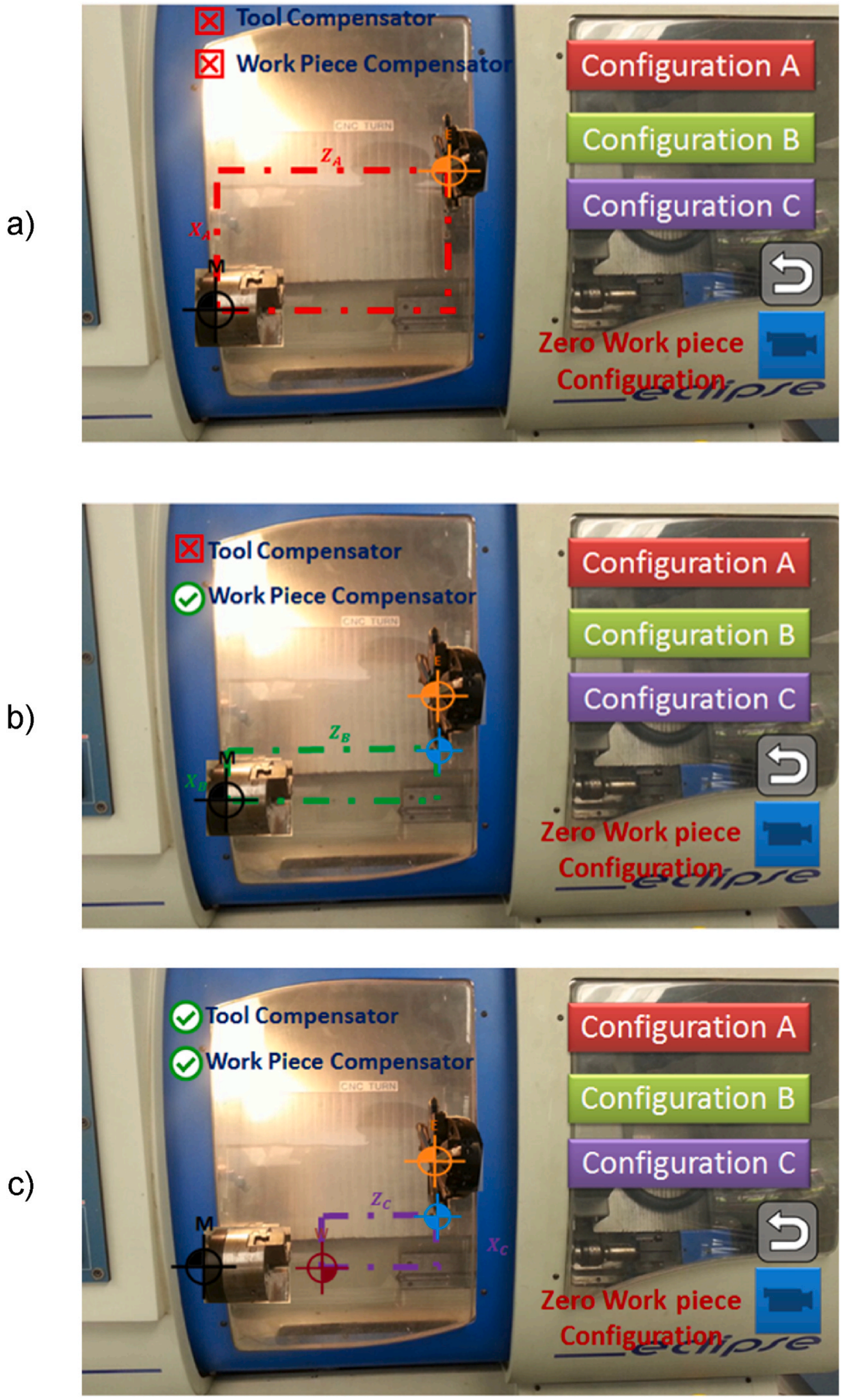

Fig. 7. Machine configurations: a) Configuration A, b) Configuration B, c) Configuration C.

their involvement in the initiative improved their comprehension of the subject matter as they contributed to the development of instructional materials for the platform. Over 50 % of participants strongly agreed that the augmented reality (AR) component enhanced their ability to use laboratory equipment with precision. However, participants' perceptions of the programming platform's ease of use varied.

Fig. 9 summarizes the results of the Likert-scale creation questionnaire.

Due to the task in question, the sample is small, and many students' opinions are in levels 4 and 5. This means that creating didactic elements to improve learning in manufacturing laboratories using augmented reality resulted in a positive perception by those

Fig. 8. Experimentation by individual students.

Table 1
Likert scale questionnaire for the creation of the AR tool.

	Item	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
1	The creation of learning modules was easy.	1	2	3	4	5
2	The development of the modules can help you in your professional life.	1	2	3	4	5
3	The creation of didactic material allowed you to learn more about the laboratory topics.	1	2	3	4	5

Table 2
Likert scale questionnaire for the implementation.

	Item	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
1	AR-ManufacturingLab helps you correctly use the machinery available in the laboratory.	1	2	3	4	5
2	AR-ManufacturingLab facilitates your learning in the use of manufacturing equipment.	1	2	3	4	5
3	The AR-ManufacturingLab platform is easy to use.	1	2	3	4	5
4	Using AR-ManufacturingLab for lab sessions is motivating.	1	2	3	4	5
5	The virtual scenario is adequate, dynamic, and straightforward.	1	2	3	4	5

involved. The values shown in level 5 are between 40 % and 80 %, level 4 between 20 % and 60 %, levels 2 and 3 did not show any participation, while in level 1, 20 % of item 2 was found.

When asked about the arguments and points of view that led them to answer the questionnaire in this way, the students who did not see a benefit in their professional life in creating this type of content commented that they did not see the impact on their future career plan since they intended to obtain an administrative position in a company; therefore their interest in knowing very technical details or focusing on generating content for their peers to learn was relatively low.

In the semi-structured interviews, comments of relevant importance shared by some students were:

> “I liked being involved in this activity because I had to think about how it would help me see some topics or concepts presented. That is exactly what I sought: that these contents would be useful for my classmates and allow me to better reflect on my way of learning".

> “The design of the content I got to develop was about one of the most used machines during my laboratory practices in a couple of subjects. At first, I thought it would be tedious to do this, but I was surprised how much it helped me to master the handling and the confidence I felt in the subsequent practices."

During the creation of all content, detailed observation recorded the attitudes and performance of the students involved. As part of this practice, we report, with emphasis, the evolution of their skills: At the beginning, the students felt a bit insecure and continuously asked if they were on the right track in their proposals, but after mastering a couple of contents, they began to perform with greater freedom, determination, and precision.

The results highlight the importance of the students participating in developing content, guided by the teachers, to reinforce their competencies and strengthen their communication, teamwork, and leadership skills.

Table 3 summarizes the statistical analysis of the *creation survey*, performed in SPSS software, which had a generalized Cronbach’s Alpha coefficient of 0.7778, which according to the literature, demonstrates an acceptable level of reliability and internal consistency. SPSS provides other data within the analysis, such as the scale’s mean, variance, and standard deviation, where the outliers found in item 2 are evident. In general, the individual variances are slight, meaning that most opinions recorded are biased towards indicators 4 and 5 of the scale.

Table 3 also shows the behavior of the coefficient when each item is removed. Note that if item 1 is eliminated, the overall reliability of the instrument goes from 0.7778 to 0.8889. In contrast, if items 2 or 3 are eliminated, the instrument’s reliability drops to values between 0.57 and 0.53, respectively.

The survey asked participants about their preference between the two methodologies. A total of 65 % (n = 35) preferred the AR-ManufacturingLab strategy. Additionally, they were queried about which of the two methodologies, including the traditional approach, they believed provided better learning. Only 28 % (n = 15) chose the traditional approach.

Fig. 10 summarizes the results of the Likert-scale implementation questionnaire.

The acceptance of the platform by the students is evident, given that a high proportion of the responses are distributed between levels 4 and 5, which means that the strategy works for learning purposes in the manufacturing laboratories through augmented reality. The values shown in level 5 are between 45 % and 54 %, level 4 between 36 % and 54 %, and level 3 between 9 % and 18 %, while there was no participation in levels 1 and 2.

Table 4 summarizes the statistical analysis of *the implementation survey* performed in SPSS software, generating a Cronbach’s alpha coefficient of 0.7321, demonstrating acceptable reliability and internal consistency. Within this analysis, SPSS shows the summary statistics of the scale items’ mean, variance, and standard deviation. Generally, the individual variances are small, meaning that most opinions register values between 4 and 5.

Table 4 also shows the behavior of the coefficient when each item is deleted. The “corrected item-total correlation” is the corrected homogeneity coefficient. It is advisable to remove the item if this coefficient is zero or with a negative value; therefore, none of this survey’s items should be removed. The overall reliability of the instrument will improve from 0.7321 to 0.7370 if item 3 is removed, which represents a minor change.

The statistical indicators in both tables represent good internal consistency suggesting that the items consistently measure the same construct, deeming the surveys reliable.

As for the qualitative results, it was possible to demonstrate the reasons for the Likert scale questionnaire results, triangulating the information with student comments. Some comments by the students during the semi-structured interviews stand out:

> “I really liked the virtual tool because I can reinforce what I have learned at any time without needing the teacher to be there."

> “It is a handy and striking tool. I can know more details of the machinery and review the information as often as I need without having to ask the teacher repeatedly."

> “I found it a valuable tool that I would use a lot, but after having had the hands-on session with the teacher, it would be good to review what we had already learned in class."

The researchers observed usability and students’ appreciation in detail during the implementation. As part of this practice, we report the ease with which students learned to use the tool and the familiarity with which they navigated through the different machines and content available after a few minutes of practice.

The students found value in having this type of instrument to reinforce their learning, but they also emphasized the need to carry out the initial practice with the teacher, as part of a complete experience in reinforcing their disciplinary competencies.

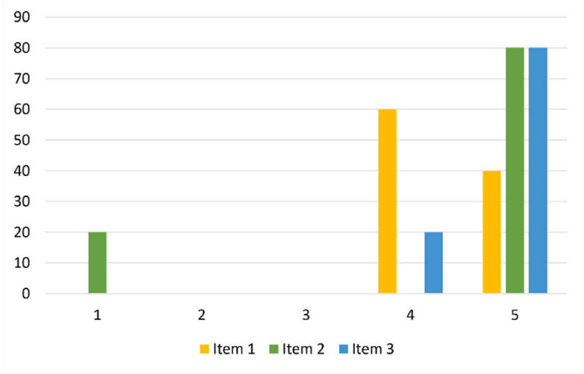

Fig. 9. Creation questionnaire results.

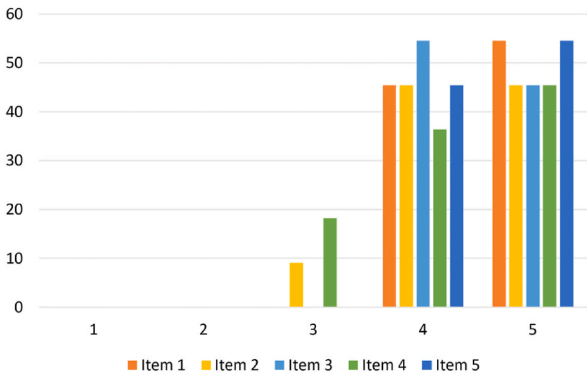

Fig. 10. Implementation questionnaire results.

Table 3
Item-Analysis from SPSS Output for the creation questionnaire.

	N	Mean	Variance	SD		
Scale Statistics	3	13.80	2.40	1.549		
	Mean	Minimum	Maximum	Range	Max/ Min	Variance
Item Means	4.6000	4.4000	4.8000	0.4000	1.0909	0.0400
Item Variances	0.3852	0.1778	0.7111	0.5333	4.0000	0.0816
Inter-Item Covariances	0.2074	0.0889	0.3556	0.2667	4.0000	0.0147
Inter-Item Correlations	0.6055	0.4082	1.0000	0.5918	2.4495	0.0934
Item Total Statistics	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted		
Item 1	9.4000	1.6000	0.4082	0.8889		
Item 2	9.2000	0.6222	0.8018	0.5714		
Item 3	9.0000	1.3333	0.9129	0.5333		
	Cronbach's Alpha	Standardized Item Alpha				
Reliability Statistics	0.7778	0.8216				

5. Discussion and conclusions

The students' questionnaire results show the relationship between the tool's ease of use and student motivation and flexibility. Understanding each of the elements comprising the machines in the laboratories brings them closer to the understanding and practice of these to carry out the exercises that go hand in hand with their learning process and the development of their disciplinary competencies.

Table 4
Item Analysis from SPSS Output for the implementation questionnaire.

	N	Mean	Variance	SD		
Scale Statistics	5	22.182	4.226	2.056		
	Mean	Minimum	Maximum	Range	Max/Min	Variance
Item Means.	4.4364	4.2727	4.5455	0.2727	1.0638	0.0140
Item Variances.	0.3502	0.2525	0.5724	0.3199	2.2667	0.0207
Inter-Item Covariances.	0.1237	0.0253	0.2694	0.2441	10.6667	0.0055
Inter-Item Correlations.	0.3529	0.1000	0.5756	0.4756	5.7565	0.0267
Item Total Statistics	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted	
Item 1	17.6364	3.1987	0.4308	0.3224	0.7088	
Item 2	17.8182	2.5589	0.6002	0.5600	0.6404	
Item 3	17.7273	3.3502	0.3386	0.3946	0.7370	
Item 4	17.9091	2.3064	0.5861	0.5812	0.6521	
Item 5	17.6364	3.0135	0.5500	0.5590	0.6704	
	Cronbach's Alpha	Standardized Item Alpha				
Reliability Statistics	0.7321	0.7317				

This applied approach also aligns with the integral education of the TEC21 Educational Model of Tecnologico de Monterrey, which seeks that the student immerse in cutting-edge technology to deal with real-world problems to have competitive advantages in his professional life.

At the end of the implementation, the surveys, the semi-structured interviews, and the observations revealed the students' acceptance of the strategy. In the additional comments, it was noted that replacing the traditional strategy is not practical, as both approaches complement each other. The students suggested that the teacher should introduce the tool and provide regular updates for the benefit of anyone who may forget the procedures. They made it clear that interactions with the instructor are not easily replaceable by technology.

Based on the results and the students' perception of motivation and the effectiveness of this tool, we created the mobile application to make it more accessible to all students, allowing them to perform the six lessons using their cell phones at the learning times that best suited them.

6. Implications and limitations

This study significantly impacts the academic community, sharing results and information of interest in investigating key elements in the successful application of technology in education, inviting researchers to find catalytic components of the different technological and didactic materials that currently exist. It has value for the academic sector because it provides teachers, instructors, and students with the opportunity to implement a teaching strategy that is flexible, accessible, and effective in developing disciplinary and transversal competencies. For the industrial sector, it provides the opportunity to adapt this type of tool as part of its training plan for its collaborators in different professional areas.

The relevance of self-management of learning is increasingly evident since the student needs techniques with which he can learn at his own pace, having the disposition that allows him to repeat the information that an instructor would regularly provide as many times as required. The student is motivated by these advantages of flexibility in their professional development and the immersion experience in the real world that technologies such as augmented reality can offer.

We identify two study limitations. The first pertains to the sample size, which consisted of only 50 students with specific profiles, thus potentially impacting the generalizability of the tool's success. The second limitation relates to interpreting the qualitative data, as the authors arrived at it based on their primary areas of interest and relevance to the proposed study.

Data availability statement

The authors confirm that the data supporting the study's findings can be found within the article and its supplementary material. The corresponding author can provide the raw data that supports the findings upon reasonable request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e22072.

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