Methodological Proposal for Use of Virtual Reality VR and Augmented Reality AR in the Formation of Professional Skills in Industrial Maintenance and Industrial Safety

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Abstract. Training in industrial safety and maintenance is an important subject in the curriculum of technicians, technologists and engineers, in order to guarantee competences on the protection of people, goods and equipment in different industrial processes. In particular, industrial and manufacturing engineers and occupational hazards professionals must strengthen skills and abilities to assess risks, find fault, detect dangerous situations and generate mitigation and intervention plans [1]. For this, the subject of experimentation in real situations or very close to the real ones is made relevant, this favors the best understanding of the studied phenomenon and the lifting of mitigation plans more in line with the reality. However, the approach to special situations to an untested student could generate real risks and difficulties in the accompaniment. Due to this, the possibility of taking the student to these environments like Virtual Reality VR and Augmented Reality AR are explored that place the student in situations or environments that reproduce reality and with more information, reducing to the maximum the proximity with the source of risk and accompanying him for his correct evaluation of the performance.

Keywords: Virtual reality · Extended reality · Hybrid laboratories in engineering

1 Introduction

Different authors have developed applications that favor the understanding of good practice in engineering based of augmented reality and virtual reality [1]. The main areas in the engineering service in with VR and AR are oriented to the area of industrial plants and aerospace and the main engineering services intervened are in their order; maintenance, training and machine inspection [1].

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These two methods; Virtual Reality VR and Augmented Reality AR share modes of operation and similar principles of development, however the basic principle of Virtual Reality takes the essential characteristics of real elements and through computer applications are virtualized in environments of low interaction [2]. The virtual elements replace the physical reality [3] and the environments are pre-designed, based on it the mechanisms of evaluation these applications are concentrated in the degree of approach with reality, its coherence with the physical environment (laws and behaviors) and interaction with the user [4].

While the AR proposal seeks to take advantage of the real environment and on this tool, generates points of interaction with the user [5], increasing the connection of the senses with the recreated phenomenon, especially the perception of location and movement.

The degree of attachment of person is greater and their perception of reality is higher than VR. The main characteristics in which these technologies are evaluated are focused on: Reliability, Sensitivity and Agility [6]. However, a variety of techniques are known that make a continuous development between virtual reality and real reality.

Although many AR and VR combinations are shown there are several clearly defined combinations. In Fig. 1, it is shown how the development of these tools is a continuous development from virtual reality to the total real.

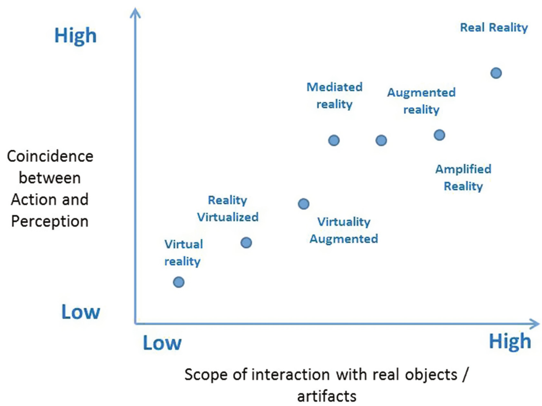


Fig. 1. Classification of reality concepts according to correlation between perception and action and level of interaction [7].

2 VR and AR Tools in Engineering

In order to VR and AR tools to fulfill the purposes for which they have been designed, it is necessary to follow a methodology of development and implementation within the context of the use of engineering laboratories, which starts from the training objectives until the evaluation in their different aspects.

To this end, an integrated methodology has been proposed for the elaboration of laboratories in different modalities; Face-to-face, remote and virtual (local and virtual in the cloud).

This methodology called SMART (by its acronym in Spanish Modular Temporal Rapid Access System), is composed of phases that incorporate documents and information in order to make a robust and coherent proposal. The final objective teaching besides generating the object of learning of VR or AR in laboratories is to incorporate the proposal generated in a broader and scalable environment, until reaching to a confederation of laboratories, teaching (Fig. 2).

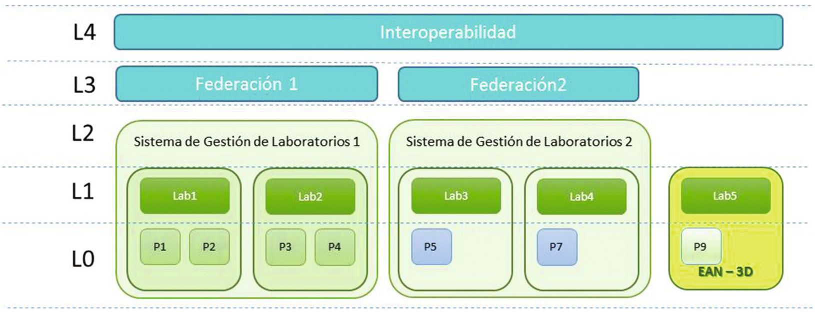


Fig. 2. Structure of a confederate labor scheme.

That is why the structure of practice in laboratories must allow interoperability, management and scalability, keeping the laboratory standards to share resources and activities. To demonstrate the use of SMART has been proposed the development of a Learning Object using Virtual Reality and Augmented Reality.

What is explained below is the development of the Virtual Activity as an experimental laboratory. The four main phases that make up SMART applied to the case of the Maintenance and Industrial Safety course of the EAN University in Colombia are:

2.1 Requirements

In this phase the requirements of curricular design with the training strategies are incorporated in order to develop the professional competences that evidence the degree of development of superior order in the formation of students in engineering.

Some of the best known standards are ABET [8], Bologna, ISCED [9], World Bank and OECD [10]. One of the most important aspects is to take advantage of the structure of the standard.

2.2 Architecture

The next phase corresponds to the design of the learning object, that is getting characteristics of the student, equipment and systems available and normative standards. For example, for Dini [1], the three main methods of aiding the generation of augmented reality experiences are optical combination, video mixing and image projection.

2.3 Construction

This phase includes two components: the preparation to put into use the first prototype. Here we determine the definition of the general laboratory structures implemented by the institution, the elements for its implementation with students and the definition of mechanisms of control and evaluation mechanisms of students.

2.4 Evolution

As a final phase, the development of the VR and AR learning experience should be evaluated. This verification is done in three aspects: Evaluation of the implementation, Evaluation of the competences reached by students and the Evaluation of the Learning students have gotten. The evaluation of the implementation is done with methods that evaluate the student's perception: Technology Acceptance Model (TAM) and ARI [11].

The evaluation of competencies is carried out using learning process evaluation tools oriented by a certification organization in the ABET study and learning with Conceiving — Designing — Implementing — Operating (CDIO) MR [12] and OTSM-TRIZ [13] and Learning Analytics [14, 15].

The methodology SMART (*Sistema Modular de Acceso Rápido Temporal* for abbreviators in Spanish), used to integrate all the phases before mentioned, is presented in the next Fig. 3.

The methodology is valid for any type of engineering competence generation experience. The way to integrate the features in each step is done through the QFD (Quality Function Deployment) tools.

3 Proposal for Industrial Maintenance Using VR and VA

Traditionally, the maintenance and industrial safety course of the EAN University (Colombia) for manufacturing engineers has been worked through scenarios and hypothetical situations, trying to represent reality through assumptions.

Particularly in the case of maintenance subject it, has been made practices of element description, but in its application it is not always possible to relate and integrate in a single experience; Machine characteristics, maintenance characteristics, equipment status and performance against the equipment.

For this experience, the student develops activities with the help of the professor and laboratory professional in short and always assisted moments, almost always generating superficial results with fragments of information, highly directed work and lack of additional information.

Similarly, in the case of occupational hazards, the experience cannot be brought into the context of a real decision-making situation with multiple sources of information to a student without a serious risk of accident or Low understanding of the phenomenon by being concentrated in the risky situation.

Based on this, the questions that this article seeks to answer are: how can the use of augmented and virtual reality technological and computer tools facilitate training in the

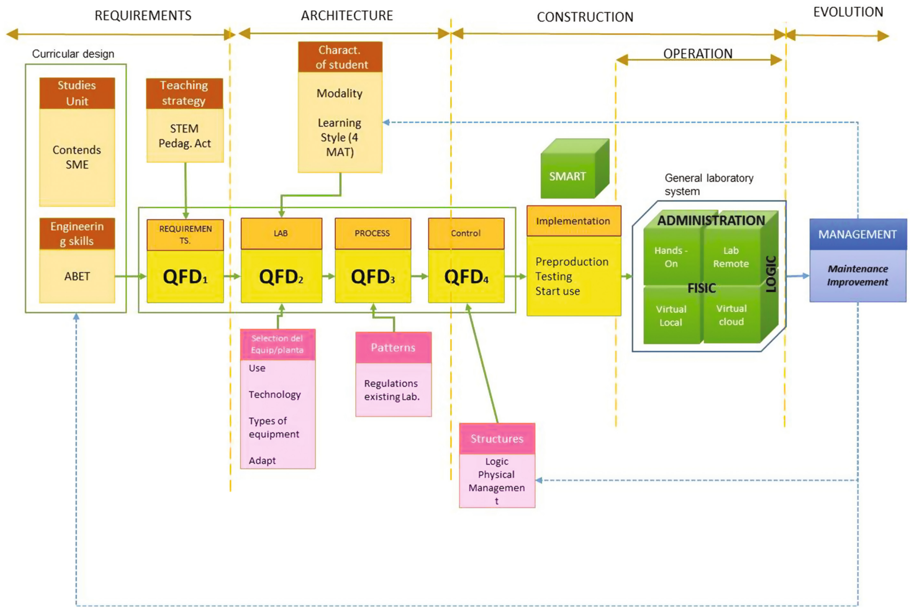


Fig. 3. SMART hybrid lab development model

field of maintenance and safety at work? And how to implement a methodological proposal from the context of training and the generation of skills in this type of applications?

The proposed is applied in the environment of the laboratory of Physics Processes course in EAN University to different groups of engineers, in different contexts where they have reproduced the different types of labor risks, information machines, equipment, and related documentation.

For the design of the Virtual Reality experience, the SMART methodology was applied. Identifying each of the four steps.

In the Requirements Phase, the Occupational Risk Factors (Physical, Chemical, Biological, Physical Ergonomics, Physical and Social Environmental Insecurity and Environmental Sanitation) [17] were consulted. Technical Standard Colombia NTC-1461 Hygiene and safety. Colors and signs of Security. This material was also shared with the students of the Unit of Studies.

For the next phase was implemented a logical laboratory and face-to-face physical architecture using virtual reality glasses and a 5-inch screen Smartphone.

The student is the main actor, for which he must have prepared his participation in the laboratory with time, reviewing the material and the subjects to be evaluated. The virtual reality learning environment was prepared by taking 4 spherical photos of areas of the laboratory with different actual risk situations intentionally placed (Fig. 4).

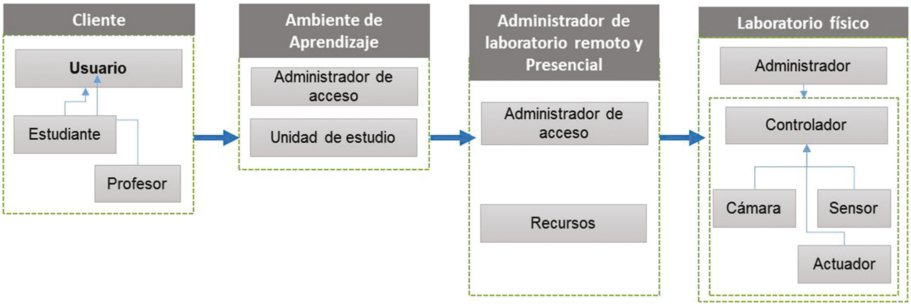


Fig. 4. Logical design of the laboratory proposal

The competences that were to be evaluated from the ABET standard were:

- An ability to perform standard tests and measurements, and to conduct, analyze and interpret experiments.
- Ability to apply written, oral and graphic communication in technical and non-technical environments; And the ability to identify and use appropriate technical literature.
- Ability to identify, analyze and solve engineering technology problems.

The physical structure is comprised of a Smartphone (with spherical image viewing applications, file editing and selection and WiFi connection), virtual reality vision glasses, control computer with Internet access and a closed space (Fig. 5).

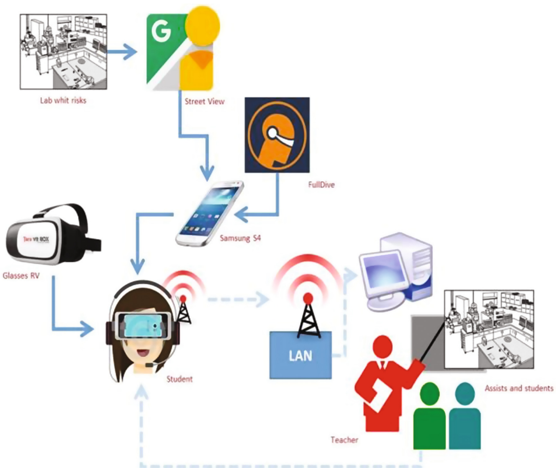


Fig. 5. Physical scheme of the proposal of virtual reality

The physical structure provides the elements of communication, control and interaction on which the student is concentrated and on which the professor evaluates the competencies proposed for students with the help of other students.

For the construction phase of the experiment, four photos were taken of the three most important risk factors that were evidenced in different spaces of the laboratory. An example of this is shown in the following photo (Fig. 6).

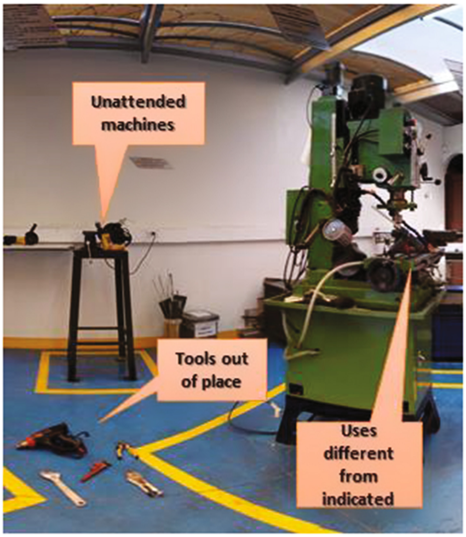


Fig. 6. Risk-generating elements in the machining laboratory of EAN university

After that, the photos are loaded into the memory of the Smartphone that is edited with the Virtual Reality App.

The constriction or development of the experience is done in the laboratory space. Students visualize the spherical photo pre-designed with the risks and based on their knowledge, first identifies the risks presented, then analyzes the degree of severity of the same and finally proposes the best way to mitigate or avoid it. The identification can be assisted by the professor or by other students.

Finally, the professor, with the help of the evidence gathered in the experience, evaluates the three aspects of the student and his experience: Evaluation of the implementation, Evaluation of the competences reached and the Evaluation of the Learning. The evaluation of the implementation is carried out by means of a survey made to the students after the reality virtual and augmented of the experience; this one is based on the perception of the technology, through the proposal Technology Acceptance Model (TAM) on perception of the technological acquisition.

The evaluation of the competences and abilities is based on the proposal of certification of ABET and the elements delivered by the student, among them.

- Risk overview
- Risk Matrix
- Audit and risk control report

Assessment of Learning is done by the professor through the CDIO (Conceive - Design - Implement - Operate) proposal and as the student progresses through each of the steps. In the step of conceiving the student must recognize the relation of the theory and the context of the photo given for the experience. In designing the student creates a risk profile on the findings in each photo and evaluates them.

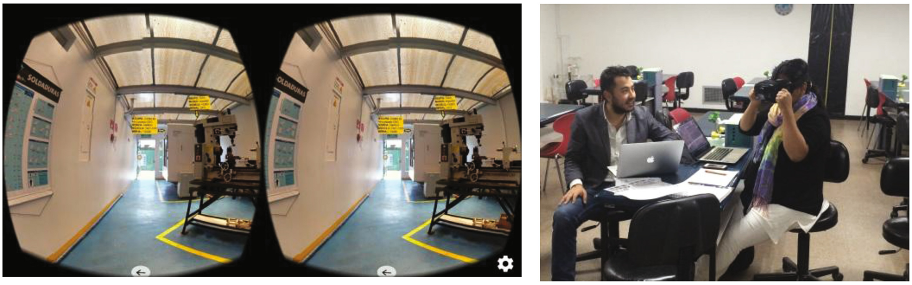
For the step of implementing the student must describe the actions to be implemented and attach the basic information to be incorporated, such as risk identification and mitigation.

And finally the step of operating relates to the handling of written information that should be given to the plans for a possible implementation in order to improve the process and decrease accidents at work.

4 Application of the Proposal (Case Study)

The methodology takes as a principle the proposal of [18] and the SMART proposal, on the application of augmented reality in operating environments and the training process in manufacturing engineers in the context of engineering design [19, 20].

Based on this integration proposal, a virtual reality activities was designed; First real spherical photos of risk situations were taken in the laboratory and presented to students through virtual reality helmets. See Fig. 1(b). Students with the support of prior information and teacher instructions, and real-time laboratory professional could interpret the situations presented to them. To See Fig. 7(a).



a) b)

Fig. 7. Photos of the experience (a) spherical photo identification of equipment (b) Students developing the industrial safety activity with AR glasses

4.1 Results

The data focus on the perception of the implementation and use of the technology of the professional versus the use of the activities implemented. To this end, the survey tool was applied which probes the characteristics of Perceived Utility and ease of use. The instrument takes into account the TAM (Technology Acceptance Model) method described by [21, 22].

Through this tool the perception of the usefulness of the technological implementation designed and the ease of use is investigated. The survey was applied after the experience. Facing the perception that the students have evaluated five questions, each on a Likert scale of 1 to 10 where 10 is the most accepted degree. The results of the students are shown in graphs 8 and 9.

Based on this it is observed that the highest values are obtained in the question: Q3 The tools used (equipment and 3D material and software) are clear. This corroborates that the strategy of using photos 360 of the laboratory or the place where the practice is performed the student achieves a good perception of reality.

Meanwhile, the lowest score in this respect is found in the question; Q0 - Your level of knowledge of practice laboratories is (at the end), this got a 8.4/10. One of the main reasons for this value is the limited time between the delivery of the support material and the practice. The other aspects are enclosed in high ratings.

Perceived utility has generally high values. The most valued answer was: Q4. The overall evaluation of laboratory integration is positive, confirming the acceptability of these novel proposals (Fig. 8).

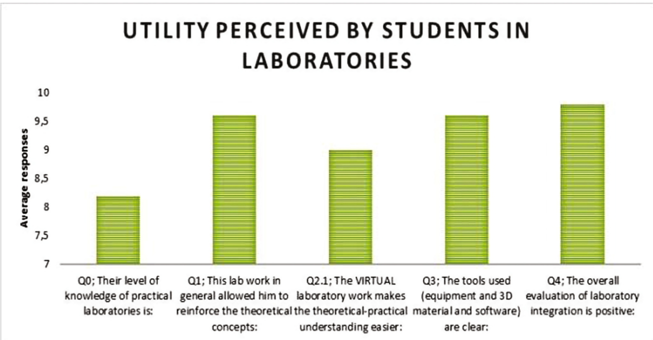


Fig. 8. Values of perceived utility of laboratory experiments

And the one of lower qualification is the one that involves the participation and intervention of the teacher. This is especially evident in the component that evaluates the perception of use. The main reason for this appreciation is the orientation given to the activity by the teacher on the tools that are used (Fig. 9).

The questions were formulated against the characteristics of the MAT model; these are:

- Knowledge:

Knowledge Achieved when implementing the tool and when used by the student, in conjunction with the application that the student can give without needing assistance from the teacher. The related questions are Q0 and Q6.

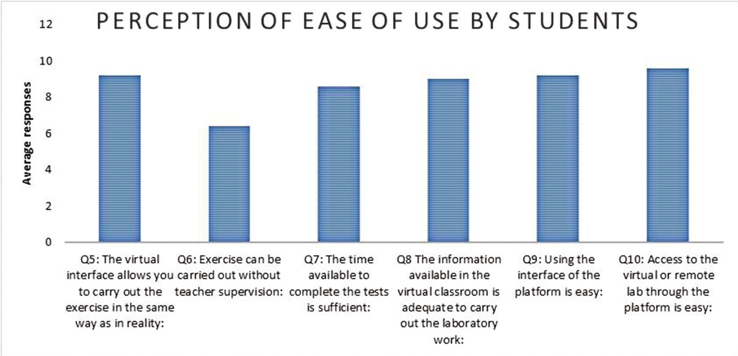


Fig. 9. Values of perception of use of laboratories

- Use

Characteristic observed in the perception that this tool can have the training by the student. And in the ease of using the tool with the basic knowledge gained. The related questions are Q1, Q9 and Q10.

- Coherence

Characteristic that looks for the strong relation between the reality and the situations that normally could be faced an Engineer. The related questions are Q2.1 and Q5.

- Clarity

Both in the instructions and in the use that is given to the implementation of the experience. The related questions are Q3 and Q8.

- Degree of acceptance

It measures the degree of conformity to what the student expects and what ultimately results from his/her experience. The related questions are Q4 and Q7.

In the following graph it is observed how the characteristics that keep an equal or similar valuation is the Usage and the coherence and the characteristic that has a greater difference between the Perceived Utility and the ease of use is the degree and knowledge that can be reached (Fig. 10).

4.2 Effectiveness in Developing Competition

For the evaluation of the effectiveness of the learning experience, it was proposed to follow the ABET competency assessment methodology [8], with the help of performance indicators and a qualification rubric. Evidence by students delivered by the students was composed of three documents, which were given a level of performance and a grade for each performance (Table 1).

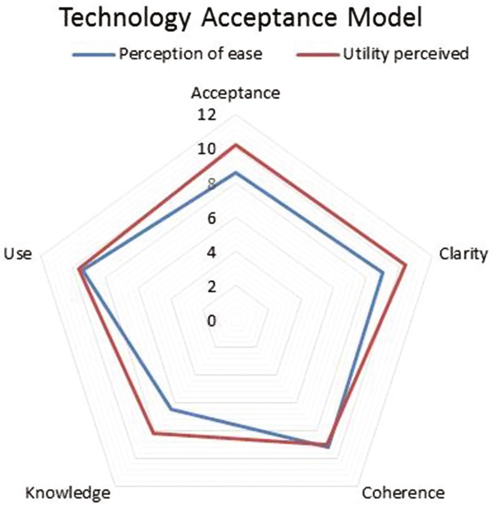


Fig. 10. Value of the characteristics of each of the factors of the TAM methodology

Table 1. Competencies evaluated in the laboratory

	Competencies ABET evaluate		
ABET competencies evaluated vs documents delivered	Ability to perform standard tests and measurements, and to conduct, analyzes and interpret experiments	Ability to apply written, oral and graphic communication in technical and non-technical environments; And the ability to identify and use appropriate technical literature	Ability to identify, analyze and solve engineering technology problems
• Risk overview	**a**		
• Risk Matrix		**c**	**e**
• Audit and risk control report	**b**	**d**	**f**

With the help of this matrix and the level of the indicator of the degree of development of the competences evaluated, a tool of evaluation of the competition was proposed based on the application of the experience of virtual reality.

The main elements of the rubric and the average grade of the group evaluated are presented in the following Table 2.

Table 2. Rubric of evaluation of the experience in the laboratory

Aspect to evaluate		Proposed Indicator		
		Low 0–60	Medium 61–90	High 90–100
Risk overview	**a**	Identifies some risks in the environments shown	Identifies all proposed risks	Identifies new risks additional to those proposed
				95.00
Risk Matrix	**e**	Values the risks found giving value to the probability and severity	It prioritizes the risks encountered and establishes an order of importance	Establish global mitigation strategies
			85.00	
	c	Identifies the failure of some of the signaling elements	It establishes the relationship between risk elements and their management	Proposes appropriate signaling for risks
				95.00
Audit and risk control report	**b**	Identifies the elements of the risk management system	Analyzes the elements of the audit and establishes characteristics of each system	Proposes integration of management plans
			80.00	
	d	State the most important elements in the audit report	Produces an orderly and complex report of proposed risk analysis	Establish a guiding document to manage all risks encountered
			70.00	
	f	Identifies the engineering elements required by the mitigation plan	Identifies the engineering elements required by the mitigation plan	Proposes the implications on the implementation of the mitigation plan
			80.00	

5 Discussion and Conclusions

With the help of exercise and VR and augmented virtual activities AR will establish practices consistent with the skills and competencies required by the course, including identification of tacit and active risks, risk rating and action plan. More tests are currently being made with environments developed with different groups. The expected results are:

• To corroborate the effectiveness of the use of these augmented reality AR and virtual VR tools in industrial safety practices. To reduce the risk to the student of dangers increasing the degree of depth in the situations. Involve the outcome of this project in a larger project or the one of hybrid laboratories for laboratories federations.

• Determine the important characteristics for the development of methodologies for the creation of hybrid laboratories. Provide more open and free information in order to generate critical thinking to the student versus the unit. Develop interconnected environments between students on the subject of safety and industrial maintenance, directed with the support of the teacher.

The use of elements that provide the experiences of the virtual reality contributes to the development of competences. The evaluation focuses on these elements and is evident in the evaluation rubric.

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