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Design and Development of a I4.0 Engineering Education Laboratory with Virtual and Digital Technologies Based on ISO/IEC TR 23842-1 Standard Guidelines

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Abstract: Knowledge transfer associated with education in the automotive manufacturing and production fields is challenging due to the requirements of physical prototyping of mechanical components and laboratory-assisted testing. In this regard, aspects of Industry 4.0 such as virtual environments and enhanced human–computer interaction have been studied as important resources to improve teaching practices and achieve the equivalent Education 4.0 paradigm. Within the context of modern manufacturing techniques in the Industry 4.0 era and advanced tools for analysis and mechanical design, the present work describes the development of a virtual/augmented reality (VR/AR) laboratory to support learning, training, and collaborative ventures related to additive manufacturing for the automotive industry. The development was performed in accordance with the guidelines of the ISO/IEC TR 23842-1 standard, to ensure that the academic programs and the conditions of use of the laboratory were optimal. Experiences with students through the development of industry-related automotive projects support confidence in the suitability of the laboratory and the expectation of positive outcomes for future developments.

Keywords: virtual reality laboratory; automotive industry; Education 4.0

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1. Introduction

Automotive manufacturing is a major driver of Industry 4.0 (I4.0) technologies and of economic wealth in industrialized countries. Although the main sources of professionals for this industry are still universities and research institutes, teaching and training have not kept pace with the advances in technology [1]. This is an important disadvantage, as engineering and manufacturing learning and knowledge transfer require innovative practices and technologies to support current I4.0 ventures.

The COVID-19 pandemic made this disadvantage evident, as many universities lacked the technological infrastructure and educational practices to overcome the unprecedented measures to reduce contagion risks (i.e., human isolation and safe-distance interaction). This further complicated the traditional knowledge transfer processes in the automotive manufacturing and production fields, which require physical prototyping of mechanical components and laboratory-assisted testing.

In this regard, aspects of Industry 4.0 such as virtual environments and enhanced human–computer interaction could have been important resources to improve teaching practices and achieve the equivalent Education 4.0 (E4.0) paradigm. Although Industry 4.0 aspects have been deployed within the automotive industry, educational institutions are striving hard to adapt to this latest industry trend [2]. Specific courses and majors such as those in medical, technical, and engineering subjects cannot be addressed through standard e-learning tools [3]. In this case, I4.0 technologies of augmented and virtual reality (VR/AR) can provide the required in situ user experience for practical learning.

Hence, updated teaching processes and infrastructure are needed in universities to move the professional student (physically and/or virtually) closer to industrial practice, generate new knowledge, and close the gap between resource-based manufacturing (labor and capital) and knowledge-based manufacturing (information and knowledge) [1].

Since such a venture requires formal guidelines, the present work contributes with the design and development details of an I4.0 laboratory with virtual and digital technologies aimed at supporting teaching and the practices of students and professors in automotive and manufacturing programs at Universidad Popular Autonoma del Estado de Puebla, Mexico. The laboratory was developed in compliance with the ISO/IEC TR 23842-1 guidelines to support the intended E4.0 features and usability/safety protocols.

Because ISO/IEC TR 23842-1 is a recent standard, only a few studies reported in the scientific literature have used it in their VR/AR projects. Thus, the present work also contributes in this context, extending the standard to I4.0/E4.0 automotive manufacturing ventures.

As evidence of the positive outcomes of this laboratory and of its founding guidelines, we discuss some projects that were developed within the automotive field during and after the critical periods of the COVID-19 pandemic (when the traditional teaching strategies were most affected). Student experience assessment tests corroborated the suitability of the laboratory, which remains an important university asset for current and future I4.0 projects.

The present work is structured as follows. In Section 2, the key I4.0 features for automotive manufacturing education are reviewed. Then, in Section 3, the development details of the I4.0 laboratory are presented. In Section 4, a set of I4.0/E4.0 projects developed within the automotive industry are presented, together with the results of a learning-experience test. Finally, our conclusions are presented in Section 5.

2. Review and Analysis of Industry 4.0 Aspects

2.1. Automotive Industry

Automotive manufacturing and production are already undergoing two major changes: (1) defining their perspective on I4.0 and (2) vehicle design automation/simulation. Although these changes can be satisfied by increasing the technological resources within the factory, their scope involves a new approach regarding ways of thinking about technology and its role within the production environment [4]. The essential components of this new industrial scenario are machines working with humans, where both work collaboratively to meet the specific needs of the society or the client. This interaction is important to achieve the fusion between virtual and real production systems (cyber-physical systems), and therefore the product is designed and tested virtually in order to foresee possible errors before the final product is manufactured [5].

Through digitization and automation of the production processes within the factory, I4.0 can integrate different technologies in a cyber-physical network to reduce costs and improve market response and resilience. This implies a redefinition of the production processes without overlooking the requirements of cost reduction and early market deployment as new competitors emerge.

The four main characteristics of I4.0 that must be considered in designing and developing such factories are: (1) vertical networking of production systems, (2) horizontal integration of global value-chain networks, (3) end-to-end engineering of overall value chains, and (4) the use of high-impact disruptive technologies.

Disruptive technologies encompass artificial intelligence (AI), augmented reality (AR), and 3D printing, and they include a significant use of smart systems such as collaborative and specialty robotics, advanced sensors and microsensors, and automation components for microprocessors and microcontrollers. The use of these technologies has already led to advancements in major areas such as the Internet of Things (IoT) and cyber-physical systems (CPS), big data (BD), and communications infrastructures [6].

Virtualization technology involves the creation of a "digital twin", based on creating virtual models of real systems and digitizing physical objects to simulate their behavior [7]. These virtual models are capable of understanding the state of physical entities through data detection, to predict, estimate, and analyze dynamic changes, where physical objects respond to changes according to an optimized simulation scheme [8]. Finally, virtual reality and augmented reality (VR/AR) enable human–machine interaction systems that fulfill three basic features: a combination of real and virtual worlds, real-time interaction via online platforms, and accurate 3D registration of virtual and real objects. In VR/AR, the virtual–digital model is capable of being controlled in the same way that the physical model would be, and in addition, the latter must respond to the changes made in the virtual model. In particular, VR/AR is an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities including visual, auditory, haptic, somatosensory, and olfactory [9].

2.2. Digital Technologies for Education

Although the recent COVID-19 pandemic has led to a revolution in teaching methods, the requirements of I4.0 involve the restructuring of university engineering curricula to create new elements in teaching–learning processes. As a consequence, the new curricula should ensure the effective transmission of new-generation engineering knowledge to students. In recent years, rapid developments in communication technologies and computer systems have given rise to innovative multimedia formats suitable for distance education. In addition, the development of radio-to-audio/video broadcasting, teleconferencing, computer-assisted instructions, e-learning/online learning, podcasting, and VR/AR has led to these elements becoming attractive for the generation of new teaching strategies.

In engineering, the concept of digital product development is essential, in order to increase the technical skills of students. The use of emergent digital technologies for engineering education aligned to meet the requirements of I4.0 improves the possibilities for successful insertion of former students into the industrial sector. Thus, in most engineering bachelor curricula, the first year covers foundational principles and engineering mathematics. The second year covers operations, including considerations of materials and safety protocols. The third year covers topics such as product development, process design, and engineering applications, with further consideration of control, the environment, and safety. Finally, advanced topics that expand specific industrial applications are covered during the fourth year [10].

In this regard, digital technologies play an important role in the learning process, not only facilitating the assimilation techniques for various theories and elements of the respective engineering areas but also the assimilation of knowledge about new techniques for specific industries such as the automotive, aerospace, and aeronautic industries, among others. The engineering students should be profiled according to the development of their science, technology, engineering, and mathematics (STEM) talents, as well as their scientific–technological vocations. In addition, collaboration between educational institutions and companies must be aimed at improving innovation and creativity competencies, providing engineering students with a professional future with better employability prospects [5].

Some of these talents can be pursued in the areas of computer-aided design, manufacturing and engineering (CAD/CAM/CAE), and digital manufacturing, as well as in different fields of specialization such as simulation of processes and physical phenomena. In addition, 3D drawing training is useful, especially when analyzing situations beyond design such as simulating flow and making/testing product prototypes, as it offers more precision and control. Furthermore, 3D CAD drawing skills are useful to former students employed in consultancy and engineering design areas [10].

Chong et al. [10] reported statistics on the students' knowledge regarding the I4.0-related areas where manufacturing, production, and digital development are most frequently identified. Specifically, 75% and 86% of the students and lecturers, respectively, had heard of I4.0, and 63% of the students were enrolled in class modules with 3D printing/I4.0 elements. These modules are mainly related to materials properties, design, and manufacturing, e.g., design projects, applied mechatronics projects, building information modeling, applied electrical and electronic engineering, and robotics. In addition, both students and lecturers found that 3D printing/I4.0 helped to improve students' lifelong learning skills, creating an innovative and forward-thinking mindset. Hernandez-Muñoz et al. [5], established nine technological pillars to be included in the curriculum within higher engineering education linked to I4.0: IoT, cloud computing, autonomous robots/AI, simulation, VR/AR, additive manufacturing, BD, informatics security, and integration of horizontal and vertical systems. Through a focused study based on statistical data from the Mexican Institute of Competitiveness (IMCO), it was estimated that only 7.5% of the courses on manufacturing and processes were aligned with any of these nine pillars.

Some of the highly industrial regions in Mexico, such as the state of Nuevo Leon, have developed projects favoring the positioning of local companies at the international level. Through implementation of I4.0-oriented clusters, including government, public, and private entities, several companies have been established and integrated with universities for the development of products within the manufacturing sector. Specifically, the following pillars have been considered: IoT, AI, VR/AR, and BD [6].

2.3. VR/AR Technologies for Education

To introduce engineering students properly to many relevant I4.0 elements, teaching and training in engineering should be oriented to specific topics such as simulation studies on real-time data and optimization, AI, BD, enhanced productivity education on additive manufacturing and advanced robotics, maintenance/logistics studies through augmented reality, and evaluation studies on the environment, society, and economics [10].

Within these topics, AR involves an alternative method for perception of the surrounding real world. This is achieved by using virtual elements superimposed through various technological devices such as smartphones, tablets, or virtual reality devices [11]. Moreover, VR is defined as the development of simulated experiences similar to real-life situations [12].

It is worth mentioning that the impact of both AR and VR has increased in the last decade with the advanced development of computer systems. Improved VR/AR is being used in the early stages of product development and the construction and validation of prototypes [13]. The virtual framework enables the generation of data which can be shared and continuously reviewed by work teams through cloud-based systems. VR/AR technologies are valuable tools not only in the design stages but also in the training of operators in assembly processes, allowing safe interaction with the product prior to commissioning.

However, the use of VR/AR technologies for industrial and educational activities requires important guidelines and protocols. In this regard, the ISO/IEC TR 23842-1 [14] standard was released in 2020, as a standard establishing guidelines on information technology for education and training based on the use and creation of VR content and applications. These guidelines are aimed to prevent issues associated with the use and development of VR technology and content such as [14]:

- Discomfort (i.e., dizziness, headache, nausea) caused when actual physical movement does not occur with respect to the visual stimulus generated in the virtual environment. This is also known as VR/simulator/motion sickness or "cyber-nuisance".
- Eyesight problems (i.e., visual fatigue, blurred vision, mechanical near-sightedness) due to the proximity of the VR hardware to the user's eyes.
- Photosensitivity syndrome, where seizures (epilepsy) occur due to rapid flashing light stimuli.
- Musculoskeletal disorders (i.e., pain or fatigue of the musculoskeletal system) due to performing repetitive tasks over long periods of time while using VR hardware.
- Hygiene problems (skin and/or eye infection/irritation) due to poor disinfection or cleaning of the VR hardware, which is used by many people.

- Accidents (i.e., collisions, falling) caused by the limitation of the user's field of view when using VR devices. These accidents may also occur when the user confuses reality with the virtual world (e.g., when users try to sit or lean against a virtual-world chair or wall that does not exist in real life).

Due to the recent release of the ISO standard, few VR/AR-based applications aligned with ISO/IEC TR 23842-1 guidelines have been reported to date. Plotnikova et al. [15] reported a VR application for development of the vestibular system taking into account the ISO standard. Barreto-Junior et al. [16] remark on the use of VR to provide a high level of fidelity and immersion for representing information in their integration strategy of CAD floor plans and VR for electric power substation supervision. Yoon [17] developed a study on smart-glass-assisted interactive telementoring, highlighting the existence of ISO/IEC TR 23842:2020 as an international standard for VR content. Hence, the present work also contributes to the use of this standard for the development of VR/AR projects, specifically for I4.0 automotive ventures.

3. Development of the Virtual and Digital Laboratory

3.1. Planning Process

The proposed VR/AR laboratory was developed at Universidad Popular Autonoma del Estado de Puebla (UPAEP), Mexico. The laboratory is managed by the Faculty of Industrial Engineering and Automotive Design, which supports the requirements of electronics, mechatronics, and automotive and industrial engineering courses.

Different proposals were evaluated for the design of the VR/AR laboratory. In these proposals, digital technology sites and infrastructure dedicated to VR/AR learning and training, collaborating elements in I4.0, and additive manufacturing for prototyping were included. In this sense, the proposals reported in [18,19] for STEM education were considered as guidelines. In addition, the guidelines of Section 5.3 of the ISO/IEC TR 23842-1 standard were reviewed to establish the educational objectives for the management of the VR/AR experiences.

Among these proposals, the most comprehensive one was evaluated and revised to meet the available financial and infrastructure resources of the institution. Subsequently, a strategy for the flexible use of equipment and infrastructure was developed. This was important in order to define the appropriate distribution of workspaces and equipment for the development of VR/AR collaborative work and projects. It also supported the acquisition process for core equipment and the adaptation of existing resources. Figure 1 presents a review of the whole planning process.

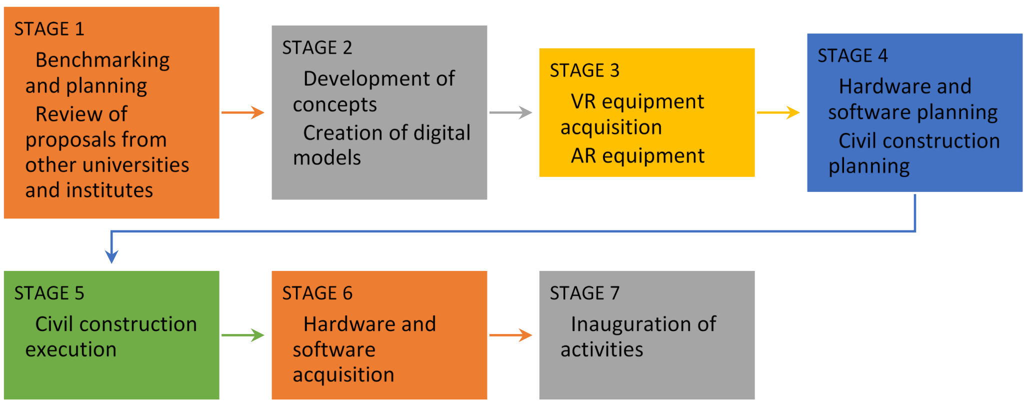

Figure 1. Planning process for the implementation of the VR/AR laboratory at UPAEP.

3.2. Space and Equipment

The VR/AR laboratory was established in two spaces:

- *A*: This space was equipped with adequate lighting, Ethernet connection points, and VR sensors. Its main purpose is to provide support for collaborative VR/AR projects, including digital design and manufacturing of automotive parts and simulation. The space is distributed in accordance with the safety guidelines of the ISO/IEC TR 23842-1 standard. Figure 2 presents the general layout of space *A*, and Table 1 presents the details of the planned VR/AR equipment.
- *B*: This space is located in a building shared with other engineering laboratories. It features an industrial KUKA robot, which was adapted for testing automotive designs. It also provides support for collaborative VR/AR projects in mechatronics and industrial engineering. Figure 3 presents the general equipment installed in this room.

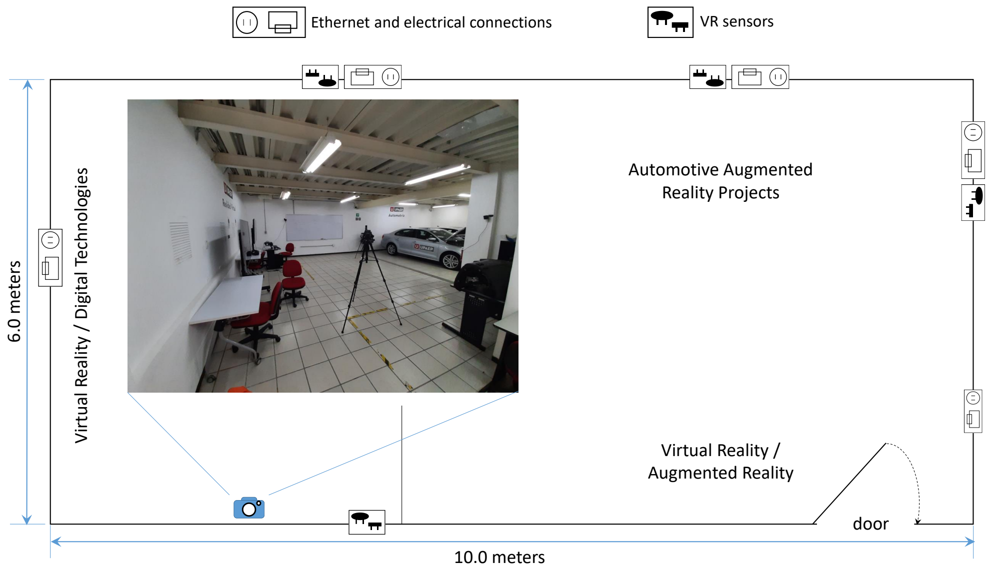

Figure 2. Distribution of work spaces, Ethernet connections, and VR sensors in the VR/AR laboratory at UPAEP: room *A*.

Table 1. Equipment and resources in the VR/AR laboratory at UPAEP: room *A*.

Equipment	Description
VR	VR Headset HTC VIVE Pro (×3)
AR	AR Headset Moverio BT-300 Developer Edition
Digital Technologies (CAD/CAM/CAE/Additive Manufacturing)	HP Z6 G4 Workstation HP ZBook 15 G5 3D Printer Markforged 3D Printer Formlabs High Resolution
Collaborative Activities and Projects	Samsung Flip 55″ Touch Screen Samsung 65 "Smart TV Ultra HD 4K (×2) Kanto MTM65PL Mobile support for TV (×2) Blackboard ALFRA 3213 Pintarron Star (×4) Neewer Portable Aluminum Alloy Camera Tripod Monopod Pepper Sacks Armchair Puff Drop Red (×6) Globa AL-1085 mobile table (×3) COSMO AL-430 VERSA chair

Figure 3. Automotive design testing in the VR/AR laboratory at UPAEP: room *B*.

The advantage of considering the ISO/IEC TR 23842-1 standard (Sections 5.2, 5.3, and 6.0) during the design process is that the laboratory consists of fully-open reconfigurable and obstacle-free spaces with safety and hygiene guidelines for VR/AR interactions. These features were valuable assets during the COVID-19 pandemic, which required social distancing protocols [20].

4. Results and Experiences on Automotive Design and Training

4.1. Automotive Projects

Since its foundation, the laboratory has provided important support for various automotive design projects, some of them undertaken as joint ventures with automotive companies. Figure 4 presents a virtual model of the interior and touch-screen features of a brand of vehicle. This immersive environment allows the virtual operation and manipulation of these features for assessment purposes.

The laboratory has also provided support for Society of Automotive Engineering (SAE) projects and competitions. One of these is *Formula SAE-UPAEP*, a competition event where teams of students and lecturers develop projects to validate dimensions, space, the positioning of vehicle components, and driver ergonomics. Figure 5 shows the digital development of the vehicle and the exhibition using virtual tools at the event.

Figure 4. Immersive environment of complete-vehicle virtual model developed at the VR/AR laboratory at UPAEP (2020–2021).

Figure 5. Digital and virtual validation of the *Formula SAE-UPAEP* project at the VR/AR laboratory at UPAEP (2019–2020).

In the *Baja SAE-UPAEP* inter-university competition, the allocation of a new car transmission was validated through the use of AR [11]. Figure 6 presents this validation.

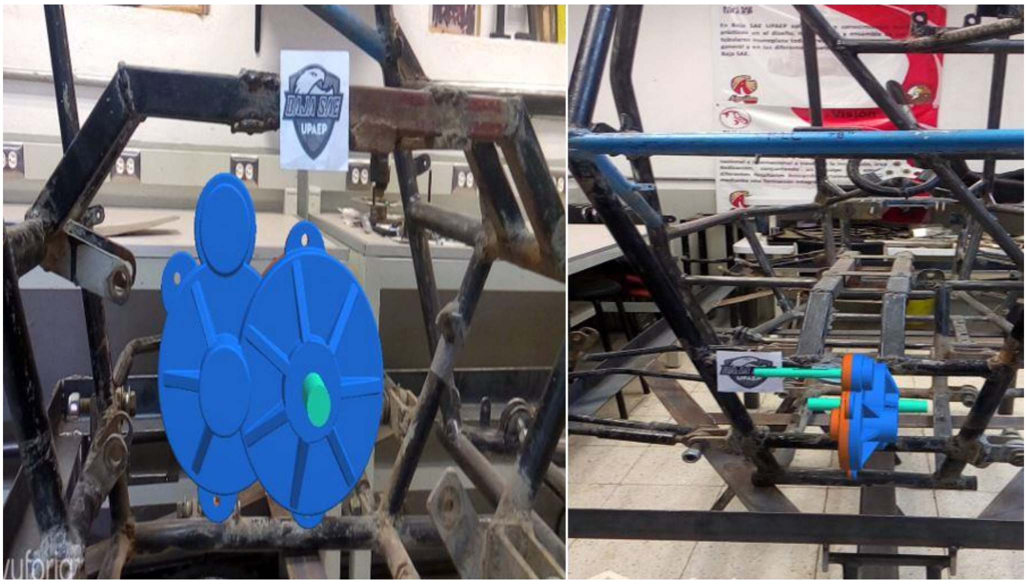

Figure 6. Transmission validation for the *Baja SAE-UPAEP* project at the VR/AR laboratory at UPAEP (2019–2020).

Other projects were aimed at virtually evaluating the performance of automotive designs. This is achieved through immersive off-road vehicle experiences in virtual environments [21]. Figure 7 shows an example of the development and execution of the immersive virtual experience in room *B*.

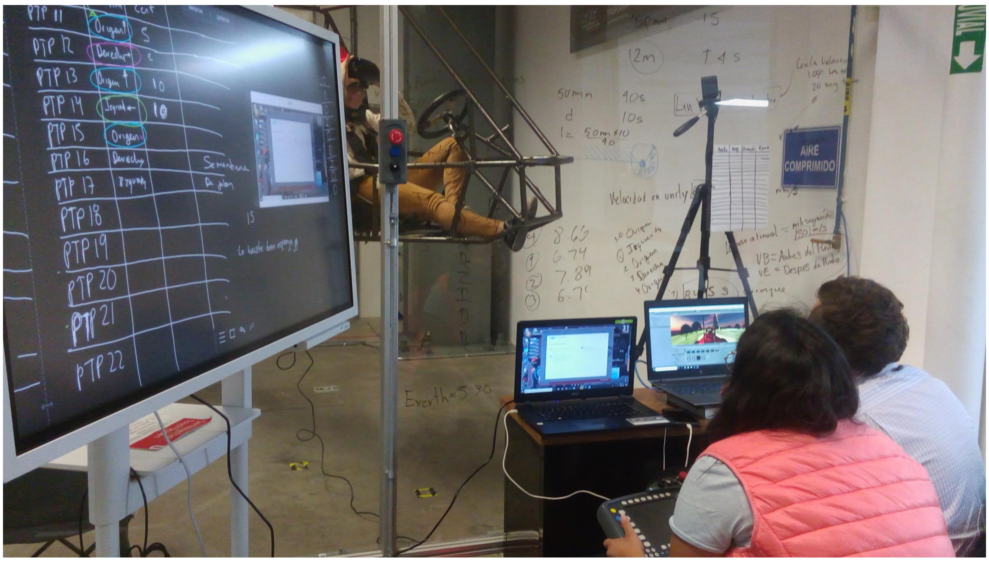

Figure 7. Immersive virtual experience in automotive projects at the VR/AR laboratory at UPAEP (2019–2021).

Because the laboratory is also aimed at supporting the dissemination and implementation of VR/AR technologies for students, these experiences have been implemented in various courses and workshops outside the engineering courses, to increase other students' interest in this field. An example of these experiences is presented In Figure 8.

Figure 8. Development of courses and training at the VR/AR laboratory at UPAEP (2020–2022).

4.2. Assessment of User Experience

The resources of the VR/AR laboratory (rooms *A* and *B*) were evaluated through the participation of 38 students during the autumn of 2021. These students were enrolled in the following programs: mechatronics (36.8%), automotive design (31.6%), bionics (13.2%), aerospace (10.5%), and industrial engineering (7.9%).

Most of these students (55.8%) were in their 4th (21.6%) or 6th (34.2%) semester. Hence, their formative courses were affected during the COVID-19 pandemic. Table 2 presents the questionnaire designed to evaluate user satisfaction regarding the laboratory resources. Most of the students "totally agree" or "agree" that the VR/AR laboratory benefited their learning experiences in engineering subjects.

Table 2. User satisfaction results for engineering students regarding the VR/AR laboratory at UPAEP.

Question	Totally Agree	Agree	Neutral	Disagree	Totally Disagree
The use of the VR/AR device was easy and the laboratory space adequate for my practice	47.4	42.1	8.0	2.5	0.0
The virtual reality models allow learning to be extended to users of CAD technologies and conventional computer laboratories	52.6	31.6	12.2	3.6	0.0
The scope of VR technologies and the VR/AR laboratory tools allow knowledge to be extended in the different areas of engineering.	60.5	23.7	13.2	2.6	0.0

Table 2. *Cont.*

Question	Totally Agree	Agree	Neutral	Disagree	Totally Disagree
VR/AR technologies facilitate learning in courses compared to technologies used in traditional laboratories.	60.5	26.3	10.5	2.1	0.6
VR content allows a more comprehensive understanding of a mechanical design in relation to the traditional CAD model, through the tools of the VR/AR laboratory.	47.4	31.6	15.8	3.6	1.6
The manipulation of the digital model in the virtual and laboratory environment extends the manipulation tools in relation to those allowed in a conventional computer laboratory.	54.1	37.8	2.8	3.1	2.2
VR models and VR/AR lab tools present better engineering development opportunities versus conventional CAD laboratories.	50.0	36.8	10.5	0.6	2.1

5. Conclusions

The conceptualization and development processes for a VR/AR laboratory were described in this work. These processes included the appropriate selection of digital, software, and VR and AR equipment, in accordance with the ISO/IEC TR 23842 standard.

This was a challenging venture due to the following difficulties:

- Lack of guidance regarding how the technologies work;
- Limited budget for financing larger facilities and technological resources;
- Scheduling and pedagogical conflicts when introducing new content and skills into the educational programs;
- Reluctance to change from the traditional pedagogical practices.

Nevertheless, experiences in the development of competitive projects supported its pertinence for automotive manufacturing ventures. The guidelines of the ISO/IEC TR 23842-1 standard also favored the operation of the laboratory during the COVID-19 pandemic.

The assessment of user satisfaction showed positive learning outcomes for the general student population on different engineering courses such as mechatronics, bionics, aerospace, and industrial engineering.

In the future, the laboratory will increase its specialization in academic projects and its participation in industrial projects. Since the ISO/IEC TR 23842-1 standard generates guidelines for educational activities and commercial activities, projects will be extended so that students can participate in industry applications. In addition, the acquisition and renewal of digital technologies, VR and AR, and the implementation of I4.0 technologies that require this type of technology will be considered. An increase is also expected in the publication and dissemination of the results of the various projects and investigations that are generated as part of the work of students and teachers.

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References

1. Chryssolouris, G.; Mavrikios, D.; Rentzos, L. The Teaching Factory: A Manufacturing Education Paradigm. *Procedia CIRP* **2016**, *57*, 44–48. [CrossRef]
2. Rekh, S.; Chandy, A. Implementation of academia 4.0 for engineering college education. *Procedia Comput. Sci.* **2020**, *172*, 673–678. [CrossRef]
3. Fauzi, M.A. E-learning in higher education institutions during COVID-19 pandemic: Current and future trends through bibliometric analysis. *Heliyon* **2022**, *8*, e09433. [CrossRef] [PubMed]
4. Engineering.com. *Whitepaper: Industry 4.0 and the Future of Engineering Education*; University of Cincinnati Online. 2020. Available online: https://www.engineering.com/ResourceMain.aspx?resid=1123&e_src=relres-ecom (accessed on 10 April 2022).
5. Hernández-Muñoz, G. M.; Habib-Mireles, L.; García-Castillo, F. A.; Montemayor-Ibarra, F. Industry 4.0 and engineering education: An analysis of nine technological pillars inclusion in higher educational curriculum. In *Best Practices in Manufacturing Processes*; Springer: Cham, Switzerland, 2019; pp. 525–543.
6. Elbestawi, M.; Centea, D.; Singh, I.; Wanyama, T. . SEPT learning factory for industry 4.0 education and applied research. *Procedia Manuf.* **2018**, *23*, 249–254. [CrossRef]
7. Tao, F.; Cheng, J.; Qi, Q.; Zhang, M.; Zhang, H.; Sui, F. Digital twin-driven product design, manufacturing and service with big data. *Int. J. Adv. Manuf. Technol.* **2018**, *94*, 3563–3576. [CrossRef]
8. Qi, Q.; Tao, F.; Zuo, Y.; Zhao, D. Digital twin service towards smart manufacturing. *Procedia CIRP* **2018**, *72*, 237–242. [CrossRef]
9. Ray, A. E-learning: The new normal in the post-covid world. *Int. Res. J. Mod. Eng. Technol. Sci.* **2020**, *2*, 866–876.
10. Chong, S.; Pan, G.T.; Chin, J.; Show, P. L.; Yang, T.C.K.; Huang, C.M. Integration of 3D printing and Industry 4.0 into engineering teaching. *Sustainability* **2018**, *10*, 3960. [CrossRef]
11. Cuautle-Gutierrez, L.; Cordero-Guridi, J.D.J. Reducción de transmisión para vehículo todo terreno con realidad aumentada e ingeniería asistida por computadora. *Rev. Politec.* **2020**, *15*, 32–40. [CrossRef]
12. Pratap-Singh, R.; Javaid, M.; Kataria, R.; Tyagi, M.; Haleem, A.; Suman, R. Significant applications of virtual reality for COVID-19 pandemic. *Diabetes Metab. Syndr. Clin. Res. Rev.* **2020**, *14*, 661–664. [CrossRef]
13. Zimmermann, P. Virtual Reality Aided Design. A survey of the use of VR in automotive industry. In *Product Engineering*; Talaba, D., Amditis, A., Eds.; Springer: Cham, Switzerland, 2008; pp. 277–296.
14. *Standard ISO/IEC TR 23842 1:2020*; Information Technology for Learning, Education and Training Human Factor Guidelines for Virtual Reality Content; Part 1: Considerations when Using VR Content; International Organization for Standardization: Geneva, Switzerland, 2020.
15. Plotnikova, D.; Volosiuk, A.; Tikhonov, G.; Tsynchenko, A.; Luneva, A.; Smolin, A. VR Application for Vestibular System Training (Pilot Study). In Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021), Online, 13–18 June 2021; Springer: Cham, Switzerland, 2022; pp. 552–558.
16. Barreto-Junior, C.D.L.; Cardoso, A.; Lamounier-Junior, E. A.; Silva, P.C.; Silva, A.C. Designing Virtual Reality Environments through an Authoring System Based on CAD Floor Plans: A Methodology and Case Study Applied to Electric Power Substations for Supervision. *Energies* **2021**, *14*, 7435. [CrossRef]
17. Yoon, H. Opportunities and Challenges of Smartglass-Assisted Interactive Telementoring. *Appl. Syst. Innov.* **2021**, *4*, 56. [CrossRef]
18. Pirker, J.; Lesjak, I.; Parger, M.; Gütl, C. An educational physics laboratory in mobile versus room scale virtual reality—A comparative study. *Int. J. Online Biomed. Eng.* **2017**, *13*, 106–120. [CrossRef]
19. Hod, Y. Future learning spaces in schools: Concepts and designs from the learning sciences. *J. Form. Des. Learn.* **2017**, *1*, 99–109. [CrossRef]
20. Pregowska, A.; Masztalerz, K.; Garlinska, M.; Osial, M. A Worldwide Journey through Distance Education—From the Post Office to Virtual, Augmented and Mixed Realities, and Education during the COVID-19 Pandemic. *Educ. Sci.* **2021**, *11*, 118. [CrossRef]
21. Cuautle-Gutierrez, L.; Cordero-Guridi, J.D.J.; Carrillo-Aguilar, J.; Lebano-Perez, E. Simulation of an All-Terrain Vehicle Driving Experience Using Virtual Reality. In *Smart Trends in Computing and Communications*; Springer: Singapore, 2022; pp. 51–60.