Industry 4.0 Competencies as the Core of Online Engineering Laboratories.

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Abstract
Online laboratories are widely used in higher engineering education and due to the COVID-19 pandemic, they have taken on an even greater relevance. At Tecnologico de Monterrey, Mexico, well-established techniques such as Problem-Based Learning (PBL), Project-Oriented Learning (POL) and Research-Based Learning (RBL) have been implemented over the years, and over the past year, have been successfully incorporated into the students' learning process within online and remote laboratories. Nevertheless, these learning techniques do not include an element which is crucial in today's industrialized world: Industry 4.0 competencies. Therefore, this work aims to describe a pedagogical approach in which the development of Industry based competencies complements the aforementioned learning techniques. The use and creation of virtual environments and products is merged with the understanding of fundamental engineering concepts. Further, a measurement of the students' perceived self-efficacy related to this pedagogical approach is carried out, focusing on the physiological states and mastery experiences of the students. An analysis of its results is presented as well as a discussion on these findings, coupled with the perspectives from different key stakeholders on the importance of the educational institutions' involvement in developing Industry 4.0 competencies in engineering students. Finally, comments regarding additional factors which play a role in the educational process, but were not studied at this time, as well as additional areas of interest are given.

Key Words
Educational Innovation; Higher Education; Digitalization; Online laboratories; Industry 4.0; Engineering Education.

Introduction
Laboratories are widely used in higher engineering education due to the necessity of not only learning, but implementing engineering concepts as part of the pedagogical process. Several strategies have been implemented since the early 2000's to provide web-based, hands-on approaches thanks to the possibility of accessing facilities remotely. Such approaches maintain the traditional objectives of on-site facilities, such as demonstrating analytic concepts, exposing students to a broad range of issues and potential problems, and comparing theoretical and real-world results (Heradio et al., 2016; Potkonjak et al., 2016). Thus, these online laboratories,

or experimentation environments, are often grouped in the following manner (Gomes & Bogosyan, 2009; Heradio et al., 2016; Potkonjak et al., 2016):

- Physical laboratories, where students are present in facilities equipped with specialized devices, either physical, virtual, or even a mixture of both, and these are used to develop the aforementioned hands-on experiences.
- Remote laboratories, where a student is able to exploit existing infrastructure using an Internet connection, usually visualizing real-time events through webcams.
- Virtual laboratories, which mainly use simulation packages to deliver the practical component of engineering education. The software is normally based on mathematical models of varying complexities and allows for a wide range of experiences, without the need of costly experiments.

Moreover, these approaches have been used in several disciplines with varying results, and lately, their impact generated is being studied with increasing frequency. For example, Gravier et al. (2012) discuss a collaborative online laboratory strategy and its association with both the tutor’s pedagogical objectives, and the management of the group of participating students. May (2020) explores new technological trends, describes how online laboratories can be cross-reality (XR) spaces in education as different realities are merged, for example, through the use of the real hands-on world in physical labs and the virtual one through simulated environments.

Additionally, online laboratories have taken on great relevance due to the COVID-19 pandemic which forced educational institutions around the world to make major changes in the teaching-learning system, thus accelerating their efforts in remote learning. For example, Lall & Singh (2020) present a study which attempts to understand the students’ perspective, attitudes, and readiness about online classes. Daniel (2020) reflects on the guidance that teachers, institutional heads and officials need to have in order to address the COVID-19 educational challenges and Arnove (2020) argues that the COVID-19 crisis offers a unique chance to improve the educational systems from a socio-economic point of view.

According to the above, the use of remote and virtual tools brings about new challenges in the application of well-established learning techniques and are being increasingly studied. Indeed, Zacharia et al. (2015) identify specific types of guidance required to support student use of online laboratories, in the context of Inquiry-Based Learning (IBL). On their side, Jara et al. (2012) present a synchronous approach of Collaborative Learning (CL) where practical experimentation is carried out in virtual and remote laboratories. Wuttke et al. (2010) explain how remote and virtual laboratories can support Problem-Based Learning (PBL) scenarios and Sucar et al. (2005) evaluate how virtual laboratories and tutors can help in the acceleration and improvement of the learning process using a Project-Oriented Learning (POL) strategy.

Even though mass-implementation of online engineering laboratories is relatively new, Tecnologico de Monterrey, Mexico, was among the first to successfully apply some of the above learning techniques when face-to-face sessions were replaced with online teaching due to COVID-19 pandemic. Nevertheless, studies of student self-efficacy within Tecnologico de Monterrey’s online laboratories have not yet been conducted and, specifically, studies regarding the students’ self-efficacy have not included an element which is crucial in today’s industrialized world: Industry 4.0 competencies.

According to Bandura (1986), self-efficacy refers to an individuals' beliefs in their capabilities to organize and execute actions required to achieve a particular outcome. Furthermore, Bandura (1977, 1997) states that there are four main sources of efficacy beliefs: mastery experiences, vicarious experiences, social persuasion, and physiological states. Mastery experiences refer to personal performance accomplishments, that is, to the individuals' perceptions based on their own life experiences of success and failure. Vicarious experiences refer to the observation of other people's experiences. Social persuasion indicates how efficacy beliefs change according to positive or negative influences of other people or certain situations. Finally, physiological states are linked to how efficacy beliefs are affected by the reactions, such as anxiety or stress, to events that occur in a person's life.

Although there are several interesting studies of students' self-efficacy that involve engineering education, online laboratories, or even competence-based learning (Bartimote-Aufflick et al., 2015; Ponton et al., 2001; Marra et al., 2009; Kolil et al., 2020; & van Dinther et al., 2014), there are few works that address self-efficacy from the viewpoint of the skills that students need to learn in the context of the so-called Industry 4.0. In this way, Cropley (2020) highlights the importance of creativity-facilitating competencies, such as self-efficacy, to better face the challenges that Industry 4.0 brings into technology education.

The Fourth Industrial Revolution, also known as Industry 4.0, is a concept which emerged from the combination of emerging information and operation technologies with the aim of upgrading production systems into smart factories. Nowadays, this concept has been extrapolated outside of the shop floor. Bongomin et al. (2020) show how the use of technologies has impacted various sectors of society, such as consumer habits, health care, transport, finance, and human development. Thus, technologies and disciplines such as automation and control, data analytics, artificial intelligence, as well as the massive interconnection of systems and devices which can be monitored and controlled remotely, set a new framework of evolving requirements, skills, and competencies that need to be considered in education. In this way, examples of studies where Industry 4.0 and education have merged to form Education 4.0 are given. Motyl et al. (2017) discuss the skills and expertise that young engineers require to be ready for the Industry 4.0 framework; Benešová & Tupa (2017) present the requirements for education and qualifications that people need in jobs related to Industry 4.0; Siti Rashidah et al. (2019) identify skills that engineering graduates need to be qualified in manufacturing and construction systems of Industry 4.0. Grodotzki et al. (2018) describe the development of remote and virtual laboratories for engineering education with a focus on manufacturing technology related to Industry 4.0; Suhaimi et al. (2019) examine the impact of a computer architecture and organization course on students' learning based on the Education 4.0 framework; and Salah et al. (2019) show how students use virtual reality in a prominent concept of Industry 4.0: reconfigurable manufacturing systems.

Although the above shows that Industry 4.0 and its related concepts already play an important role in the teaching-learning process, it is also extremely relevant to know if students perceive that Education 4.0 is something positive within their professional training. Further, it is also of interest to know if they perceive that Industry 4.0 competencies aid them to achieve a good academic performance. Thus, measuring students' self-efficacy regarding Industry 4.0 competencies and their impact, is an important study which will likely help improve the learning techniques implemented in the online laboratories of Tecnologico de Monterrey. In this way, examples of studies on the students' self-efficacy using online laboratories are given by Nickerson et al. (2007), who propose a model for testing the relative effectiveness of engineering laboratories in education through on-site and online labs; Viegas et al. (2018) describe how the interaction with teachers has a significant influence, not only on the students' performance, but also on their perception of their learning process and the overall satisfaction with remote laboratories and Fabregas et al. (2011) perform an analysis of the impact of remote experimentation on the academic performance of students, and its influence on the quality of the learning process via an online control engineering laboratory.

Therefore, our work is focused on the following two aspects of students' self-efficacy:

- Physiological states; where students’ efficacy beliefs were affected by the COVID-19 pandemic. In this sense, they feel that the absence of face-to-face and hands-on experiences in engineering laboratories has been detrimental to their learning.
- Mastery experiences; where students’ self-efficacy can be improved by obtaining successful results in activities and tasks related to Industry 4.0.

With this in mind, this document attempts to answer the following research questions:

- How can we ensure that students develop a sense of fulfillment in their online learning process, considering that they appreciate the hands-on approach of traditional laboratories?
- Can we help students to maintain a sense of self-efficacy by implementing activities and tasks similar to those carried out in an Industry 4.0 position within the courses?

Thus, an analysis of the students' self-efficacy, perceived around the acquisition of knowledge and the development of competencies related to Industry 4.0, is performed. Such competencies are related to the use and development of virtual environments, and products, to interconnect real and virtual systems using existing infrastructure in Tecnologico de Monterrey. This is being done to prepare an engineering workforce capable of facing future challenges in an increasingly digitally-connected world.

The way in which Industry 4.0 competencies are being developed within the pedagogical method is described in the following section, showcasing examples of such approach. Later, in the results’ section, the way in which the self-efficacy of the students was analyzed is shown by explaining the exit survey implemented throughout various engineering courses, regarding the use of online laboratories within the proposed framework. Finally, in the discussion and concluding remarks, the impact of this approach from the point of view of both students and teachers, exposing the perspective that engineering professionals have on the importance of the educational institutions involvement in developing Industry 4.0 competencies in engineering students, is discussed.

Industry 4.0 based learning

The current work was developed in the context originated by the lockdowns implemented after a state of pandemic emergency was established, related to the SARS-CoV-2 virus. Tecnologico de Monterrey, a private Mexican University, was among the first to switch to online classes prior to an official government mandate in order to protect their studentship and employees.

This was achieved through the use of Zoom Video Communications Inc. (2020) for online communications and Instructure Canvas, (n.d.) as the learning management system, coupled with a synergic use of simulation packages and online laboratories. Before the pandemic, students were able to interact with diverse engineering software, through academic licenses, as well as specialized automation hardware and other equipment at the university's facilities. After the lockdown, the computers, specialized automation hardware, and compatible devices were set up in a way that students could still use them remotely.

As known, Problem-Based Learning (PBL) is a teaching technique that uses real-world problems to promote learning in students by focusing on the process carried out to solve these problems (Wood, 2003). On the other hand, Project-Oriented Learning (POL) focuses on obtaining a final product over a certain period of time, without overly considering the development process (Moesby, 2005) and Research-Based Learning (RBL) is an approach that promotes and develops student competencies related to research practice as well as additional activities linked to research (Noguez & Neri, 2019).

As mentioned, the approach presented promotes the use of the existing infrastructure to allow the students to create and use virtual environments and products following the aforementioned learning strategies (i.e. PBL, POL, RBL) to boost their skillset and adapt it to the needs of Industry 4.0. Therefore, a review of existing practices to maintain the techniques' educational intent, while adapting them to the current needs and possibilities was required.

The mode of work affects the behavior of society (Bauer et al., 2015). Nowadays, the lifecycle of products and processes is shorter which means that production processes must now be flexible, robust, and low cost. Saturno et al. (2018) established that information technologies, such as telecommunications, cybersecurity, and databases have been integrated with operational technologies like sensors, actuators, controllers, and interfaces to establish the pillars of Industry 4.0 (i.e. industrial internet of things, big data, cloud computing, models and simulation, extended reality, among others).

The knowledgeable use of telecommunications, artificial intelligence, creation of virtual environments, and the interpretation of results obtained from simulations are some of the skills required in this new digital age (Bauer et al., 2015; Papanastasiou et al., 2019). To achieve the development of these competences, changes must be made in the content and teaching methods, where integrating industrial tools into the classroom is of the utmost importance. Leng et al. (2019) considers that the creation of a smart factory requires three main concepts: a digital twin (DT), internet of things (IoT), and cyber-physical systems (CPS). The exchange of data between devices through a communication protocol (i.e. IoT) allows us to generate a model that represents the behavior of these devices (i.e. DT). CPS refers to the interconnection between physical and virtual systems and their development represents one of the main Industry 4.0 competencies that students can develop to be prepared for the future. The successful implementation of a CPS is the result of a digital transformation deployment, a process which has several stages and components which can range from the computer-aided visualization of the system in question, to the remote manipulation and reconfiguration of an entire manufacturing process using virtual and augmented reality tools.

The pedagogical method presented attempts to implement many of the concepts described above to enhance the learning experience. Thus, to better understand the approach, the authors present the Digital transformation deployment diagram (Figure 1), which includes the key Industry 4.0 components that were implemented in the learning environments. Each stage of the deployment is assigned a specific color and will be used throughout the remainder of this text.

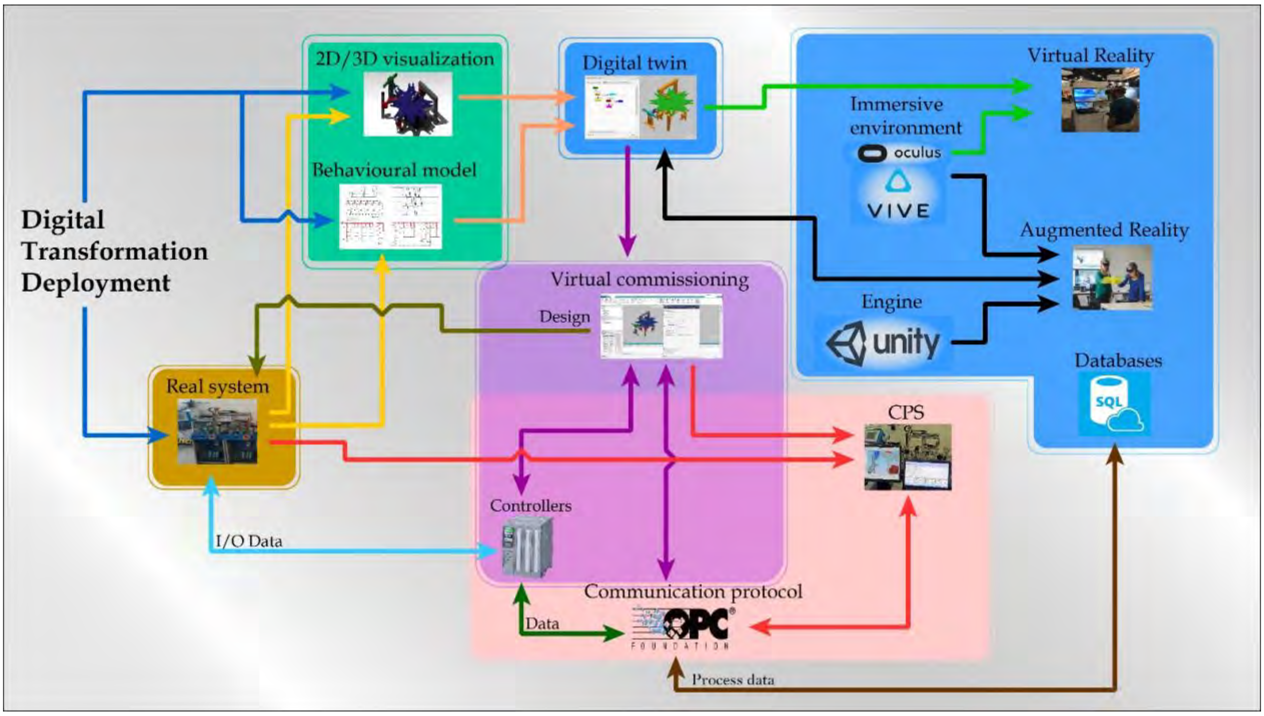


Figure 1. DTD diagram including the elements involved in each phase and associated flow of information. The logos included (i.e. OPC, Unity, VIVE, SQL) show some of the protocols or software used in certain stages.

For a better understanding of the stages and to simplify the transfer of knowledge between courses, these concepts were split into four cases according to the level of digitalization applied. A synthesized summary of the cases is presented in Figure 2 which shows how each stage is built on another as the interaction between physical and digital elements is tightened.

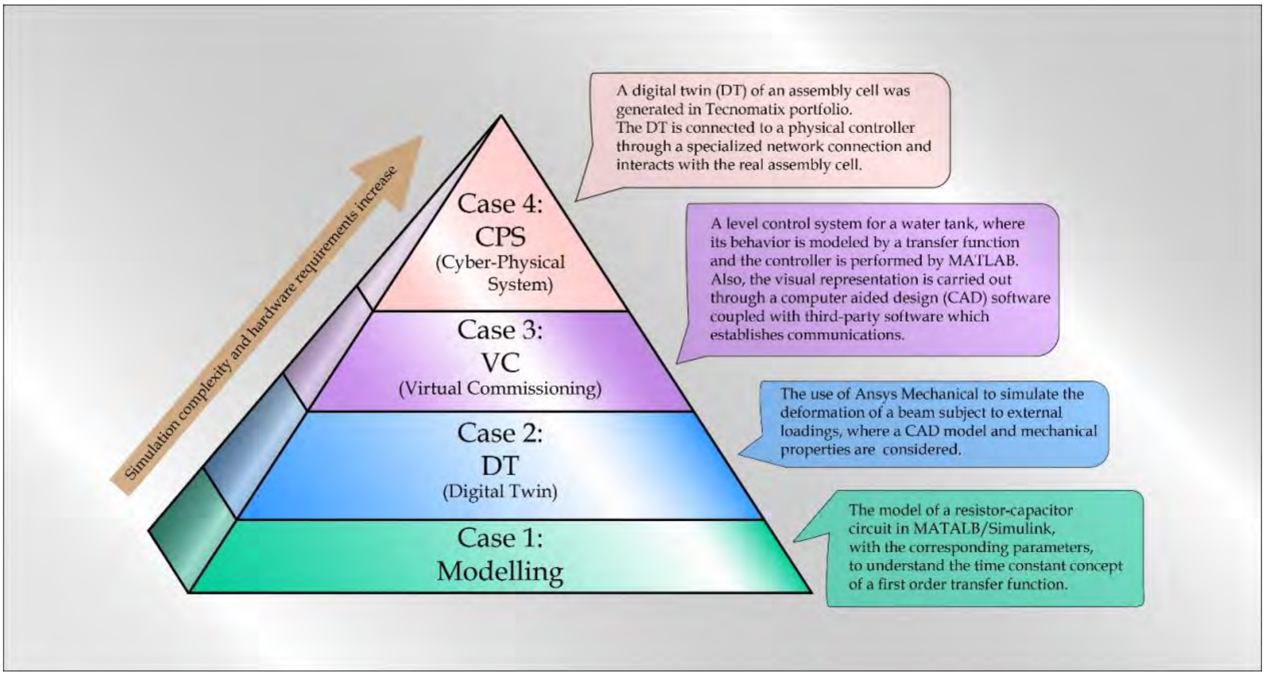


Figure 2. Synthesis of the proposed cases. The colors are associated with the stages of the DTD diagram (Figure 1).

Case 1: Modelling

Consists in the use of behavioral, logic, geometrical, or visual information to represent a physical phenomenon. This is the most generic use of traditional Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) tools such as Siemens NX, Mathworks Matlab/Simulink, Ansys Fluent, among many others.

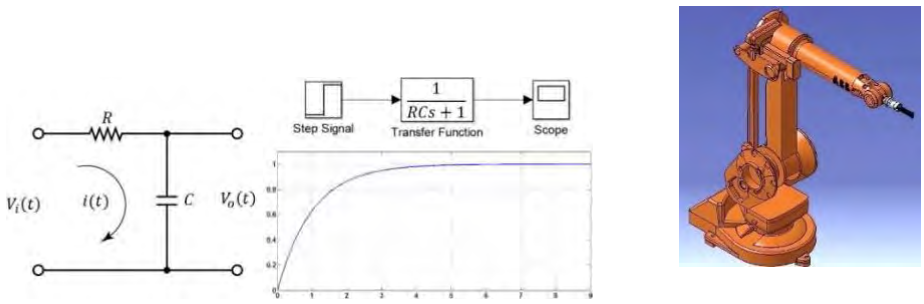


Figure 3. Examples developed by the authors throughout diverse courses, including a behavioral model (left) of an RC circuit (Matlab), and a CAD model (right) of an ABB IRB 1400 robotic arm (DS CATIA).

Case 2: Digital Twin (DT)

Requires both a visual representation and a behavioral model to be simulated. The visual representation reacts to a stimulus and generates a response according to the pre-defined behavior. A DT is a reliable representation of a physical phenomenon, which is often used to evaluate “what if…?” scenarios (Esqueda et al., 2020). This kind of representation is usually obtained within the same software but can also be achieved by linking different packages. For example, Siemens SIMIT can be used together with Matlab Simulink and other modules, in order to ensure that physical laws govern the behavior of the virtual prototype.

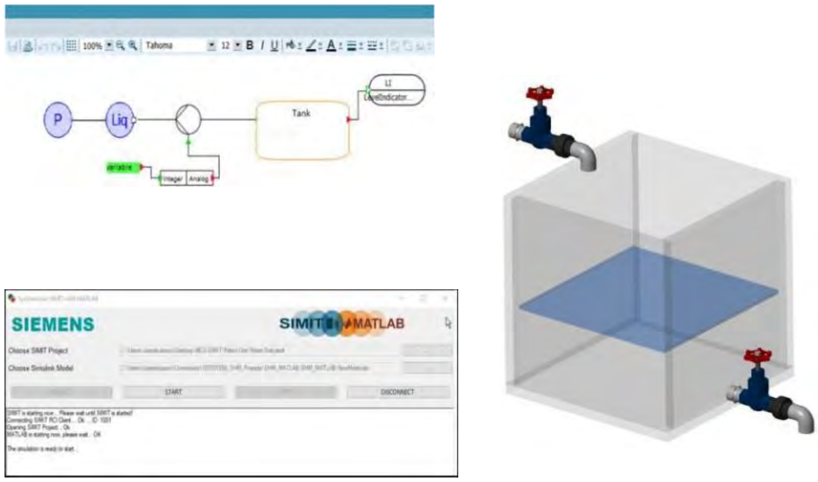


Figure 4. A Siemens SIMIT simulation (left) of a water level control system running within Matlab Simscape (right) developed for a process control course.

Case 3: Virtual Commissioning (VC)

Refers to a connection between the DT and an external control system, often used to debug programs. The information is exchanged using established communication protocols (Guerrero et al., 2014). For instance, an Arduino board can interact with Matlab in order to obtain a reaction from the DT mentioned in Case 2.

Figure 5. Representation of an Arduino card used to control the behavior of a system modelled in Matlab using a transfer function.

Case 4: Cyber-Physical Systems (CPS)

Consists in the connection of a DT with a physical system. Physical elements can trigger changes in the digital environment and vice-versa (Villagomez et al., 2019). Cyber-physical systems allow students to verify that the behavior of the digital twin is similar to that of a real product or process and understand what may cause variations between them.

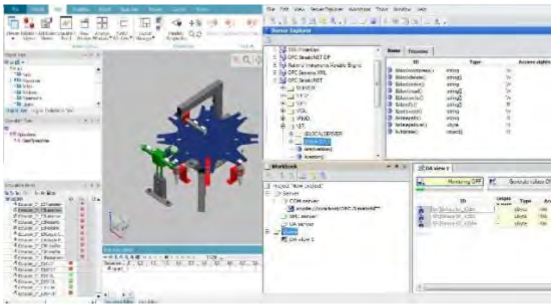


Figure 6. Monitoring of the interaction between a physical system, including sensors and actuators and its DT using specified communication protocols.

These cases were implemented across twelve courses which had a change of objectives and general strategies to fit with the implemented online synchronous and asynchronous model. In the former, students and lecturers interact online, while in the latter, lecturers assign activities for students to develop at their own pace which are reviewed periodically.

Before presenting how the aforementioned Industry 4.0 competencies were incorporated into the online laboratory courses, the traditional on-site approach, together with the course objective, and an overview of the activities performed are described. The courses have been grouped according to the main topic to allow for a simplified presentation. It is important to note that some are mainly theoretical, whereas others are laboratory-oriented. However, since the theoretical courses mentioned traditionally included a considerable amount of hands-on and simulations activities, they were adapted using the current pedagogical method and are therefore included in this work.

Courses on Process Automation and Control

Depending on the level of understanding required for their engineering degree, students learn about the analysis, design, implementation and evaluation of automatic control systems and logical controllers of batch-type, continuous and discrete processes. Traditional PBL based activities, with situations related to the regulation of physical variables (temperature, pressure, flow, etc.) in industrial systems, carried out on-site included:

- Interpretation of piping and instrumentation diagrams (P&ID), to define a problem in which students need to identify automation and control variables in industrial processes.
- Modeling and characterization with first and second order systems, or nonlinear electromechanical dynamical systems.
- Implementation of combinational and sequential logic processes using electro-pneumatics as well as Programmable Logic Controllers (PLC's), microcontrollers and related technologies.
- Implementation of an automatic system considering security elements such as emergency stops and alarms.
- Tuning of continuous and discrete PID controllers via pole placement, root locus, and frequency analysis design, as well as the implementation of non-conventional control algorithms using artificial neural networks and fuzzy logic.

Courses on Mechatronic Product Design

Oriented towards allowing students to understand and apply various design methodologies (i.e. Stage-Gate, Integrated Product Development, Design Thinking, Lean Startup, Agile, V-Model) to develop a mechatronic prototype (Esqueda et al., 2019) while considering manufacturing constraints, technologies, and tools, as well as an analysis which ensures the viability of the business and desirability of the market. These courses are presented as POL since the student is guided through activities that iterate their design throughout the semester, having as outcomes, a finished prototype and business plan related to the idea proposed, that involves the:

- Evaluation of the feasibility of a product considering Design for Manufacturing and Assembly, Failure Mode & Effects Analysis, anthropometric analysis, etc.
- Production of a prototype solving a specific market need, iterated by means of primary and secondary market research, Quality Function Deployment, A/B Testing, among other tools.
- Presentation about the viability of both, the product, and the business to external multidisciplinary industrial reviewers and internal faculty.

Courses on Industrial Automation and Networks

Students learn to design, deploy, evaluate, and optimize production processes by applying Process and Product Lifecycle Management (PLM) solutions, together with operational technologies such as PLC's, industrial networks, and human-machine interfaces. An RBL approach is used by students to justify the development of activities based on multiple sources of information, such as articles published in journals and conferences with high impact factor. On the other hand, a PBL approach is used to carry out activities like:

- Modelling and simulation of production systems.
- Connecting production models to PLC's and industrial automation devices.
- Improving existing industrial operations using PLM solutions and Operation Technologies.

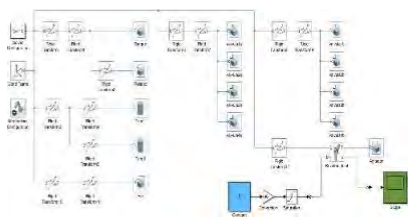
Courses on Mechanical Analysis of Solid/Fluid Systems

Students learn to study solid or fluid systems, analyzing their behaviors and reactions to changes of the surrounding environment. An RBL approach is employed, allowing students to use experimental and simulation tools to generate and test their own hypotheses about the topics covered. Activities involved consist in the:

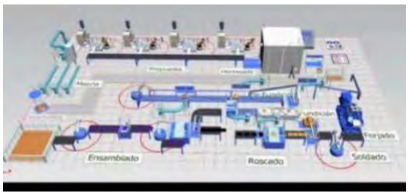
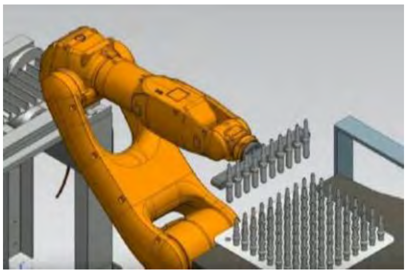
- Design and construction of a test-rig to measure the deformation of beams subject to varying loads, followed by a comparison of the theoretical and experimental results. Slight guidance is given in the use of specialized equipment, while students are encouraged to formulate and test their own research questions.
- Simulations of fluid-related systems to predict the behavior when subject to changing forces and geometries on a system of their own choosing. Optimizations and improvements for the systems are proposed according to the results obtained.
- Written reports are required to present the results of their studies using scientific writing and adequate formats according to the discipline.

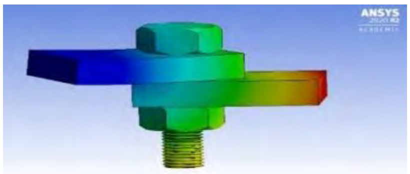
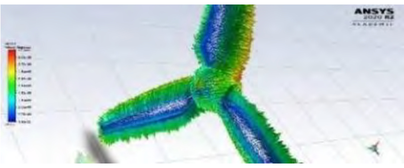
To complement the above traditional learning techniques, Industry 4.0 concepts were incorporated to develop related competencies by using and creating virtual environments and products to motivate learning in students. Thus, some study cases that show the implementation of this pedagogical approach are shown in the following table. The stage of the DTD shown in Figure 1 associated with each of the competencies is shown by the colored bullet, where more than one can be involved in a given course.

Table 1. Courses impacted by the implementation of the pedagogical model, competencies developed and examples of work carried out by the students. The color of the bullet corresponds to the stage of deployment used according to Figure 1.

Course names and benefited majors	Industry 4.0 competencies currently developed	Target Industry 4.0 competencies	Examples of successful implementations
Process Automation (theoretical course) Process Automation Laboratory Logical Automation Laboratory Majors: Chemical engineering Biotechnology engineering Mechatronics Engineering	■ Development of DT's to understand P&ID diagrams and the physical devices involved. ■ Construction of DT's to validate the parametrization of first and second order dynamic systems.	■ Implementation of PLC control algorithms for the VC of chemical processes.	  DT of a continuously stirred tank reactor. Programming (top), behavioral simulation (bottom).

Course names and benefited majors	Industry 4.0 competencies currently developed	Target Industry 4.0 competencies	Examples of successful implementations
Modern Control Engineering (theoretical course) Control Engineering Laboratory Integral Automatic Control Laboratory Majors: Mechatronics engineering. Mechanical engineering. Digital systems and robotics engineering.	Development of DT's to validate the mathematical model of dynamical systems. Implementation of control algorithms for the VC of electromechanical systems. Development of DT's to test closed-loop control response of nonlinear unstable dynamical systems. Use of digital twins to implement automation techniques and validate the behavior of electro-pneumatic processes.	Build dynamic electromechanical systems and virtualize them to create CPS's. The performance of control schemes is evaluated using the generated data. Digitalization of automation and control processes to perform VC with PLC technologies.	   Balance control of an inertia wheel pendulum. DT programming (top), control program (center), 3D simulation (bottom).

Course names and benefited majors	Industry 4.0 competencies currently developed	Target Industry 4.0 competencies	Examples of successful implementations
Mechatronics Design (theoretical course) Mechatronics Laboratory Majors: Mechatronics engineering. Mechanical engineering.	Development of a DT for the prototype of the mechatronic product. Use of augmented reality to present the DT and obtain feedback from the target market. Virtual pitch with faculty staff and external guests from the industry using a DT.	Validation of the behavior of the DT to emulate the physical system, and exchange signals mutually.	 Use of AR to showcase the DT of the product.
Industrial Networks (theoretical course) Industrial Networks Laboratory Advanced Industrial Automation Majors: Mechatronics engineering. Digital systems and robotics engineering.	Development of an industrial production system's DT using Siemens Tecnomatix PLM solutions. Deployment of VC using Siemens PLC's. Deployment of a cyber- physical production system using PLM solutions, PLCs, and physical sensors and actuators.	Use of industrial Big Data and data-driven models and simulations to optimize processes.	  Model and simulation of a spark plug production system (top) and a simulation of pick and place operation connected to a Siemens PLC S7-1516

Course names and benefited majors	Industry 4.0 competencies currently developed	Target Industry 4.0 competencies	Examples of successful implementations
Materials Engineering Fluid Mechanics Majors: Mechatronics engineering. Mechanical engineering. Automotive design engineering	Development of DT to allow for system optimization. Validation of DT subject to varying conditions using experimental values.	Development of a CPS which mirrors the conditions of a physical system within a simulation environment to predict future behavior.	  Simulation of stresses generated on a simple nut-bolt assembly (top) and wind-turbine in the presence of uniform flow (bottom).

According to the above, apart from the engineering knowledge and skills that students acquire from traditional learning techniques, this pedagogical approach complements the educational models in the sense that it encourages the development competencies related to Industry 4.0 as shown in Table 1. However, the use and development of virtual environments and products, to motivate and improve the learning process in students, does not necessarily mean that they consider this beneficial for their professional development. Therefore, the following section aims to measure the students' self-efficacy perceived around the acquisition of knowledge through the development of these Industry 4.0 competencies.

Research Methodology and Key Results

As mentioned, there is a gap in the literature related to the sense of self-efficacy in online laboratories which implement Industry 4.0 concepts. Early research has shown that students have difficulty maintaining focus over long periods of time (Brunce et al., 2010), with even bigger challenges in the current context that might compromise the quality of the learning experience (Husseln et al., 2020). While most publications focus on evaluating the efficiency of the courses, little has been published regarding the sense of fulfillment of students enrolled in these courses.

At Tecnologico de Monterrey, students have increasingly expressed the relevance and importance that having a hands-on approach in the engineering laboratories has for them through focus groups, interviews and surveys. Since it is the belief of the authors that the voice of the student can work as a catalyst for innovation in Education, the authors decided to look into their sense of self-efficacy as an indicator of self-fulfillment in their learning. In particular when they cannot physically interact with the tools and equipment of the laboratories.

It is important to note that this same context is boosting the use of Industry 4.0 as a tool to improve efficiency and collaborative work in companies all around the world (Grodotzki, Ortelt, and Tekkaya, 2018). As new jobs require a deeper understanding of the use and development of such technologies, engineering education must also evolve to prepare the future workers for those positions. The research questions thus aim to validate this need for additional skills and at the same time increase the level of satisfaction of the students.

Moreover, education in this particular context involves a new set of variables which affect its correct development, which may lead to a different experience for every student. For example, their own adaptability, computing power, internet speed connection, and remote availability of laboratories and software were seen as the top factors that could generate significant differences in the students' experiences. Students' self-efficacy, as presented in the research framework by Lee & Mendlinger (2011), would then be measured by contrasting their sense of perceived usefulness (i.e. Online teamwork was more effective than meeting in person), perceived ease of use (i.e. Digital classes can perfectly replace traditional lectures), and perceived efficacy (i.e. The virtual practical approach enhanced my skills considerably) with affirmations related to the Industry 4.0 competencies approach (Adaptability: "I adapted quickly to online learning"; Personal Computer: "My computer allowed me to work just fine"; Online/Remote Facilities and Activities: "Specialized software and remote laboratories gave me confidence to interact with real systems").

Likert-scale questionnaires have shown to be very useful to measure self-efficacy as long as they are designed properly (Nemoto & Beglar, 2014), and were therefore used to collect data from students via a Google Forms online survey carried out in Spanish.

As described in Table 1, different courses were adapted to one of the cases previously presented and final projects were evaluated in order to verify the students' learnings of the semester. As previously indicated, one of the goals was to validate if this pedagogical method, based on Industry 4.0, would be of their satisfaction.

Undergraduate students who were enrolled in the aforementioned courses during the February-June 2020 and August-December 2020 semesters were invited to answer an exit survey that measured the impact of the work developed during those terms. The survey included 6 questions that were aimed at identifying the usefulness of the pedagogic method, their perceived self-efficacy (Lee & Mendlinger, 2011), and the context of use of the digital tools presented through a 5-point Likert scale. A total of 300 responses were collected. The most important characteristics of our sample of students are given in Table 2.

Table 2. Student sample characteristics considering their gender, age and field of study.

Gender	74% Male 25% Female 1% Prefer not to say
Age	5% 18-20 73% 21-23 19% 24-25 3% Over 25
Major	55% Mechatronic Engineering 17% Chemical Engineering 5% Mechanical Engineering 2% Automotive Engineering 12% Robotics Engineering 9% Biotechnology Engineering

The results associated with the students' perception of self-efficacy that were part of this test study are seen in Figure 7, where this heatmap was built up by contrasting questions related to the resources available to the students and their sense of self-efficiency within the courses. The number of students that selected the same response on the Likert Scale in both questions were counted and following this approach of grouping the results and analyzing them, some observations are presented:

- The majority of students felt they had adapted quickly to online learning, and most also reported that their computer is good enough to work in the online classes. This last point was a major factor since many of the activities done in the courses involved can be computationally demanding, and the success and ease of implementation strongly depends on the equipment used.
- In general terms, there seems to be a dislike towards online classes. However, this data was built based on the responses from two semesters and it is noted that this discouragement emerged mainly in the second semester studied, possibly due to students being jaded by the lockdown.
- While most of the students agree that the virtual approach was useful to them, it is also clear that whenever remote laboratories and specialized software were used in the courses, the overall acceptance of the online approach improves.

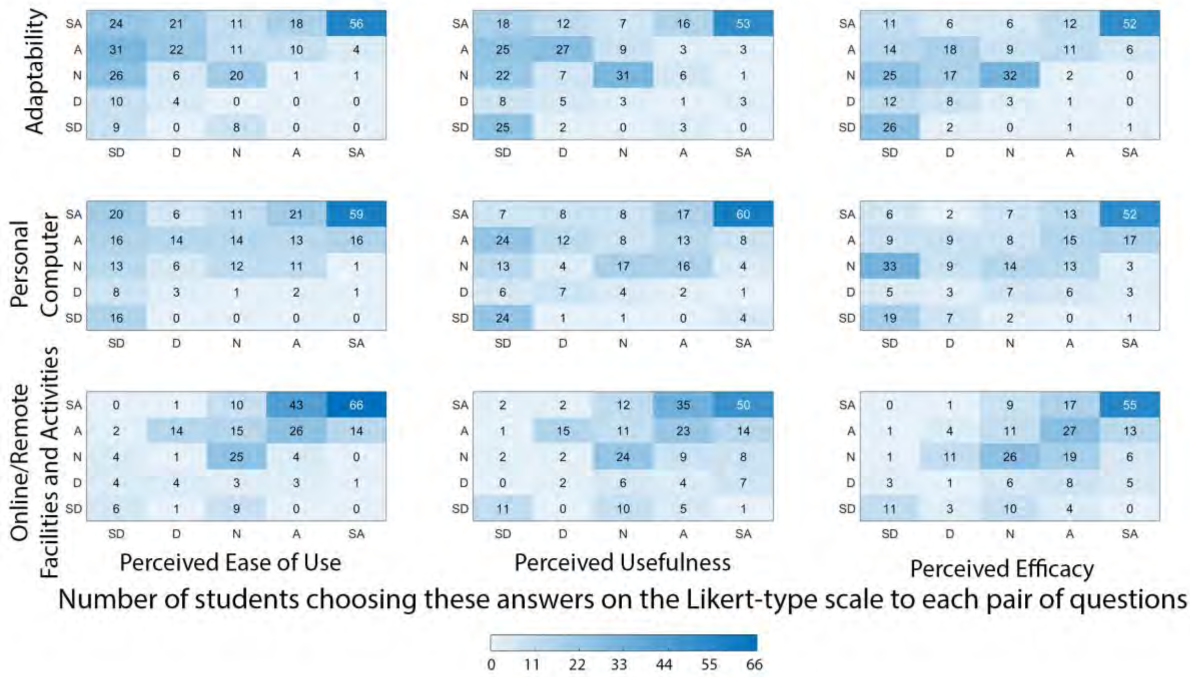


Figure 7. Correlation of questions linking the students' resources (adaptability, personal computer, online/remote facilities and activities) with their sense of self-efficacy in categories (perceived ease of use, perceived usefulness, perceived efficacy). Possible answers were "Strongly Disagree" (SD), "Disagree" (D), "Neutral" (N), "Agree" (A), and "Strongly Agree" (SA). The colors indicate how many students considered each pair of questions at the value indicated in the row (digital tools questions) and column (self-efficacy questions). The color scale reflects the registered number of responses, per pair of questions.

The data also shows distinct patterns which can be associated with the four sources of efficacy beliefs. For example, the possibility of using specialized equipment remotely and having an adequate computer will directly impact the perception of the students' success or failure in a given course. Since these factors may impede the correct implementation of an activity and the mastery experiences will be hindered. Furthermore, the varying levels of online teamwork developed and use of tools which allow interaction affect the vicarious experiences, since there may be little or no observation of other students, and therefore, the perception of the benefits of remote learning may not reflect the actual impact.

Discussion And Concluding Remarks

The COVID-19 outbreak and resultant lockdown have been the main drivers of digitization over the past year. Changes in the classroom have caused students to gain knowledge through the use of models, simulations, and telecommunications tools, where the latter are commonly used in modern industry since the beginning of the Fourth Industrial Revolution.

Online learning has many advantages over traditional classes. However, continuous improvement is required in its pedagogic strategy so that students can have a satisfying experience, particularly when they are unable to validate their skills in a physical environment such as in a laboratory. Lecturers therefore must focus on creating realistic virtual environments and rely on various forms of online or remote laboratories to ensure that students graduate from universities with the required skills and confidence to enter the world of work.

Due to the ever-changing demands and needs of the working world in terms of the skills, competencies, and knowledge required, the participation of industry specialists in the learning process is of the utmost importance. The industry now requires students who can adapt to radical changes, foster the digital transformation of organizations, and accept diverse points of view. "Incorporating key concepts from Industry 4.0 and the development of relevant competencies favors the exchange of ideas within companies, as well as collaboration with industrial environments in the coming years'' -Rebeca Gonzalez (ZF - Talent Acquisition Specialist in the Global Recruitment Center).

Over the course of two semesters, and after the onset of lockdowns in Mexico, lecturers at Tecnologico de Monterrey adjusted their courses to be delivered in an online format using telecommunication tools. At the same time, concepts and ideas related to Industry 4.0 were implemented to teach students through a novel pedagogical approach that allows them to develop skills, competencies, and knowledge which is required in this emerging industrial environment.

The implementation of this approach led to the identification of various factors which affect the development of the students' self-efficacy, as well as an evaluation of the impact that the use of technology and other tools have on the learning process. From the surveys, a rather positive outlook from the students' perception towards the proposed approach was noticed. As a matter of fact, from the first to the second semester of this study, answers shifted towards something more positive when involved in activities of this Industry 4.0 based model. However, we also believe that part of this was related to the professors also feeling more confident since the first semester they were forced to modify their teaching methods within the classroom and adapt them into an online learning system in a very short amount of time. The influence of the professor's self-efficacy assessment can also be a potential direction of future studies.

As stated in the introduction, this work was focused on two aspects of the students' self-efficacy: physiological reactions due to the COVID-19 pandemic and mastery experiences about Industry 4.0 activities. Therefore, three indicators were measured as an attempt to answer the posed research questions: the students' perceived usefulness, the students' perceived ease of use of the tools, and the students' perceived efficacy. However, this study can be complemented by considering the two additional aspects of the self-efficacy theory: social persuasion and vicarious experiences.

Social persuasion can play a significant role in the students' self-efficacy in the sense that seeing the importance that engineering professionals give to Industry 4.0 could serve as motivation for the students. However, it can also bias the opinion of a student if someone openly shares a different point of view. While some professors at the University continuously asked students about their sense of satisfaction with online learning, we do believe that an exit survey allowed us to reduce bias originated by social persuasion. On the other hand, vicarious experiences could be added to the analysis if, for example, new students observe the successful results that current students have in Industry 4.0 related projects or tasks.

The authors will continue to adapt their courses with the aim of strengthening the development of such competencies related to Industry 4.0 and thus, give the students an advantage over graduates from other institutions. The use of industrial digitalization, together with visualization tools, will remain an essential part of this new strategy and in coming studies, more of the key concepts related to Industry 4.0 will be brought over to the educational approach. Additionally, it was also noted that an adaptation of the methods used to evaluate hard and soft skills is required alongside the modifications which have already been implemented.

Further evaluations will be done to measure the students' digital literacy, industrial partners' perception of the development of the Industry 4.0 competences, as well as a continued analysis of students' self-efficacy perception.

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