Chapter 22
Open Innovation Laboratory to Foster Skills and Competencies in Higher Education

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22.1 Introduction

Today's society is undergoing constant shifts at various social, economic and environmental levels. Price Waterhouse Coopers, in a study entitled "The World in 2050," stated that by the middle of the twenty-first century, there would be significant changes in the so-called emerging nations (E7) as they achieve better social and financial conditions (Hawksworth and Chan 2015; Boiardi et al. 2013). The paradigm shift in the global economic balance will increase the consumption of goods and services. Promoting economic development in the different productive sectors will be necessary by creating innovative tools, models, and structures that meet the growing population's needs (Mauricio-Moreno et al. 2015). This increased integration will allow all sectors to benefit from the accelerated evolution of technology, driven primarily by increased computational power, such as artificial intelligence, robotics, data analytics, cloud computing and the internet of things. The growing adoption of technologies, mainly in industry, makes it possible to reinvent, redesign, and integrate models that have led to a crucial evolution in manufacturing processes called Industry 4.0 (Drath and Horch 2014). There are numerous paths to integration in the medium and long term. Higher education institutions must integrate their programs with industries' technologies, tools, and objectives to achieve this necessary transformation in the academic field. The productive sectors are constantly evolving and require professionals to address current problems and future challenges through

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specific skills and competencies, enabling them to propose innovative solutions that disrupt current paradigms.

Education also is undergoing a profound revolution as coming generations of professionals adopt new learning techniques to cope with the transformation of industry and services (Mourtzis et al. 2018). Thus, there is a continued effort by schools worldwide to transform their curricula to develop the skills and competencies demanded of graduating students by the labour market (Martin et al. 2011). This radical transformation in learning, Education 4.0, is the first giant leap from traditional education in decades. Integration is a fundamental part of this transformation; the various productive sectors and governments have developed different initiatives with educational institutions to generate models and projects that benefit both parties. This two-way collaboration is a fundamental pillar of the growing adoption of the Open Innovation (OI) culture. In this regard, this work describes the approach taken by Tecnologico de Monterrey to lead educational transformation through its Open Innovation Laboratory.

This work is structured as follows. Section 22.2 briefly explores the concept of Education 4.0 and how advances in technology applied to industry impact future professionals. Section 22.3 is about Open Innovation Laboratories (OIL) from the academic perspective and its structure to boost scholars' skills and competencies. Section 22.4 details how OIL at Tecnologico de Monterrey is a learning environment to foster experiences in Education 4.0 and Open Innovation. Last but not least, Sect. 22.5 elaborates on three OIL case studies that illustrate a real-life deployment of the concept at Tecnologico de Monterrey.

22.2 Education 4.0 Overview

Education 4.0 has multiple definitions. One of them explores this concept as the adoption of novel methodologies and cutting-edge instructional spaces that completely alter the paradigm of traditional education. This notion fosters better development of hard skills and further refining of soft skills (Aziz Hussin 2018). On the one hand, there is intense research covering that covers the skills needed in college students; on the other hand, there are different methodologies and learning techniques to develop them. The industry's transformation has given way to defining the specific skillset to be promoted in the third decade of the twenty-first century (Şahin 2009). However, these defined workforce skills will change as new technologies are integrated.

Thus, it is essential to note that various organizations, such as the 2016 World Economic Forum, have made great efforts to publicize the industrial trends in skills and competencies for this decade (Forum 2016). Their survey collected data from over ten million people and dozens of corporations. The findings demonstrate the growing need to develop soft skills as technology reduces the need to perform repetitive, highly technical tasks. Higher education institutions are aware of these trends and seek to train students to meet the expectations demanded by modern industry. Modern learning models will strengthen the technologies, methodologies and tools that facilitate the integral development of students. Some of these allow customizing teaching to accommodate students' different learning styles. Active-based learning and problem-based learning are strategies that leverage the main features of new educational methodologies and spaces.

This paradigm shift has significantly improved compared to traditional areas for developing skills and competencies. Communication software through broadband internet has enabled continuous and flexible education. Thanks to these tools, many physical classrooms have been exchanged for virtual spaces that allow the students and teachers to be in ubiquitous remote classes and courses. These make it possible to reach worldwide audiences with online platforms such as massive online open courses (MOOC). As a critical strategy (West et al. 2008), Open Innovation also takes advantage of the new trends in education to provide an environment of participation among different entities (government, industry and academia), thus allowing the development of the skills required by students.

22.3 Open Innovation Laboratory

Open Innovation is a powerful concept, contributing to the flow of knowledge among entities; hence, ideas can come equally from internal or external actors participating in the same project with different perspectives on the same development (Faems 2008). Higher education institutions have played an increasingly important role and work closely with Industry to create new research agendas. However, this collaboration falls flat if no infrastructure and framework are provided. In this regard, academic institutions have created collaboration hubs where facilities, technologies, innovative tools, and experts from academia and industry come together in spaces known as Open Innovation Laboratories (OIL). These provide the infrastructure to raise, shape and integrate ideas, offering a unified approach to design, development, testing and launching.

Due to the complexity and technological resources required for complex projects, OIL provides a cost-effective solution compared to the performance of a single entity: Development times and costs are reduced, and implementations have higher success rates. Compatible with technological parks worldwide, OIL aims to establish collaboration to solve novel societal challenges, exploit market niches in short periods, and develop applied research with industry participation. OIL improves student competencies by enriching their knowledge in a daring environment where attitude, skills, knowledge and participation are boosted through Challenge-Based learning and Project-Based learning. Thus, for academia and research institutions, three pillars sustain the collaboration and deployment projects with third parties: (i) Learning Methods and Techniques, (ii) Design Methodologies, and (iii) Rapid Product Realization Platforms (see Fig. 22.1).

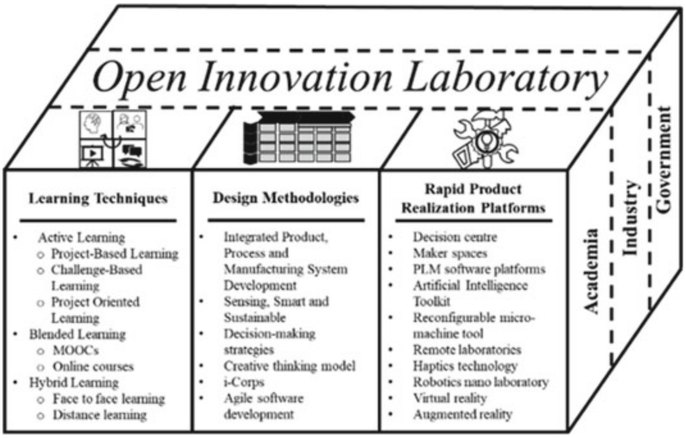

Fig. 22.1 Open Innovation Laboratory. Schematic representation of participating entities and the three OIL pillars

22.3.1 Learning Techniques

Learning techniques are a series of practices to improve the profile and competencies of scholars. Among the learning techniques found in the literature, active learning improves the most desired competencies in 21st-century scholars (Chesbrough 2003). Multidisciplinary teams, knowledge, and hard and soft skills are necessary to develop innovative solutions to real-life problems and challenges. Also, developing individual competencies, blended and hybrid learning aim to enhance skills previously acquired, allowing students to learn about external topics and implement solutions through the project. When developing projects using the OIL infrastructure, participants have improved at least the following competencies: communication, critical thinking, creativity and innovation, collaboration, and cooperation. They provide the foundation to deal with real-life problems requiring commitment, active participation, communication, information sharing, innovative solutions and multidisciplinary teams to attain a feasible solution. Emerging technologies support and enrich learning techniques (Moirano et al. 2020). Notwithstanding, the implementation of OIL requires that participants understand and follow these principles: (i) comprehend the central problem and goal of the project, (ii) communicate, share, and contribute interactively to elevate the understanding of the group and (iii) voluntarily participate, to arrive at a faster, better, and more structured solution.

22.3.2 Design Methodologies

During project development, the series of steps and structure determine the solution's perspective, activities, tools and assessment. The project's multidisciplinary and complex nature allows participants to uncover new necessities during the development, resulting in multiple solutions requiring additional resources. Wandering is undesirable; thus, to prevent deviations, it is necessary to identify the structure that allows the idea to move from the beginning of the project and guides it to implementation. In this infrastructure are the design methodologies. Their purpose is to provide the actions to be followed during the endeavor, with recommended activities, toolboxes, and tollgates defining a roadmap and setting the project's duration. The general structure of the methodology should encourage participants to explore opportunities (divergence), analyze options (synthesis), and materialize solutions (convergence). There are multiple methodologies for project fulfillment, such as standardization, industry best practices, and literature review to analyze the setbacks that preceded research groups. Therefore, during the beginning of the project, participants must define the approach to document the problem and reach a solution within the defined budget.

22.3.3 Rapid Product Realization Platforms

These tools stand as the backbone of the OIL. They include a blend of hardware and software from both emerging and traditional technologies and approaches. They promote participant collaboration and supporting the innovation process during the project. The platforms rely on involved parties' application, transmission, and training to exploit the resources for design, manufacturing, testing, simulating, and evaluating proposed solutions. The synergy of learning techniques and methodologies occurs in this pillar, coming together in a physical space to shape ideas. Rapid product realization platforms include (i) laboratories, (ii) machinery and equipment, and (iii) facilities.

Laboratories include a wide variety of spaces, physical and virtual laboratories to test CAD, CAM, CAE, PLM, and ergonomics technologies. Other activities involve computer sciences, include data analysis, programming, cloud analysis, and social media analysis. There are science laboratories for physical, chemical, thermodynamics and mechanical testing; creative spaces for arts, audio, photography and video production; and electronics labs for PCB design, electrical analysis and test benches. According to the project's necessities, multiple laboratories accommodate needs, which could vary during the implementation.

Machinery and equipment support a wide variety of processes. They consist of basic and advanced manufacturing techniques and include traditional, and Computer Numerical Control centers for large-scale or precision volumes. Also, there are additive processes, such as sintering and 3D printers; and subtractive processes to execute lathe, milling, and drilling; and transformative processes for trimming, shaping, marking, etching, soldering, melting, painting, and sanding.

Facilities correspond to physical spaces where participants interact. Decision theatres, video conference rooms, and Gesell chambers, among others, are used for interactive purposes. However, implementing of ICTs has allowed innovative spaces that thrive in digital domains and can be ubiquitously accessed remotely. Virtual facilities allow participants to share ideas in real-time to shape design and execution strategies. Both physical and virtual environments aim to increase the collaboration and cooperation of participants; thus, OIL relies upon these spaces to increase productivity during project development, but above all, to foster competencies and skills in scholars.

22.4 Open Innovation Laboratory Deployment

OILs turn to the three pillars to develop joint projects with internal and external entities working for a common agenda. There are no rigid guidelines on what an OIL should include. Each project aims to be multidisciplinary, with flexible timetables in different areas and different purposes depending on the interested parties. In this combined effort, academic institutions align traditional courses to fit challenges, projects, or case studies. While institutions have dedicated laboratories or specialized departments, it is still necessary to establish a collaborative process because OIL spaces (third pillar) require availability and accessibility for external actors to participate. Thus, to show an OIL, it is paramount to define: (i) adequate workspaces, (ii) laboratories' capabilities, processes' definition with a directory of available technologies in defined spaces, and (iii) design methodologies to align efforts.

OIL deployment at Tecnologico de Monterrey derives from an initiative to provide laboratories for students, industry, and government to create projects in the same space. Nevertheless, the backbone of the projects comes from design methodologies (second pillar) that focus on developing products, processes, manufacturing systems, promotion, and marketing. A commonly used method brings together efforts for rapid product development (represented at the top of Fig. 22.2): The Product Path Development (PPD) has four colour stages: (i) ideation, (ii) conceptual design, (iii) detailed design, and (iv) prototyping. It includes three sub-paths that parallel the progress for mechanics, electronics, and the informatics system. It also considers the underlying impact of S3 (Sensing, Smart and Sustainable) characteristics on defining a viable product according to current social, technological and environmental trends. Each activity is carried out using OIL physical spaces located at the CEDETEC building on the campus. At the bottom of Fig. 22.2, a brief schematic represents the location of some physical laboratories for the PPD.

The above resources aim to develop integrated learning techniques (first pillar) to boost skills and competencies, thus completing the desired professional profile of students. The three main reasons for constructing and implementing this OIL from

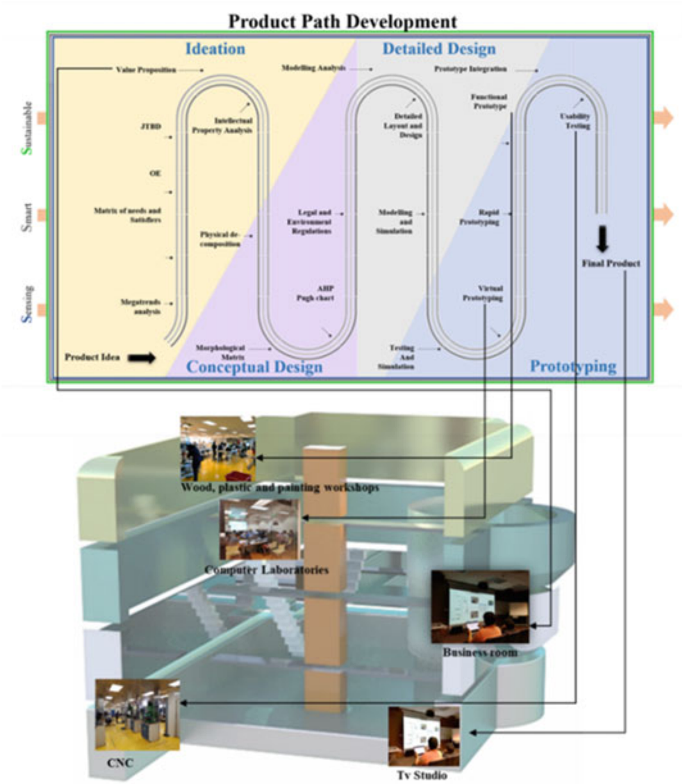

Fig. 22.2 Tecnologico de Monterrey's OIL. Methodology for product development carried out at CEDETEC building

the academic viewpoint will be summarized in the following aspects. (i) Promote desirable skills among digital native collaborators. In Tecnologico de Monterrey's OIL, the skills presented in section three that correspond to relevant competencies for the twenty-first century professional are promoted. (ii) Improve the learning experience. Due to the dynamics involved in working on projects, students develop capacities and abilities that traditional techniques do not offer. OIL's infrastructure broadens the students' vision to propose solutions to current real problems and positively impacts their professional training. (iii) Consolidate knowledge. The lecturer is a facilitator as massive amounts of information are broadly available in various sources. OIL encourages students to play an active role with available resources to seek and deepen practical solutions through collaborative and multidisciplinary projects.

22.5 Case Studies

Joint efforts during 2019 and 2020 to provide experiences in Education 4.0 environments brought remarkable instances documented in case studies, where collaboration and participation of internal and external agents successfully deployed attended real-life problems such as continuous education, product development, and lecture improvement. Taking advantage of this approach. The following case studies documenting this approach were developed within the OIL at Tecnologico de Monterrey.

22.5.1 Massive Open Online Course

The Massive Open Online Course (MOOC) "Rapid Innovative Product Development for Emerging Markets" arose from the Integrated Product, Process and Manufacturing System Development reference framework, a design methodology that has been applied in face-to-face courses. It belongs to the second pillar of the OIL. This MOOC introduces participants to the design methodology and drives them to develop innovative ideas that materialize quickly following a structured procedure.

The course uses different learning techniques within the first pillar of the OIL by encouraging the users' creativity and guiding them with descriptive videos and documents with the necessary knowledge to progress gradually. The proposed activities are graded among "peers," possibly from different geographical locations, encouraging them to develop the desired competencies and receive multidisciplinary feedback. The MOOC is held in eight weeks. Through specific tasks and weekly exercises, students advance through the three phases of developing the product: imagination, conceptualization, and design. This course has a nontechnical approach to encourage the adoption of its principles among different persons with variety of geographic locations, areas of study, ages, among others. The course has had an excellent reception in the Latin American community; most users come from Mexico, Colombia and Peru. Nearly twenty thousand students have enrolled since its launch in 2016, and course statistics have quite favourable ratings, 4.6 out of 5 stars. Comments are primarily positive and are considered by the designers to improve students' experience in the future.

22.5.2 Integrated Manufacturing System Course

The Integrated Manufacturing Systems Course (IMS) is offered to undergraduate sixth-semester students in the Industrial Engineering major at Tecnologico de Monterrey, Mexico City campus. It has a duration of four months in a three-hour scheme per week. In a physical course, students attend the classroom to share information, sources, and techniques provided by the lecturer. The method has been adapted as a Challenge-Based Learning course; therefore, a final project is required for the final grade, demanding five extra hours of individual active learning per week. IMS uses the OIL third pillar to shape proposed ideas into physical prototypes. Tollgates (delivery points) are defined along the course, and students are responsible for their coordination; thus, collaboration is needed to accomplish all activities on time.

In the end, documentation on the four stages of the IMS is delivered. These are Stage one: generate ideas considering manufactured articles available in the market. The product and information model, as well as product attributes, are developed with engineering tools. Stage two: identify necessary manufacturing processes for their products considering the material properties such as roughness, volume, finishing, tolerances, and shape. Schematize an optimal process path showing suppliers, manufacturing cycles, and availability for a given time of production. Stage three: Simulate and optimize the system's operation, considering all resources needed, using plant design software, and including machines and processes times to distribute their facility. Stage four: Conceptualize the enterprise to define the best strategy for proposing a business model to commercialize the products. Expected learning outcomes are developing competencies such as critical thinking, collaborative work, problem-solving and increased active learning. Also, according to the ABET accreditation program focused on students' competencies, expected outcomes include a global vision, leadership, and entrepreneurial spirit within the OIL ecosystem.

22.5.3 Summer Research Stays

Summer research "boot camp" stays are held each year at the Tecnologico de Monterrey between June and August. Public and private institutions participate in collaborative exchange research projects as part of Open Innovation initiatives. Students involved belong to the last semesters of an undergraduate program and come from different formation areas; thus, the participants form a multidisciplinary group. These boot camps are held in the OIL and take advantage of the design methodologies, facilities, and technologies. Hence, participants are challenged for seven weeks to create a product. This methodology integrates the participants' knowledge to elaborate the product, process, manufacturing system, and business model. Participants use spaces and tools to generate the ideas, basic design, detailed design, and functional product prototypes.

It is an intensive stay; other OIL instances boost students' performance, such as the MOOC from the first case study, which provides the necessary insight into the product design. The result is knowledge of how a product is developed when participants enter their stay. The course design has proven high success rates, appropriately adapting to different engineering areas such as mechanical, electrical, electronics, mechatronics, industrial, and textile, to mention a few.

Even if participants start with a vague idea of the product to develop, the intensive course and methodology encourage them to solve existing societal problems. For example, "Attachable garments" arose during the 2018 summer as a product that came from collaborating participants in Textile, Industrial, Mechatronics and Industrial Chemical Engineering. The project contributed to supplying garments in developing countries to people with scarce resources. A wide variety of solutions were studied, and finally, the production of clothing products assembled by end-users was chosen, thus reducing costs without losing sight of the product utility and resistance. It was created using rapid product realization platforms (third pillar) such as reconfigurable micromachines as a prototyping tool. The attachable garments project developed the processes, manufacturing system, and business model aiming for viable commercialization. This OIL instance generated a change of thinking among the participants. In their words: "This project provided the tools, steps, and guidance through engineering, process and economic analysis to develop and launch products."

22.6 Findings and Conclusions

This work presents the OIL's schematic approach and delves into the methodology deployed at Tecnologico de Monterrey. It presents three cases, referring to the implementation of the concepts raised in practical projects developed inside the institution and involving the participation of internal and external actors. The participants' skills development and knowledge reinforcement in various periods and contexts were observed using the OIL ecosystem. Improvement in at least the following competencies was observed: collaboration, cooperation, critical thinking, communication, creativity, and innovation. Design methodologies play a fundamental role in how projects are structured, while learning strategies motivated students to take advantage of available resources for project development. Finally, technologies, laboratories, and spaces promoted interaction, testing, and development of innovative projects.

OIL deployment in higher education has positively impacted how students perceive knowledge, interact and develop practical skills to fulfil projects in conjunction with the industrial sector. In this way, not only does knowledge become practical and prevail for a longer time, but prompt interaction with the industrial sector promotes exchange and understanding of needs in both directions. Future work will focus on an OIL's achievement and learning measurement.

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