World Academy of Science, Engineering and Technology
International Journal of Educational and Pedagogical Sciences
Vol:11, No:5, 2017

Open Innovation Laboratory for Rapid Realization of Sensing, Smart and Sustainable Products (S^3 Products) for Higher Education

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***Abstract*—**Higher education methods need to evolve because the new generations of students are learning in different ways. One way is by adopting emergent technologies, new learning methods and promoting the maker movement. As a result, Tecnologico de Monterrey is developing Open Innovation Laboratories as an immediate response to educational challenges of the world. This paper presents an Open Innovation Laboratory for Rapid Realization of Sensing, Smart and Sustainable Products (S^3 Products). The Open Innovation Laboratory is composed of a set of specific resources where students and teachers use them to provide solutions to current problems of priority sectors through the development of a new generation of products. This new generation of products considers the concepts Sensing, Smart, and Sustainable. The Open Innovation Laboratory has been implemented in different courses in the context of New Product Development (NPD) and Integrated Manufacturing Systems (IMS) at Tecnologico de Monterrey. The implementation consists of adapting this Open Innovation Laboratory within the course's syllabus in combination with the implementation of specific methodologies for product development, learning methods (Active Learning and Blended Learning using Massive Open Online Courses MOOCs) and rapid product realization platforms. Using the concepts proposed it is possible to demonstrate that students can propose innovative and sustainable products, and demonstrate how the learning process could be improved using technological resources applied in the higher educational sector. Finally, examples of innovative S^3 products developed at Tecnologico de Monterrey are presented.

***Keywords*—**Active learning, blended learning, maker movement, new product development, open innovation laboratory.

I. Introduction

THE maker movement consists of a culture of hands-on making, creating, designing, and innovating. Thus individuals and groups are involved in creating innovative products. According to Rosenfeld E., the maker movement is defined as "the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others" [1]. In this sense, Open Innovation Laboratories and makerspaces surged as a physical forum in order to offer a place where people could be able to design, invent, make, create and learn. In addition, these types of spaces are also known as Hackerspaces, Invention Labs, Invention Studios, Innovation Laboratories, Product Realization Labs, and FabLabs [2], [3]. In this context, the internet has an important role in the maker movement since there are data resources like forums, video sharing-websites, and MOOCs to provide a channel for sharing experiences and knowledge.

The maker movement is related to shared experiences and knowledge, and there are different techniques and resources to accelerate the interchange of information; thus, this proposal uses the Open Innovation concept to support the sharing process through an Open Innovation Laboratory. According to Chesbrough, "Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" [4]. A recent definition of Open Innovation is given by Chesbrough and Di Minin, where they define Open Innovation as "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model" [5]. Lausern and Salter mentioned that "an Open Innovation model is using a wide range of external actors and sources to help them achieve and sustain innovation" [6]. Therefore, applying this concept in combination with a laboratory is possible to get collaborations of partners for the development of new products and services in priority sectors such as energy, education, biomedical, agribusiness, aeronautics, robotics and industry 4.0.

In this work is presented an Open Innovation Laboratory for Rapid Realization of Sensing, Smart and Sustainable Products (S^3 Products) that has been implemented in NPDNPD and IMS topics at Tecnologico de Monterrey. The Open Innovation Laboratory includes three specific resources: (1) use of specific platforms developed by Tecnologico de Monterrey e.g. S^3-Microfactory, (2) use of specific methodologies for NPD e.g. the Integrated Product, Process and Manufacturing Systems (IPPMD) for the development of S^3 Products (Sensing, Smart and Sustainable). And (3) use of specific learning methods such as Active Learning and Blended Learning.

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II. Literature Review

A. The Maker Movement and the Manufacturing Sector

Manufacturing has a crucial role in the economy since it generates millions of direct and indirect jobs and generates a significant percentage of the gross domestic product (GDP) of countries. For example, a report from the Manufacturing Alliance of Communities (MAC) indicates that in the USA "the manufacturing sector produced 12 million direct jobs and 17.4 million indirect jobs" and its GDP is 12.5%, which is higher than other sectors [7]. In Mexico, the manufacturing sector contributes about 30% of the national GDP. In this sense, the maker movement is an excellent channel to promote the development of the manufacturing sector by carrying out the development of new products that could solve current problems of society, and thereafter the development of new manufacturing enterprises.

The maker movement has been growing rapidly in the last years, implementations of makerspaces in schools, libraries, shops and digital resources have been adopted by many developed countries. Developing countries have begun to use it too, for example, in Mexico, the Mexican Institute of Entrepreneurship (INADEM) has certified 15 makerspaces [8] and the international organization of hackerspaces reports a total of 18 makerspaces in South America [9]. These data reflect that it is important to provide more initiatives and more accessible resources in order to increase this movement.

B. The Maker Movement in Education

Lee, M., identifies three main elements of the marker movement related to education; (1) Digital tools, including rapid prototyping, and low cost microcontroller platforms; (2) Community infrastructure that includes online resources such as MOOCs and video sharing-websites, and in-person spaces and events such as makerspaces and innovation labs; and (3) the maker mindset [10]. The relationship between the maker movement and education is summarized in Table I; there are identified seven aspects: curriculum, sophisticate tool, observation, experimentation, technical skills, learning environments, and learning communities (see Table I).

C. Active Learning Method

The Active Learning emerges from the need of society and organizations to have graduates with the skills, experiences, and knowledge necessary to tackle the current problems of society; thus, they have to be able to propose solutions in an analytically, creatively and practical way [11]. According to Bonwell and Eison, the Active Learning concept implies that "Students must do more than just listen in the classroom". Therefore, students must do different activities during their learning process (e.g. teamwork, use video sharing-websites, use learning platforms, implement group discussions, etc), in order to applying their skills, knowledge, and experiences learned to propose solutions to social problems [12]. The dynamic of this method allows students to gain constant feedback from peers and/or teachers. Therefore, the learning process is customized and improved in comparison with traditional learning methods. In addition, this active learning method promotes the use of emerging didactic technological resources such as video sharing-websites, social networks, online learning platforms, MOOCs and so forth. The main objective of this method is to provide students the analytical skills, development of creativity skills, and that they have the initiative to propose solutions to current problems of society; all these, through different teaching resources e.g. using technological devices or using specific techniques. Some of the techniques used in Active Learning for this particular work are Problem-Based Learning (PBL), Case-Based Learning (CBL), Project Oriented Learning (POL), Service Learning (SL), Challenge-Based Learning, and Online learning using MOOCs [13].

TABLE I
Relationship between Maker Movement and Education (Adapted from Lee [10])

Aspect	Relation
Curriculum	The making process aligns with the curricular demands of schooling.
Sophisticate tool	The making process gives youth access to sophisticated tools for building and for thinking. Thus the student could learn how to use them.
Observation	The making process involves creating things, seeing how they perform and sharing them with others.
Experimentation	The making process is highly tolerant of errors. Thus, it leads to the development of conceptual knowledge and promotes adaptability in the face of challenges.
Technical Skills	The making process advocates a growth mindset, encourage persistence, and challenge seeking and learning.
Learning environments	Learning environments that support autonomy and control of their endeavors.
Learning communities	Making occurs within linked learning communities, spanning face-to-face classes and online courses, and involving people of a wide range of ages and knowledge.

D. Blended Learning Method

Blended Learning method has been defined as "the thoughtful integration of classroom face-to-face learning experiences with online experiences" [14]. Other authors defined it as "the current trend to complement face-to-face classes with web-based materials" [15]. In the literature, this way to teach is also known as "hybrid courses" or "mixed-mode courses" [16]. The Blended Learning method is considered as a new paradigm in modern education, and it has been implemented in many institutions of higher education with significant results. The American Society for Training and Development (ASTD) identified the term "Blended Learning" as one of the most important trends to emerge in the knowledge delivery industry. The Blended Learning method has three general purposes: (1) enhanced pedagogy, (2) increased access and flexibility, and (3) improved cost-effectiveness and resource use [17].

III. Open Innovation Laboratory for Rapid Realization of Sensing, Smart and Sustainable Products

Tecnologico de Monterrey is interested in supporting the economic development of Mexico promoting the maker movement. In addition, it is aware the novel learning methods need to be used in order to transmit knowledge effectively.

Therefore, it proposes the implementation of an Open Innovation Laboratory for Rapid Realization of Sensing, Smart and Sustainable Products (S^3 Products). This laboratory assists in the development of a new generation of products that adopt the concept of Sensing, Smart, and Sustainable. Furthermore, the courses for NPD are complemented by the implementation of the S^3-Microfactory, the use of specific frameworks for NPD such as the IPPMD reference model and the Creative Thinking Model (CTM) to develop new products, the implementation of the Active and Blended Learning methods and the use of specific rapid realization platforms developed by Tecnologico de Monterrey. The scope of the Open Innovation Laboratory is presented in Table II.

TABLE II
SCOPE OF THE OPEN INNOVATION LABORATORY

Areas of Application	Methodologies and Learning Methods	Tec Rapid Product Realization Platforms
• Aeronautics • Agribusiness • Biomedical • Education • Energy • Industry 4.0. • Robotics	• IPPMD reference model • Creative Thinking Model (CTM) • Active Learning using the techniques of: PBL, CBL, POL, SL • Blended Learning using MOOCs	• S^3-Microfactory • Artificial Intelligence Toolkit • Apps Development • Virtual Prototyping • Rapid Prototyping • Remote Laboratories • MOOCs

The Open Innovation Laboratory is using the concept "S^3" for the development of products which adopts the characteristic to be sensing, smart and sustainable. The sensing concept means the capability of a product to monitor its functionality, so the main objective is to collect data from an environment in order to provide specific information that will be used to improve the product functionality (e.g. optimization, monitoring, control, autonomy). The smart concept is applied to design and develop products enabling to work in an interconnected environment, so then connected products offer exponentially expanding opportunities for new functionality, greater reliability, higher product utilization, and capabilities that cut across and transcend traditional product boundaries and also this concept is applied to improve the decision-making process in order to enhance the product performance, and thus, different types of control algorithms are used [18]. The sustainability concept is also related to design sustainable products and manufacturing processes pursuing environmental, social and economic objectives [19]. So then, consumers will take advantage of the resources offered by the product and will support to reduce environmental damage. The adoption of the S^3 concepts aims at generating innovative low-cost products, the birth of enterprises, and employment generation.

The Open Innovation Laboratory may contribute to promote entrepreneurship in the university. Thus it gives students an opportunity to tinker with the products they already own, as well as simplify the process of developing new products and services [20]. In other words, the Open Innovation Laboratory may offer the tools and technologies to build and invent new products of different sectors such as energy, education, biomedical, agribusiness, aeronautics, robotics or industry 4.0. This laboratory could support the generation of Small and Medium-Sized Enterprises (SMEs) by students because of the easy access to emergent technologies that support the quick development of prototypes which is an essential component of bringing products to the marketplace.

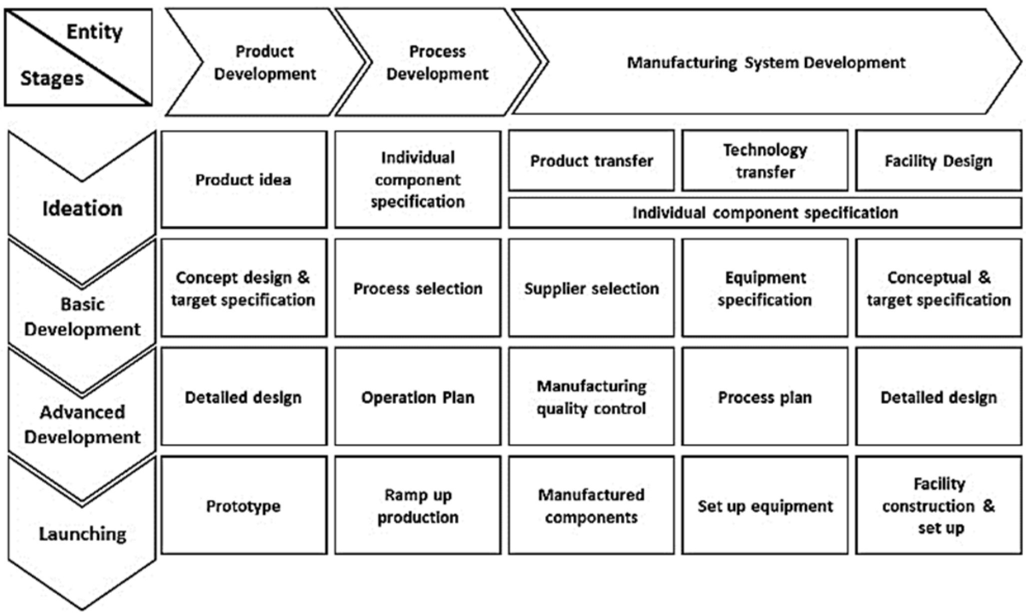

Fig. 1 Integrated Product, Process and Manufacturing Systems Reference Model for the development of products

The framework used in face-to-face classes is the Integrated Product, Process, and Manufacturing Process Development (IPPMD). The IPPMD is a reference model used for the development of products, manufacturing process and manufacturing systems; therefore, all the product life-cycle stages are considered during the product realization process. The IPPMD provides a generic model that is composed of three axes: Stages (ideation, basic development, advanced development, and launching), views (function, information, resources, and organization), and processes (product development entity, manufacturing process entity, and manufacturing system entity) (see Fig. 1). In this implementation, is only used the entity of Product Development for the development of S^3 Products, so then the stages of Product Idea, Concept Design and Specification, Detailed Design and Prototype are taught in the courses [21], [22].

The S^3-Microfactory proposed is the primary physical resource of the Open Innovation Laboratory. It is composed mainly by Reconfigurable Micro Machines Tools which are Sensing, Smart and Sustainable Machines [23], [24]. These machines provide different functionalities useful in makerspaces, such as 3D Printer, Lathe, Laser Cutting/Engraving Machine, Drilling, and Milling Machine (see Fig. 2).

As mentioned before, the courses are enriched using the Active Learning method, which is based on implementing different techniques such as PBL, CBL, POL and Online Learning; the Blended Learning is implemented in face-to-face courses in combination with the course "Rapid Development of Innovative Products for Emerging Markets" which is a MOOC taught by Tecnologico de Monterrey in Coursera since 2013. This MOOC has involved about 65,000 students from about 105 countries. The MOOC is based on the Creative Thinking Model presented in Fig. 3. Thus it is divided into three stages: Divergence which main objective is to generate the product or service idea. Structuring which has activities to understand customers need, and finally, the stage of convergence where the concept is converted into a prototype [25]. This MOOC is offered at the same time as the face-to-face classes during the first eight weeks of the semester, and there the students are learning about Product Idea, and Concept Design. Then, during the last eight weeks of the semester (only face-to-face classes) the students are learning about Detailed Development and Prototype Development.

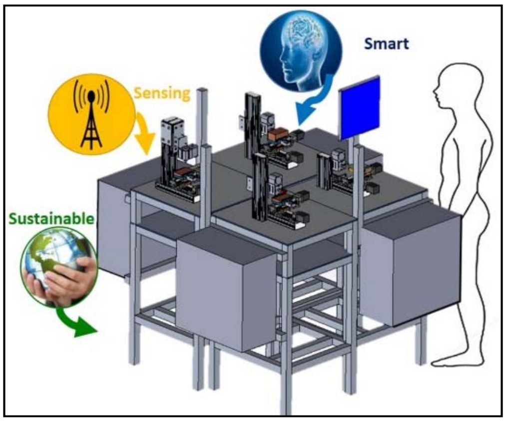

Fig. 2 S^3-Microfactcory as primary physical resource used in the Open Innovation Laboratory

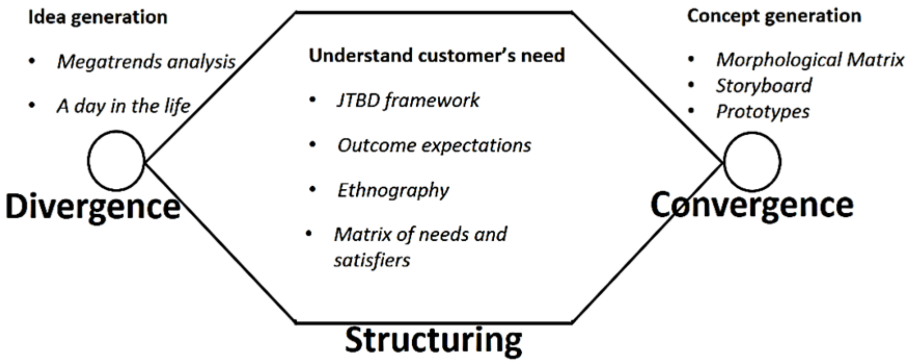

Fig. 3 Creative thinking model used in the MOOC "Rapid Development of Innovative Products for Emerging Markets"

IV. Case Studies

In this section are presented five examples of prototypes that were developed using the entity of product development of the IPPMD. These prototypes are considering specific requirements for the S^3 Product Development and using specific resources hardware and software provided by the Open Innovation Laboratory.

A. Sustainable Intelligent Greenhouse (Agribusiness Sector)

The Sustainable Intelligent Greenhouse was developed in order to improve the environmental conditions in which plants are growing. The Sustainable Intelligent Greenhouses includes the appropriate equipment that can further improve the environmental conditions by means of climate and irrigation control. There are several tools for improving and controlling the climatic and irrigation conditions in a greenhouse, and one of that is applying an Intelligent Control System; so, then it is implemented in LabVIEW™ and based on the Intelligent Control Toolkit for LabVIEW™ (ICTL). In addition, a NI USB-6211 data acquisition (DAQ) target is used for acquiring and generating signals. It is a device optimized for good accuracy at fast sampling rates. Digital triggering is also offered with this device. No external power supply is required. These software and hardware are optimized for simulation and validation. Three control systems were designed for regulating environmental conditions, i.e. temperature and light intensity. Additionally, Relative Humidity (RH) is also controlled with an on/off controller to keep it in a range of 50%RH to 70%RH (see Fig. 4) [26].

B. Robot Assisted Play for Children with Autism (Biomedical Sector)

This prototype is a robot called TEC-O which is used in autism therapies. The robot was specifically designed for the treatment of autism, and can be applied to the complete spectrum of social-therapies. TEC-O is mainly designed to attract the child's attention in autonomous mode; when the child does not pay attention, the therapist can use the manual mode to again capture the child's attention using different social resources (see Fig. 5). The software is developed using LabVIEW™ and developing a graphical interface. With LabVIEW™, results are obtained automatically. The vision system is performed using the NI IMAQ module of LabVIEW™ [27].

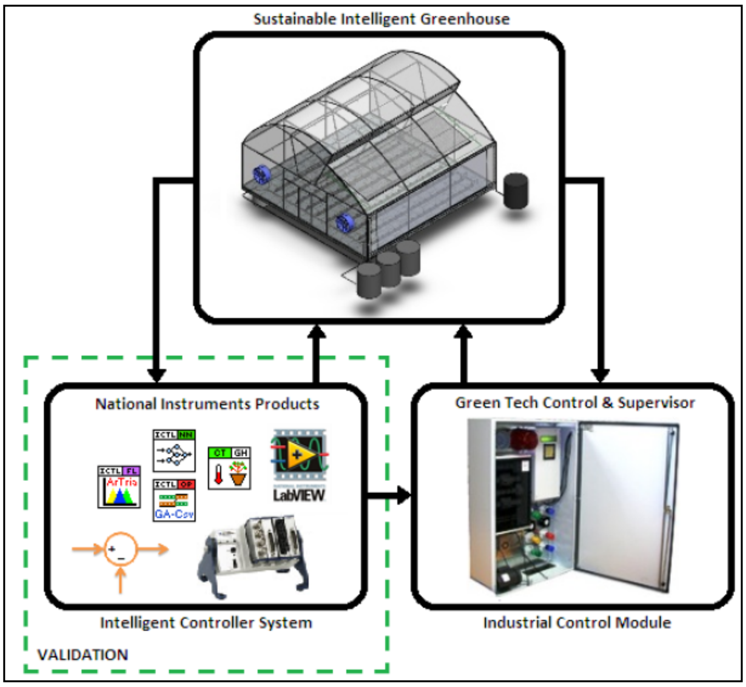

Fig. 4 Sustainable Intelligent Greenhouse using AI Toolkit

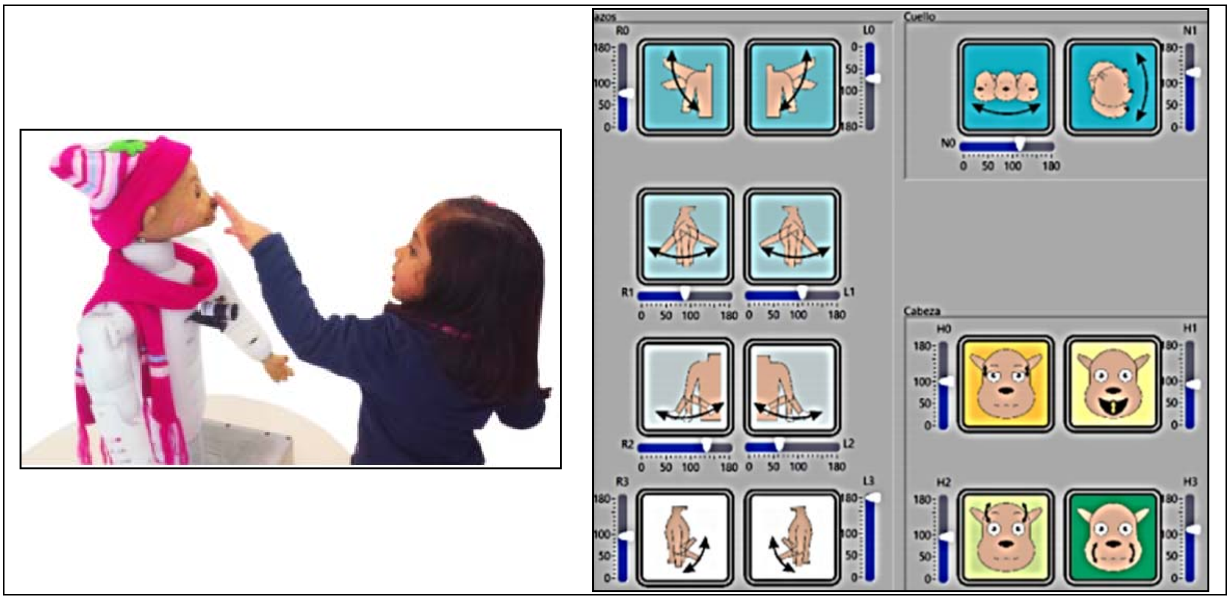

Fig. 5 Prototype of a Robot for autism therapies using rapid prototyping and app development

C. Reconfigurable CNC Micro Machine-Tool (Educational and Industrial Sectors)

This proposed teaching tool involves a mechatronic system focused on modern manufacturing areas, which are significant for educational purposes. Concepts such as the reconfigurability of the system (hardware-software) and system size (portable) have been deeply studied and can now be further developed. Miniaturization, reconfigurability, emerging design methodologies, and the use of low-cost elements are innovative features that bring advantages over the existing machines in the market, and enable the acquisition of the reconfigurable manufacturing systems to educational institutions. The Reconfigurable CNC Micro Machine-Tool was designed to fulfill three technological processes of machining; thus, it has a collection of parts that can be configured in: Lathe, Drilling and Milling Machine [23] (see Fig. 6).

Fig. 6 Prototype of a Reconfigurable CNC Micro Machine-Tool as Cyber-Physical Production System

D. Edu Trends: Remote Laboratories (Educational and Industrial Sector)

The main objective of this project is to implement technological platforms for distance learning and training, promoting collaboration and implementation of knowledge, place the institution at the forefront of Innovation and Technology in Education and mark a clear element of differentiation and leadership in the national and international context [28]. The Remote Laboratories are technological platforms that allow performing experiments and laboratory practices with remote and real-time access; thus, they are equipped with controllers for industrial use and scale models of real processes, for electronic, automation and control areas. The Remote Laboratories Platforms meet three specific goals: (1) Provide students remote access to laboratory resources outside the classroom and school hours. (2) Allow teachers to present laboratory experimentation activities without leaving the classroom. (3) Share laboratory resources available to each campus through a network of remote laboratories.

Today, Tecnológico de Monterrey has an intercampus network which is composed by 10 workstations (Remote Labs) in four campuses and four more that are in process of implementation (see Fig. 7). Also, we are working in the development of two more platforms for MOOCs within the Electrical Engineering area and finally, three platforms more called "National Remotes Labs" for Power Electronics, Electric Machines, and Energy.

Fig. 7 Rapid Prototype of a Remote Laboratory

E. Visuo-Haptic Simulators (Education and Training)

The objective of this project is to develop new knowledge about how haptic-based learning experiences can mediate conceptual understanding and representational competence of difficult concepts and acquisition of skills and competences for certain process [29]. In this regard, the use of haptic devices, which reproduce the sense of touch, combined with appropriate virtual environments has the potential to make abstract and difficult concepts in science accessible to learners. In particular, we investigate the best uses of touch technologies to help students connect systems behaviors in terms of governing forces and their different representational forms. The newly derived knowledge will inform our understanding about how students "learn by touch" as well as the interplay between conceptual understanding and representational competences, as well as the acquisition of skills and competences for certain complex tasks that require the sense of touch. In Tecnologico de Monterrey we have developed two groups of applications:

A. Virtual environments for training suture skills, which use two Sensable Phantom Omni haptic devices [30] (see Fig. 8).
B. We explore how haptic devices can be used to effectively enhance learning experience in traditionally difficult concepts from Physics.

Fig. 8 User interacting with a mechanical visuo-haptic environment using virtual prototyping and app development platforms

V. CONCLUSION

This paper proposes an innovative learning process based on new educational paradigms, ad-hoc technological platforms, and emerging technologies. This learning process is sustained on the concept of Open Innovation Laboratory for Rapid Product Realization of Sensing, Smart and Sustainable Products. This laboratory uses the maker movement to stimulate an entrepreneurship culture and foster the incubation of companies for economic development. This paper has presented the fundamentals elements of the laboratory (Methodologies for NPD, Learning Methods and Rapid Product Realization Technological Platforms). This Laboratory has been the foundations to support different courses at Tecnologico de Monterrey to demonstrate how students and teachers can propose innovative products enabling to solve current social issues without geographical limitations. Using this learning process, students have an active learning experience through engineering practices, exercise and experimentation, and thus, they can address real-life problem scenarios and propose solutions by developing novel products.

ACKNOWLEDGMENT

This project is founded by the Connected Communities Initiative from CITRIS at California University, Berkeley and Tecnologico de Monterrey, and the NOVUS program funded by Tecnologico de Monterrey.

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