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A comprehensive methodology for developing technological and potentially innovative projects

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Abstract. Based on their technological competencies, students must develop projects based on an integral methodology that responds to real problems with empathy and a sustainable vision so that, at the end of their studies, they can become entrepreneurs and generate jobs, or else technology transfer could occur. This methodology has been developed and tested at the Emiliano Zapata Technological University of the State of Morelos (UTEZ) with the support of experts from other Higher Education Institutions (HEI) since 2016, maturing through developing and improving selected prototypes aligned with strategic areas. This methodology was developed by integrating various existing strategies, techniques, and tools entrepreneurs use to provide students with tools and experiences that allow them to carry out technology-based entrepreneurship at the end of their studies since employment opportunities are generally scarce. This methodology has fostered learning activities that are participatory and interactive based on STEAM among students. It supports the formation of creative and empowered engineers capable of working in collaborative teams. The results obtained from participation in various innovation contests and competitions validate the methodology, which has enabled the student teams to receive awards and recognitions at the national and international levels. Previously, this type of participation was incipient. However, a tremendous pending step is the transfer of technology.

Keywords: Collaborative teams, Technologic Universities, SCAMPER, Experts Evaluation. Empowerment.

1 Introduction

An excellent challenge for higher education institutions (HEIs) in Mexico is to ensure that the knowledge generated has an economic impact on the lives of students and the generation of employment through the creation of technology-based companies (TBCs). Once a product or process has been validated and protected by Intellectual Property Rights (IPR), it may be used as a basis for creating technology-based companies or transferred. Therefore, it is essential to know these last two terms.

Technology-based entrepreneurship (TBE) is an action oriented to commercialize and develop new products or services derived from a high level of knowledge management [1]. It is intended that the graduates of the Mechatronics degree of the Universidad Tecnológica Emiliano Zapata (UTEZ), in case they opt for entrepreneurship, should be a technology-based entrepreneurship, preferably.

Technology Transfer (TT) is a process that allows enterprises to gain a competitive advantage in the marketplace. It is characterized by the transmission of knowledge generated by the university or other instances capable of generating knowledge to an enterprise, allowing it to innovate and expand its technological capabilities [2]. That is, through the appropriation of knowledge, the knowledge learned can be used to generate optimal solutions that reduce dependence on foreign companies and costs in technical assistance and technology acquisition [3].

On the other hand, if a novel technology is valuable, it is likely to be copied, reducing the potential profits of the original inventor and potentially removing the incentive to engage in innovative activities [4]. Therefore, it is necessary to protect the technology through appropriate intellectual property protection to conduct the negotiation process aimed at TT.

In addition, several techniques have been proposed for creating new products and services, intending to speed up the processes and fit them to the needs of the users and the market. Some of these techniques will be described in the following section. Based on their knowledge and the environment, it is possible to identify and add elements to integrate a methodology suitable for the Mechatronics program at UTEZ, which can be replicated in similar environments (see Figure 1).

The intention is to generate competitive prototypes oriented to solving real problems, aligned to current interests, and embodied in regional, national, and/or international development plans, making them relevant and of interest to carry out entrepreneurship or TT. It also contributes to training engineers capable of developing projects with these characteristics to propose solutions, develop, and implement them with a business vision.

Technological Universities in Mexico, which emerged in 1991 to offer intensive studies to students who complete their high school studies in Mexico, so that they can enter the labor market in a short time, seeking that the study programs are related to the demands of local, state and national industry [5]. The number of careers in this subsystem and the type and enrollment of each one are shown in Table 1, according to [6]. As can be seen, engineering and technology constitute more than 50% of undergraduate programs in the field of training, so the proposed methodology can be instrumental in the sector, starting with UTEZ.

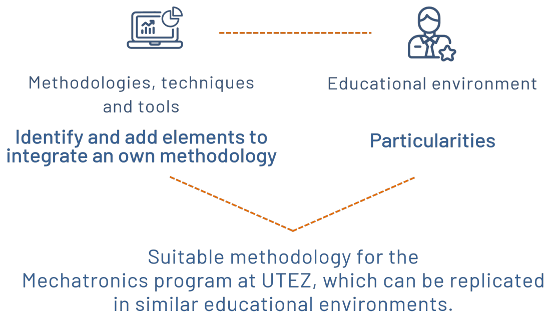

Fig. 1. Bases and vision of the proposed methodology.

Table 1. Technological Undergraduate programs by field of training [6].

Areas of Knowledge	Careers
Arts and Humanities	5
Social Sciences and Law	19
Business and Administration	501
Natural Sciences, Mathematics, and Statistics	35
Information and Communication Technologies	391
Manufacturing and Construction Engineering	971
Agronomy and Veterinary Science	105
Services	7.53

This work aims to design a methodology for developing potentially innovative projects at UTEZ to increase their relevance and the possibilities that they can be the basis for entrepreneurship and/or TT. This methodology seeks to support the training of students, as well as to increase the innovation potential of the projects carried out on the Internet of Things Laboratory of UTEZ, with the support and evaluation of experts in entrepreneurship and innovation of other institutions, as part of the activities carried out in the Integrating learning units, developed in the third, fifth and tenth four-month periods of the Mechatronics career. In addition, during the projects´ development, it is possible to detect areas of opportunity for improvement or the need to acquire new knowledge or develop new abilities.

Students must also appreciate that their preparation in STEAM (Science, Technology, Environment, Engineering, Art, and Math) is relevant to the development of the proposed projects since the level of complexity they face is generally very high. These areas form the solid basis for carrying them out.

In the projects carried out with the methodology shown in this article, it has been essential to consider artistic elements, since the acceptance of the proposed solutions depends to a large extent on how they are presented, highlighting the order, size, and shape, in the case of the hardware developed. For example, the image, distribution, color, and shape are decisive in presentations, apps, and packaging. In [7], it is established that "*Design adds Art and the environment to the STEM equation to contribute site specific, culturally connected, contributions to creative economies*". It should be noted that electrical and electronic designs are an art [8, 9], where simplicity and module layout are highly valued [10]. When these elements or modules are integrated, complex systems are formed that work in harmony, often requiring software to achieve this. In turn, electronic systems can be designed as tools for making art [11]. Finally, communication is also an art that must be developed to present and transmit the relevance of the projects carried out and their subsequent dissemination. In addition, it will be of ample use in their working life [12].

The content of this article is as follows: In section 1, information about the challenge that originates this research and some fundamentals are briefly presented; section 2 describes the theoretical framework. Section 3 shows the methodology designed. In section 4, the experimentation and results are provided. Finally, Section 5 summarizes the findings and provides some concluding remarks.

2 Theoretical framework

To build a customized model for the development of the projects carried out at UTEZ, it is necessary to know the environment in which they are developed, prioritizing the problems identified as strategic. It is also essential to consider the lack of motivation and the incipient participation in competitions, as well as to know some of the representative methodologies, which have demonstrated their usefulness, being adopted by several companies, and finally, to review some tools that are used in such methods, which can be of great utility, to strengthen this model of project generation, and which in turn is an engine of attitude change and fosters competitiveness. The block diagram followed in structuring the proposed methodology is shown in Figure 2.

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Fig. 2. Block diagram followed in the elaboration of the proposed methodology.

2.1. Strategic goals and lines

Sustainable Development Objectives. The Sustainable Development Goals (SDGs) were adopted by the United Nations Organization in 2015 as a universal call to end poverty, protect the planet, and ensure that by 2030, all people enjoy peace and prosperity [13, 14]. Educational institutions should also be drivers of the SDGs, creating awareness and actions for it in their researchers and students. The SDGs are: 1. No poverty. 2. Zero hunger. 3. Good health and well-being. 4. Quality education. 5. Gender equality. 6. Clean water and sanitation. Affordable and clean energy. 8. Decent work and economic growth. 9. Industry, innovation and infrastructure. 10. Reduced inequalities. 11. Sustainable cities and communities. 12. Responsible consumption and production. 13. Cimate action. 14. Life below water. 15. Life on land. 16. Peace, justice and strong institutions. 17. Partnerships for the goals.

Strategic Lines. Unlike others, Singularity University, located next to the NASA Research Center, emerged as a complement to traditional universities to promote entrepreneurship, innovation, and technology. Its Entrepreneurship Program considers the problems shown in Figure 3 as a call to leverage technology for social impact. Its mission is to educate, empower, and inspire leaders to apply exponential technologies to addressing humanity's grand challenges [15].

2.2. Representative Project Management Methodologies

DesignPedia two rhombus model. Based on the double rhombus model, an iterative process composed of four development phases was built, which is not linear. Each phase of work constitutes the entry to the next step. Depending on the results achieved, it is possible to go backwards or forwards. The phases of this methodology are mapping, exploring, constructing, and Testing [16]. Information about this model is restrictive.

Lean Startup. This advantageous methodology (Figure 4) for starting a business, product, or service, widely adopted by companies that create and launch products, was provided by Eric Ries [17, 18]. It aims to iterate business ideas, helping entrepreneurs to decide their feasibility early [20]. The fundamental activity of a startup is to convert ideas into products, measure how consumers respond, and learn when to pivot or persevere, facing conditions of extreme uncertainty [19]. It is about creating a product that the customer needs and is willing to pay for, using the minimum number of resources. A problem of many failed entrepreneurs is that they create a business plan, get the financing, and develop the product, but only get feedback from customers after launching it to the market [21].:

- Build: It involves launching the Minimum Valuable Product (MVP), which should be a version with the minimum functionalities to collect the maximum amount of learning validated by customers [21].
- Measure: It is the most challenging stage, which consists of measuring how consumers respond, i.e., whether real progress is being made, and providing sufficient information to influence strategic planning and make appropriate decisions [19, 31].
- Learn: Determine whether the business is viable and, if so, persevere or, if not, pivot, i.e., substantially readjust ideas that are not working [9, 21].

Fig. 3. Strategic lines of Singularity University's Entrepreneurship Program. Adapted from [15].

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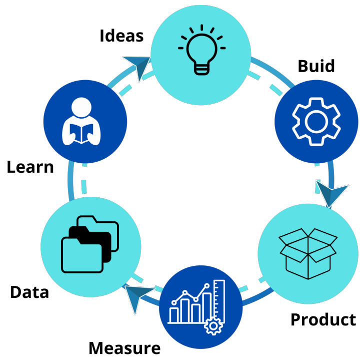

Fig. 4. Lean Startup Methodology [19, 21].

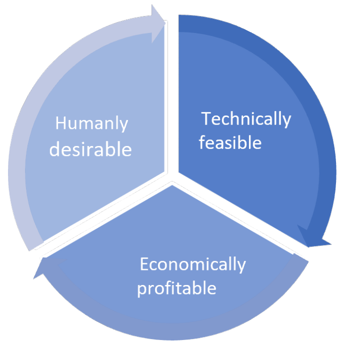

Fig. 5. Aspects considered by Design Thinking [24].

Once the hypotheses and assumptions have been established, the entrepreneur validates them with the customers through the PMV. This allows one to know from a small investment if the developed idea is accepted in the market. If it can be shown that it responds to the customer's desire, its functionalities will be increased. However, a new approach will be considered if the product does not fit the market. The essence of this methodology is to learn quickly, with a minimum investment of resources [21].

Design Thinking. This method solves problems practically and creatively, where a solution to the problem must be generated at the end [22]. It is a not linear iterative process to innovate in products, processes, or services. It constantly moves forward and backward. At the end, a prototype is created, and it is possible to go through the Design Thinking process again. This methodology decreases risks and increases the chances of success. It starts by focusing on human needs, that is, on people, and from them, observes, creates prototypes, and tests them. It connects knowledge from various disciplines to generate a humanly desirable, technically feasible, and economically profitable solution through a creative strategy [23] (see Figure 5) [24].

The creator of this technique, Tim Brown, employs the sensibilities and methods of designers to match people's needs with what is technologically feasible and what a viable business strategy can turn into customer value and market opportunity [24]. It encourages the participation of employees, customers, suppliers, and professionals from different disciplines. This methodology consists of several stages that each designer groups differently, but in essence, they must understand, observe, define, ideate, prototype, test, implement, and learn. In each stage, problems can be defined, questions can be asked, and solutions can be proposed (see Figure 6).

Fig. 6. Stages of the Design Thinking Process. Adapted from [24].

a) Understand. It seeks a deep understanding of what the people for whom the final product is intended do. Meeting with some end users and paying attention to them is essential. An appropriate team is formed to solve the problem [23], comprised of experts from different areas to provide solutions from other approaches. The objective is to solve something, integrating a product or service that offers exceptional value for the customer, which could not be achieved individually [24].
b) Observe. Empathy is generated with the user and his/her environment. It is observed what the consumer does, not only what he/she says [23]. Different interviews and empathy maps are conducted with potential product or service buyers [24]. To connect with customers, it is necessary to understand how they are in their daily lives [25]
c) Define. All possible alternative solutions to the problem are considered, from the most obvious to the most adventurous, without taking any of them for granted. The problem must be structured and defined to clarify and focus the challenge. Subsequently, it is necessary to communicate the project using various tools such as mind maps, conceptual maps, mood boards, or storytelling [24].
d) Ideate. The focus must be kept on the problem without judging too early. At the end of this phase, it is necessary to express the thought with visual tools such as photos, sketches, diagrams, and moving notes. Brainstorming is a handy technique, as it is a way to generate many ideas and take advantage of collective thinking [24, 25]. In [25], the need for a creative leader to move spirits and minds and motivate personnel to solve problems is emphasized

e) Prototype. It consists of building the product or service as quickly as possible by making sketches, mock-ups, foam models, and 3D prints, among other things [20], and even rebuilding again [23]. In [25], the importance of methodology in the educational field is mentioned, where the prototype is the protagonist.

2.3. Representative tools

Customer Journey Map (CJM). It describes the user journey by representing the different touch points that characterize their interaction with a product, service, or company. An example is shown in Figure 7, about the a student of a HEI of Morelos State, based on the free template provided in [26]. It visually describes what customers do, what they think and feel when approaching a brand. It represents what it would mean to be a real customer and indicates to brands where they can offer the experience when acquiring their products or services. CJM is partially unknown in Mexico [27], even though this method is fundamental to all experience design and strategy. It will become necessary for designers and managers working on a brand [28].

2.3.2. Empathy Map

It collects the user's point of view regarding a need or problem, product, or service (Figure 8). The aim is to capture the way of being and acting by answering the following questions [30]:

- What does he/she say and what does he/she think? Opinions and facts.
- What does he/she do and what does he/she feel? Actions and behaviors.
- What does he/she see and what does he/she hear? Things and events the user appreciates or facts and data are reported.

Pain points: Fears, frutrations, obstacles, etc. Gain points: Needs, goals, etc.

With this tool, we can empathically understand the scenario in which the client develops according to the analyzed need.

Focus Group. This is an interview with a small group, which is typically composed of six to twelve homogeneous participants. However, larger or smaller groups and a trained moderator whose role is to guide the discussion so that it does not stray from the topic of study have sometimes been recommended [29]. This group freely answers questions about the product or service, and generally, a significant gift is given to them. This interview is essential in the definition stage, but improving the product or service characteristics is also important.

Field Visit. In this stage, the researchers go to the established place to observe *the users, the environment, and the agents involved in situ*, among other factors. To generate a good field visit, we must start from some hypotheses or facts we want

Interaction Design and Architecture(s) Journal - IxD&A, N.63, 2024, pp. 235 - 267
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to check. It is also necessary to close the objective of the visit to focus on those actions.

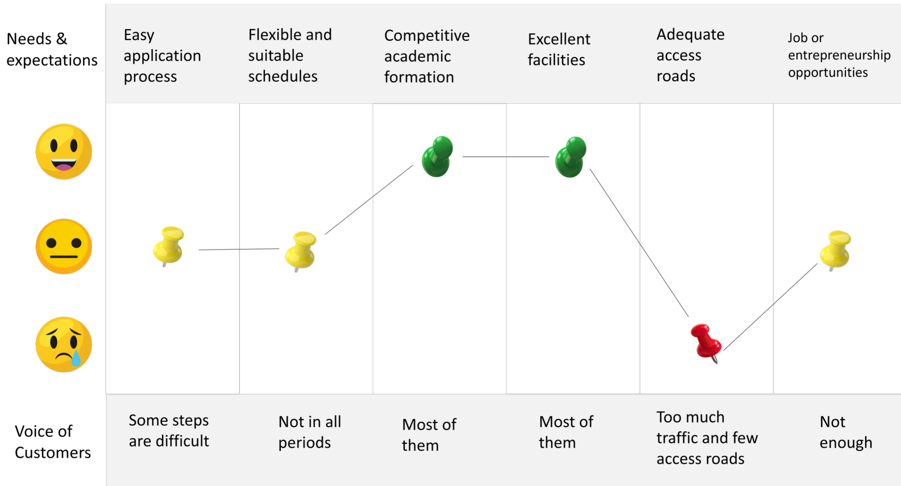

Fig. 7. Customer Journey Map [20].

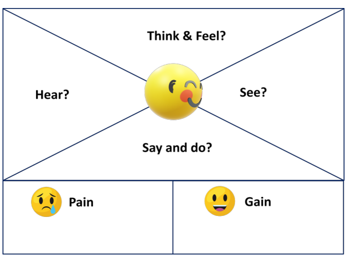

Fig. 8. Empathy Map. Adapted from [30].

Fig. 9. Stages of the Canvas Business Model. Adapted from [30].

Canvas Business Model. It is one of the main tools of the lean startup [20], which captures on a canvas the realities that every entrepreneur must articulate. It is a tool for analyzing business ideas, which logically describes how organizations create, deliver, and capture value (see Figure 9) [30]. This technique allows teams to assess [21] and articulate their assumptions about the business idea [20] quickly. Its nine blocks [19, 30] are shown in Figure 9. Interviews with customers and other stakeholders are conducted to confirm or disconfirm these assumptions [20].

Interaction Design and Architecture(s) Journal - IxD&A, N.63, 2024, pp. 235 - 267
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SCAMPER. It is a convenient technique for developing creative thinking skills [31], and the generation of ideas is favored by answering a preset list of questions [32]. It is considered one of the most complete tools in generating ideas. Each of the letters of its acronymous is the first letter corresponding to a verb that triggers a series of questions that establish a certain order in the process of idea generation (Figure 10):

Fig. 10. Stages of SCAMPER. Adapted from [32].

Video Marketing. It is extremely useful to capture in a multimedia file information about the main concept of the project, the problem, its objective, as well as the proposed solution. Different video editing tools can be used to create these materials. It is recommended that their duration does not exceed 3 minutes. A well-made video catches the viewer's attention.

Technology Readiness Level (TRL). It is used to measure the technological maturity of the technology, which arose at NASA but was later generalized to be applied to any project. It is an accepted way of measuring the degree of maturity of a technology. This scale considers nine levels that extend from the basic principles of the technology to its successful testing in a real environment (see Figure 11) [33].

Fig. 11. Technology Readiness Level [33].

3 Methodology proposed for development of innovative projects

After reviewing the methodologies found to be relevant, both those found in the literature and those learned in different innovation contests, and considering the strategic problems, an integral method was proposed to be congruent with the Mechatronics curriculum of the UTEZ. Its structure increases the relevance and the possibilities of the developed projects, with the objective that it can be aspired to constitute the basis for entrepreneurship and/or TT. At the same time, this methodology seeks to support the training of students as part of the activities conducted in the Integrating learning units of the Mechatronics degree program. Motivation was also considered a fundamental requirement. These learning units are four-monthly, so the methodology must be agile and adapted to the duration; therefore, the phases of the method must be specific.

Figure 12 shows the distinct phases of this proposed methodology, based on the experience in developing projects with innovation potential. The blue lines show the desirable successive sequence; however, in each of them, it may be necessary to go back to previous stages, which is shown with the red lines. This means that it is possible to move forward or backward, to any stage, depending on the needs. It should be noted that the stages integrate tools, methods, and models. It also includes steps that are considered necessary, such as motivation, expert evaluation, and dissemination. In this last stage, participation in exhibitions and competitions is emphasized. The stages of the proposed methodology are:

Fig. 12. Stages of the proposed Methodology.

Stage 1: Motivation. Presentation of Challenges and Opportunities. It consists of two essential activities that must be carried out to encourage students to carry out research projects aimed at solving strategic problems. These activities are:

- Background on Innovative Projects. Students are shown a series of videos on innovation projects, such as the call for the "James Dyson Award." This contest is held every year at the national and international levels. The objective is to reward the best designers in innovative solutions.
- Motivation by Background. Motivation plays a leading role in searching for and generating innovative ideas. Students are shown current projects carried out by students who preceded them and achieved significant results with the methodology used during their participation in technological innovation contests and competitions.

It should be noted that, previously at UTEZ, projects were developed aligned in solutions entirely for the local industry, so there was a different approach to developing projects, where the ones with the highest cost and size were considered the best. Since 2016, the Centro Morelense de Innovación y Transferencia de Tecnología has issued the TecnoCemiTT calls for participation with different innovative projects that solve problems. Since then, the projects have sought to solve a problem with a well-defined market. Since this year, all the projects carried out in the integrative subject have sought to empathize with one of the problems identified by Singularity University and the SDGs. In addition to the fact that this stage focuses on motivation, it is shown that projects oriented towards regional, national, and international priority issues have greater chances of success by adding relevance and interest to the proposed solution. It was not until 2018 that the complete methodology proposed here was applied.

Stage 2: Empathize. Teachers and students detect different opportunities for innovation through the generation of ideas using some of the following techniques:

- Idea Generation. This phase will support the definition of the possible projects to be carried out, reviewing the different actors and scenarios where impact is sought. Ideation begins based on the strategic lines of Singularity University and the SDGs. As a result, students or teams of students will have several ideas about the project they will develop, supported and backed by a professor who, according to his/her experience and the projects developed, will give his/her opinion on the relevance of these ideas, making idea selection.
- Customer Journey Map. It identifies users' positive and negative experiences and proposes solutions that respond to user needs positively. Before proposing ideas, we could identify our users' current journeys to better understand their activities and problems.

- Empathy Map. This tool allows one to synthesize the user's emotional and rational aspects in greater depth through a canvas that captures their actions and feelings in relation to the problem addressed.

Stage 3: Definition. The teams define the idea based on the data and results obtained from the previous stage. Among the tools suggested to explain the concept are:

- Focus Group. Information should be obtained about the problem addressed and the idea developed to solve it, identifying their shared experiences or desires.
- Field Visit. Once the different spaces of concurrence of our problem/person/object of study have been identified, the students go to the established place to observe in situ the users, the environment, and the agents involved, among other factors. Previously, the hypothesis or facts that are sought to be verified and identify the objective of the realization are established.
- Business model. It is designed to evaluate the idea being proposed quickly. By having the respective commercial proposal and identifying the elements required to comply with each of the segments, a complete picture is obtained, both technical and financial, which seeks to reduce uncertainty and risk during its execution.

Stage 4: Ideate. Once students have defined the ideas, considering their feasibility, relevance, and potential, they must select the one with which they identify. To do this, a consultation is carried out with the teacher who, based on his/her experience, will be able to select and determine the best idea to work in the other stages (Figure 13). It is necessary to mention that, in this process, communication skills between students and with the teacher are also reinforced. Feasibility requires solid knowledge about the physical systems involved, the technology involved, and the engineering that will support the proposal, making the importance of these STEM areas remarkable in the previous training of the members of the work teams. About relevance and potential, among other tools used at this stage are:

- SCAMPER. The corresponding questionnaire is used to define the project's characteristics simply through a series of questions agreed upon as a team or individually.
- Video Marketing. This deliverable gives the project a strong presence in the different contests and presentations that are held. In addition, some of them explicitly request it.

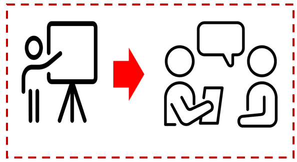

Fig. 13. Ideation process with teacher assistance.

Stage 5: Prototyping. Teams are given a maximum of five weeks to have an MVP. At this stage, the following activities are developed:

- Prototype Design. A sketch, a 3D print, or a design made in a computer-aided design program is provided. This is an important activity to visualize the product in a physical form and perform the next activity.
- Manufacturing and Testing. This activity is of the utmost importance for all projects. It defines the project's qualification in the field of integrator, but beyond that, having the prototype will make the project venture into different contests, competitions, or project presentations. To do this, 4 weeks are allocated for obtaining the materials and supplies to make the prototype. To conclude this activity, projects should be presented to different innovation specialists to get feedback.
- Technological Maturity Level. This tool helps us measure the technological maturity of the developed projects, which will be an indicator in the expert review and evaluation.

To carry out a successful prototyping, students must have knowledge, skills, and abilities in STEM, such as basic knowledge in the areas of science or engineering involved, since to develop computational models it is necessary to handle software, with a deep understanding of how the systems involved work. Sometimes, they need to know new computational and/or technological tools. Mathematics is also present in this phase. According to [28], in the success of the prototypes with greater fidelity presented in competitions, the tests and observations carried out *in situ* have been key, which has allowed us to know the situations and conditions in which they will operate, clarifying the doubts of the designers and taking actions to correct the necessary details.

Stage 6: Expert Evaluation. Projects should be presented to a committee of innovative experts to obtain different points of view and feedback to fine-tune prototype details. The experts' profiles must be comprehensive, including a solid academic background, experience or complementary training in entrepreneurship or TT, or work experience in the industrial or creative sector. This stage is relevant since different external opinions feed the project based on the recommendations and the identification of the best practices to be implemented. This is another differentiating phase of the proposed methodology, allowing for a broader, more competitive vision. At this stage, students prepare their materials for presentation with the support of their professor. With the accumulated experience, strategies such as storytelling, among other strategies, have been incorporated, which allows for a clear context of the need to be met. In the projects' presentations, an evaluation is made in which each expert on the panel establishes their rating after listening to the presentation of no more than 5 minutes and the round of questions and answers. The evaluation forms are easy to fill out. They consider the following aspects and maximum weightings:

- Originality: 25%
- Originality: 25%
- Business model: 25%
- Minimum Viable Product: 25%

In addition, at the end of these forms, in the corresponding section, comments are issued to improve the projects presented. After making the improvements, both in the technical aspect and in presentation, according to the comments and suggestions issued, the selected projects, or those with the highest scores, are chosen to compete in external calls or competitions (Table 2). It should be noted that the aspects considered relevant in the competencies on technological innovation consider aspects such as those mentioned here.

Stage 7: Dissemination of Results. Finally, at this stage, all projects can be published in various media to show the developments the Academic Division of Industrial Mechanics is making (Figure 14). For this, print media, through local newspapers and in the youth news section, and institutional social networks, such as Facebook and Twitter, are used. Generally, students and their teacher are interviewed, gaining experience in this activity.

Table 2. Format for project evaluation.

#	Item	Score assigned, lowest to highest (In each item, mark your selection with an X)				
		1	2	3	4	5
1	Problem					
2	Originality					
3	Business Model					
4	Minimum Viable Product					
Comments and recommendations:						
Name and signature						

The number of participants has depended on the number of students in the group, generally composed of 4 to 5 people, who have naturally assumed roles similar to those in a TBC, under the teacher's supervision. The roles are: a project organizer or leader (such as a Chief Executive Officer, CEO), a student in charge

Interaction Design and Architecture(s) Journal - IxD&A, N.63, 2024, pp. 235 - 267
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of technological development (such as a Chief Technology Officer, CTO), a student who is the CEO's support in the organization and maintains the cohesion of activities (such as a Chief Operating Officer, COO), a student who is in charge of costs, purchase of materials and everything related to basic finance (such as a Chief Financial Officer, CFO), if there is a fifth student, focuses on obtaining and managing information, (like a Chief Information Officer, CIO). Although there is a particular responsibility in each of them to carry out the tasks, with the direction and monitoring of the teacher, camaraderie and teamwork are privileged, since everyone is sought to participate in the activities, to generate experience and knowledge in each of them. Due to the short time available, participation in planning, technological development, testing and presentation must be very intense and complementary.

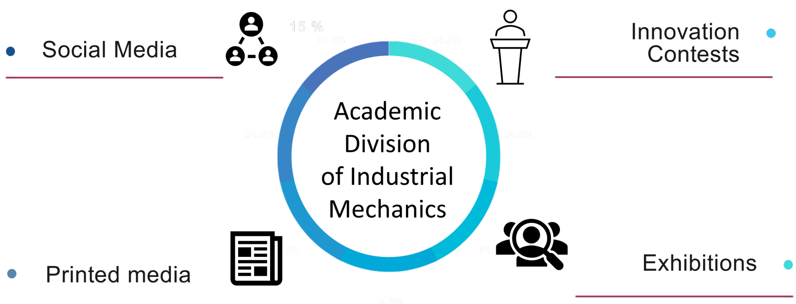


Fig. 14. Dissemination of projects.

Finally, Table 3 allows visualizing what was specifically taken or improved from each of the methodologies, methods, models and tools reviewed. The elements marked with * are stages or tools used in the Design Thiking methodology, with **, in Lean StartUp, and with *** to DesignPedia two rhombus model.

Table 3. Methodologies, methods, models that constitute the stages of the proposed Methodology.

Stage	Methodologies, methods, models or tools used	Modified or improved	Differentiation element
1. Motivation	Background of innovative projects,	Not	Not
	Motivation by background.	N. A.	Yes
2. Emphatize	Idea generation*,	Not	Not
	Customer jouney map,	Not	Not
	Empathy map*.	Not	Not
3. Definition	Focus group,	Not	Not

	Field visit,	Not	Not
	Business model.	Not	Not
4. Ideate	Idea selection*,	Not	Not
	SCAMPER*,	Not	Not
	Business model.	Not	Not
5. Prototyping	Prototype design*,**,	It is done to know the feedback of experts	Yes
	Manufacture and testing*, **, ***	Not	Not
	TRL.	Not	Yes
6. Expert evaluation	Experts evaluation.	N. A.	Yes
7. Disseminarion of Results	Social networks,	Not	No
	Printed media,	Not	No
	Innovation contests,	N. A.	Yes
	Exhibitions.	Not	Not

It should be noted that adjustments have been made to the methodology, according to the demands faced, for example, during the COVID-19 pandemic, expert evaluations were carried out online. In addition, as new success stories are available, they have been added to the list in the motivation section. The panel of experts was also adjusted, since for example the participating student obtained his degree and did not continue with the collaboration. For the dissemination of the results, there was also a UTEZ digital channel, through which this activity was also carried out. In addition, if students require it, they can continue with the improvements of their projects in the stays programmed in their study plan.

4 Example of application of methodology

In [34], an automated pill dispenser was developed in 2018 to promote adherence to treatment in chronic and elderly patients based on the application of the proposed methodology. After the *motivation stage, the presentation of challenges and opportunities, we continued with the empathy stage,* based on the information on the importance of treatment adherence, from which the development idea was generated. Generally, when faced with an ailment or discomfort, people go to the doctor for treatment, as it is well-known that self-medication is a risk. However, after conducting the research, it was identified that not complying with the regimen assigned by the doctor can have its complications. In 2009, Pfizer established that medicines are one of the primary therapeutic resources for health care. However, their benefits can be impaired by non-adherence, worsening the disease, increased morbidity and mortality, reduced quality of life, and the need for additional treatments, increasing the consumption of social and health care resources. The empathy map generated is shown in Figure 15.

The purpose of developing the automated pill dispenser to combat non-adherence in chronic and elderly patients was to help people suffering from any illness, whether chronic or acute, to improve their quality of life and speed up their recovery through this tool that can facilitate adherence to their treatment. The route map shown in Figure 16 was obtained considering a commercially available automatic pill dispenser. Some essential characteristics were proposed from this map.

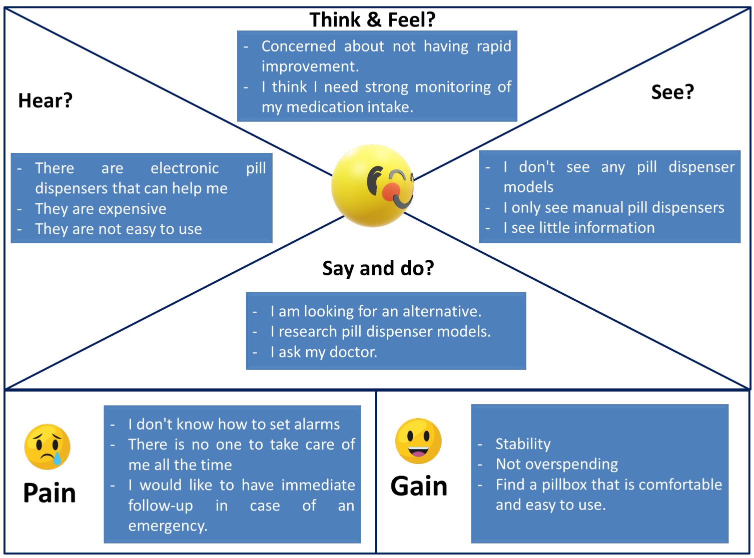


Fig. 15. Empathy map.

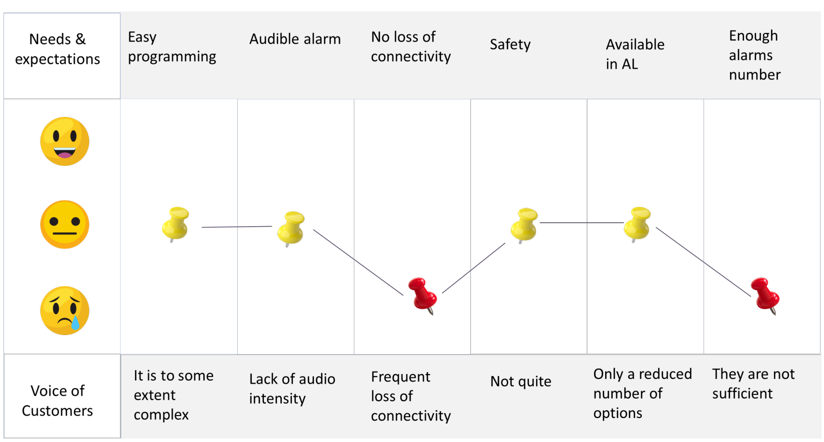


Fig. 16. Route map of an automated pill dispenser.

On the other hand, commercial options were investigated, observing similar options and identifying areas of opportunity in integrating functions that these products did not offer or complementing them, thus creating a more solid value proposal. Regarding cost, products were found with prices ranging from approximately $400 to MXN 1600. Those priced in the lower ranges had a limited number of alarms per day, an audible alert (though lacking a visual one), no security features and even less connectivity; the higher priced option only had compartments to store seven individual doses, an LED as the only indicator and although it had an App to which it could be synchronized, it had a Bluetooth connection, limiting its range to approximately 10 meters (Figure 17).

Subsequently, the size of the market segment for Mexico was defined, considering the number of people who suffer from a chronic disease (Table 4), among which the elderly can be found. Still, the last data was not specifically found, so the information was restricted to three dominant chronic diseases. The sum was almost 70 million people, considering only 1% of that total, a market segment of 609,600 people was estimated. The business model is shown in Fig. 18, with financial advice and a financial projection. The consultant determined that the initial estimated production cost could be reduced by up to 80% in the case of mass production through a third party.

	DoseTime	Product 1	Product 2	Product 3	Product 4	Product 5
Compartments	6	7	28	5	7	7
Audible alarm	✓	✓	✓	✓	✗	✓
Visual alarm	✓	✗	✗	✗	✓	✗
Sefety	✓	✗	✓	✓	✗	✓
Connectivity	Wi-Fi	✗	✗	✗	Bluetooth	✗
Tone-Volume Configuration	✓	✗	✗	✗	✗	✗
Alarms per day	Ilimitaded	5	6	5	7	7
Availability in Latin America	✓	✗	✗	✗	✓	✗
Price (MXN)	X	421.62	1602.56	604	1437.05	841

Fig. 17. Comparison with commercially available pill dispensers.

Table 4. Chronic diseases are considered TAM and SOM [34].

Population	TAM	SOM

Interaction Design and Architecture(s) Journal - IxD&A, N.63, 2024, pp. 235 - 267
DOI: 10.55612/s-5002-063-011

	Percentage		
Systemic arterial hypertension (SAH)	25%	30, 000, 000	300, 000
Diabetes	15.8%	18, 960, 000	189, 600
Chronic Obstructive Pulmonary Disease (COPD)	10%	12, 000, 000	120, 000
	Total	60, 960, 000	609, 600

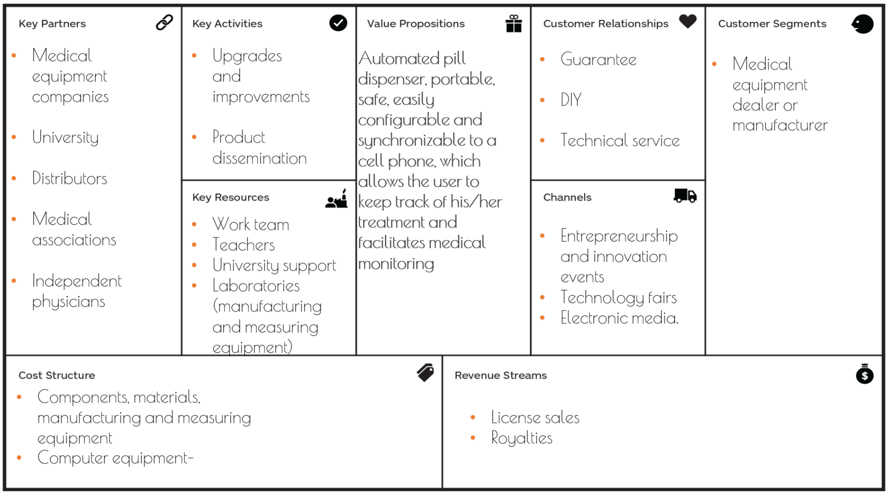


Fig. 18. Canvas business model

In the *prototyping stage*, a simple-to-configure electronic pill dispenser was developed, which calculates and alerts the user about the times at which he should take his doses, thus eliminating the three main errors present during the medication process are: forgetfulness, confusion when two or more different drugs are taken, and finally the repetition of doses when confusing or forgetting the time at which a drug should be taken. The programming and physical implementation of this prototype required theoretical calculations, experimentation, and adjustments to the design, allowing students to reinforce their knowledge in these areas of science, technology, and engineering and apply them to a real problem.

Prototype design. An Arduino Nano was used to integrate the microcontroller and external hardware on the same board with minimum size, simplicity of language, and compatibility with multiple components. An LCD Oled display was chosen due to its small size, resolution, SI2C support, and viewing angle. An external RTC was selected as the most viable option due to its accuracy in providing date and time. The DS3231 RTC, whose performance made it ideal, was considered as it

DOI: 10.55612/s-5002-063-011

shared the same I2C communication protocol with the other components. An external 1.55V battery powered it.

One of the requirements for the device interface was that it should be simple and require as few components as possible, so a menu was implemented, divided into screens dedicated to configure each alarm parameter individually. Navigation through the menus would be done with the help of two buttons, one used to increment the numerical value or status of the current parameter, the second one acting as a confirmation button. The interface had only five subsequent screens, the home screen showed the current time, date and day, the status screen allowed configuring whether the alarm was enabled or disabled, the hour and minute screens configured the time at which the first alert would sound, and finally, the interval screen determined the space between hours in which the alarm would sound (Figure 19).

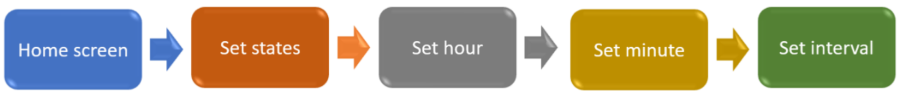


Fig. 19. Order of the configuration screens.

Safety measures was established to avoid deactivation of the alarm without ingestion of the corresponding drug by the user, a gyroscope should be implemented, through which the alarm would be deactivated only if an inclination more significant than 45 degrees was detected in the container, since this is the position in which the device is placed when serving a pill. An MPU integrating an accelerometer and a gyroscope with I2C communication was used. It was decided that the interface should allow the choice to switch between physical and digital programming, increasing the accessibility and manageability, as well as the monitoring capability of the device.

Container design. A template was designed with the shape and size of the pieces that would make up the casing, which was manufactured in acrylic. Notches and edges were provided to facilitate the structure assembly and perforations for the push buttons and the box where the OLED screen was located. The prototype was named "DoseTime". The search on the internet did not find any company or product that was the property of this name. With the support of the designer Cesar Malvaez, the logo shown in Figure 20 was obtained, which was considered simple to remember, friendly, and easy to relate to the product.

Fig. 20. Selected imagotype.

In 2018, this project was in the *TRL* 4 stage, experimental pilot. This development was shown in the first edition of the "FarmApp 2018" Contest held in the city of Puerto Vallarta, Jalisco, obtaining a recognition to the university talent with an economic incentive to integrate improvements to the project. Regarding the *dissemination stage*, this recognition was disseminated [35].

As can be seen, this team work required knowledge about the functioning of the human body, as well as skills in electronic and mechanical design, programming, electronic devices, among other areas of STEM, as well as soft skills, such as and critical thinking, communication, and collaborative work to determine the characteristics and strategies that allow generating a competitive proposal. In [36], the creation of critical thinking through the selection of strategies in the development of projects is highlighted, in addition to emphasizing its importance as a central element in solving problems in STEM education and everyday life.

5 Results

Table 5 shows the demographic statistics of the expert group. Each evaluation was assumed to have at least 5 of them (Figure 21). As can be seen, most of them have training or experience in entrepreneurship or TT, in addition to robust training in STEAM areas, which allows them to have a comprehensive vision. Keeping these experts monitoring the projects was critical, as they knew the development history. Only those projects considered relevant were given continuity.

Fig. 21. Photograph of the panel of experts.

Table 5. Demographic statistics of the expert group

No.	Age	Gender	Technical Qualification	Complementary training in entrepreneurship	Experience in entrepreneurship or TT	Work experience in companies
1	53	F	Ph. D in Electronics	Yes	Entrepreneur	Not
2	45	F	Ph. D. In Computing	Not	Not	Not
3	50	F	Ph. D in Materials	Yes	TT	Not
4	50	M	M. Sc. In Information Technologies	Not	Not	Yes
5	30	M	Student of Mastery in Commercialization	Yes	Not	Yes
6	39	M	B. Architecture	Yes	Entrepreneur and TT	Yes
7	55	M	Ph. D. In Cognitive Sciences	**Not**	Entrepreneur	Not

Since 2018, when the application of the Methodology began, the projects previously selected by the professor were analyzed by the group of experts, with the participation of 8 projects in the sessions in average, as can be seen (Figure 22), this is an approximate total of 24 projects per year, which obtained higher averages were approximately 40%. During the COVID-19 pandemic, assessments were conducted online. In addition, in some cases, continuity was given to

Interaction Design and Architecture(s) Journal - IxD&A, N.63, 2024, pp. 235 - 267
DOI: 10.55612/s-5002-063-011

previous projects or to a line of research and development to improve or strengthen them. The methodology ceased to be applied in 2023, as the teacher with whom the process was carried out changed workplace.

Table 6 shows some of the projects in which this methodology was applied and the results obtained in different national or international technological innovation competitions. It also observes the projects participating in technological innovation competitions from 2018 to 2023.
Representative developed projects are described below.

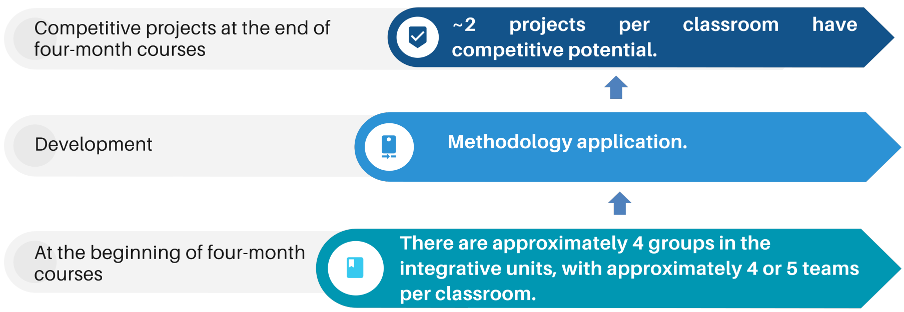


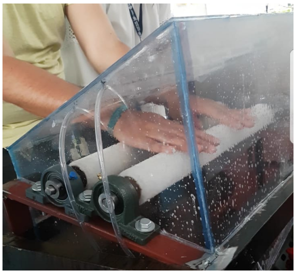
Fig. 22. Project selection.

5.1. Hawa

Because of this methodology, in 2019, the project "Hawa" obtained second place at the national level. This project sought to reduce the amount of water wasted in toilets and sinks, and it was able to use this device in public spaces (See Figure 23). The hoses dispense the necessary amount of water, avoiding waste, while the acrylic cover prevents splashing.

5.2. AMILI Robot

The problem that gave rise to this project focuses on people working in the fields who are exposed to the pesticides used to fumigate the crop fields, which can threaten their health. This assistance and service robot aims to perform the spraying activity more safely for the field workers. In principle, the robot operates in two modes: radio-controlled and autonomous, with the former being the predominant operating option, as knowledge and experience in autonomous vehicles to perform movements without instructions from an operator is still being developed. Figure 24 shows the AMILI Robot project in its final stages. AMILI participated in different tournaments, such as the Robotics and Advanced Technologies Tournament (TRYTA) of the National Polytechnic Institute, where it won first place in the Ecotech category in 2019.


(a)

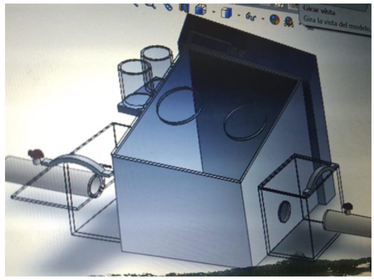

(b)

Fig. 23. Hawa project. (a) in operation. (b) Design.

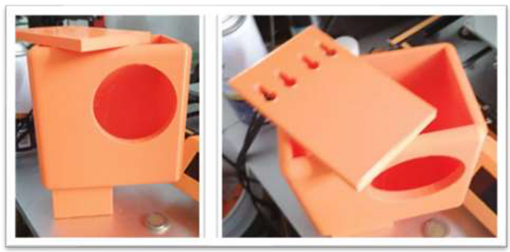


Fig. 24. AMILI Robot.

Fig. 25. First prototype of the dispenser, year 2020.

5.3. Smart Dispenser

One of the problems encountered during the COVID-19 pandemic was using various devices to carry out prevention functions in public spaces. This fact, added to the lack of personnel and culture to conduct the corresponding temperature checks, as well as the necessity of using face masks, was the origin of the creation of this project to design an intelligent electromechanical device capable of supplying antibacterial gel to people for the promotion and application of preventive hygiene measures with the use of Computational Intelligence tools and Embedded Systems.

It was initially carried out in 2020, but its tests were not carried out due to the pandemic conditions. In Figure 25, the first prototype of this project, made by a student in the internship stage, is shown.

In 2021, it was decided to redesign and validate this prototype in different technological innovation contests and competitions. The new version considered other functions that would enhance this project, such as including a facial recognition system for detecting face masks (Figure 26). However, due to the pandemic environment, the proposal was not implemented.

Interaction Design and Architecture(s) Journal - IxD&A, N.63, 2024, pp. 235 - 267
DOI: 10.55612/s-5002-063-011

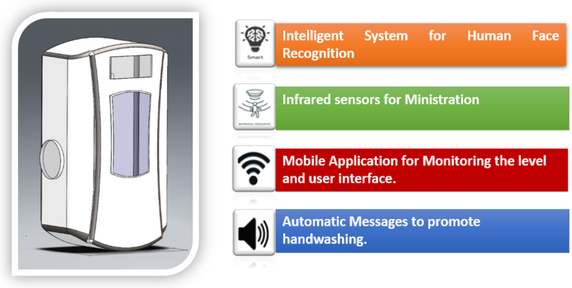


Fig. 26. Schematic proposal of the Second version of the Smart Dispenser.

Fig. 27. Third version of Smart Dispenser, 2021.

In the third version, infrared sensors were incorporated to administer antibacterial gel without needing to touch the dispenser, a form of virus transmission. An App has been added to view the amount of antibacterial gel and refill it quickly. Finally, a system was added that emits a voice to give directions and recommendations (See Figure 27).

Finally, this project was presented at the 2021 edition of the IEEE YESIST (Youth Endeavours for Social Innovation Using Sustainable Technology) event held virtually, in which an honorable mention was obtained for the presentation of this project.

5.4. IoT device to measure water quantity and quality

The problem it addresses has to do with water scarcity. Currently, many houses in Mexico suffer from lack of water or constant service cuts, which causes residents to acquire water tanks, cisterns, and pumps for their continuous supply. However, one of the main problems is that when administering vital liquid, people cannot administer something they cannot measure. In addition, visualizing the water level of water tanks in buildings is often dangerous for people. (See Figure 28). To solve the problem of water management and the danger that visualizing the water level represents for families, the idea arose of remotely measuring the quantity and quality of the water in the water tanks of the different homes, for which it is supported by sensors of level, pH, turbidity, and temperature (see Figure 29).

Fig. 28. Location of water tanks in residential areas.

Fig. 29. Placing the device in the water tanks.

An App was also developed. With this project, we participated in the Youth International Science Fair 2023 held in Bali, Indonesia, obtaining a silver medal. This project is still in development. Products such as research articles and a poster on artificial intelligence and robotics have been derived for presentation at student congresses. In addition, other awards or recognitions on a smaller scale have been achieved, in addition to those shown in Table 6. Of all the cases studied, only one has generated a startup.

Table 6. Technological projects developed with the proposed methodology.

Project	Issues / SDGs	Prize	Level / Year
Pill dispenser	Health/ DG 3	Recognition of the university talent	National / 2018
Amili: Assistance & Service Robot	Security/SDG 11	Silver Medal	International / 2019
Hawa Project	Water Care/SDG 13	Second place	National / 2019
Intelligent Automatic Dispenser	Health/ DG 3	Honorable Mention	International / 2021
IOT device to measure water quantity and quality	Water Care/SDG 13	Silver Medal	International / 2023

It is worth mentioning that another project to which this methodology was applied served as the basis for a graduate's establishment of a technology-based company.

The elements of each phase of the proposed Methodology are fundamental.

The aspects that are generally evaluated in the competitions in which we have participated have been:

- The potential impact is based on the selected problem and its coverage, as well as on the technical quality of the proposal.
- Originality, since it, together with the creativity that gives rise to it and the basic knowledge, can make the protection of intellectual property possible, which is extremely necessary to start a business with greater chances of success.
- The business opportunity is based on the market segment addressed and the business model created.
- A prototype or minimum viable product is useful for testing the validity of the proposal quickly, a highly desirable characteristic for determining its acceptance.

It can be said that the variables in our project evaluation format have been validated not only nationally but also internationally with the proposed methodology.

6 Conclusions

An element of differentiation of the proposed Methodology is found in the initial phase, since the motivation and leadership achieved has made the students manifest an empowerment that was not observed before. Another relevant step is the evaluation by experts, which increases the vision and improves the projects under development, instead of only one teacher. We have had excellent results in projects derived from the integrative learning units (or courses) for the third, fifth, or tenth four-month period within the Mechatronics career. The scope level depends mainly on the knowledge in STEAM areas available in each case, which in turn allows students to be aware of the need to continue learning so that their performance is more competitive in the following integrative learning unit. In addition, developing projects allows them to apply their knowledge and reinforce what they have previously learned when facing real problems to solve, for which they require the integration of previous knowledge and new and novel skills in various areas. Improvements have also been observed in the presentation and dissemination of their projects and how they carry out collaborative work. The places obtained in different national and international competitions show the relevance of the alignment of the projects with the other strategic lines selected, such as Renewable Energies, Water Care, Poverty, Food, Security, Environment, and Health. Thanks to the methodology results and the leadership at the state level, the motivation achieved shows the students' remarkable empowerment, strengthening their graduation profile. Another notable element of differentiation of the proposed methodology is the evaluation of experts since it allows for the improvement of some characteristics and/or conditions and a much broader and more competitive vision. It should be noted that the stages integrate tools, methods, and models, some of them well known, as well as strategies generated from experience. In the dissemination stage, participation in exhibitions and competitions is encouraged. In future work, this methodology is expected to be applied in other UTEZ careers, such as maintenance, industrial processes, and nanotechnology. An example of the application of the proposed method was included. On the other hand, there is still much work to be done, as it is necessary to foster the culture of high-impact entrepreneurship, which is not usually promoted in public institutions, and to develop the vision of creating scalable ventures.

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