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Co-Design of Water-Saving Prototypes in Rural Areas of Colombia: An Analysis of Student Participation With Social Impact Through poCDIO Framework

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Abstract— According to the CDIO framework, the skills to Conceive, Design, Implement and Operate products, processes, and systems, are the basic principles of engineering. Engineers Without Borders Colombia, an inter-university group that develops engineering projects with vulnerable communities, understood that engineering education could be applied to real contexts generating social impact through community participation, and added two elements to the CDIO framework: an observation stage and a participatory approach (poCDIO). This paper uses the poCDIO framework to analyze a case study in rural areas of Colombia where a collective process of active learning is generated, bringing engineering education beyond the classroom. There, professors, students and rural communities developed technological solutions for water saving. The analysis of poCDIO within this context allowed the identification of strengths and weaknesses in the development of engineering projects with communities, taking participation and co-design as the main axes of engineering education that can contribute to social change.

Keywords—CDIO framework; Co-design; Engineering education; Participation.

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1. Introduction

Engineering projects with social impact have the objective of contributing in the resolution of challenges in the context of a community's sustainable development. Usually, there is a group that benefits from the project and that has a need that may be fulfilled through applied knowledge. Over the years, the idea that the engineer is a "problem solver" has clashed with this type of projects because it usually focuses on the development of products, processes, or systems based on the understanding of the technical requirements. This is why Engineers Without Borders Colombia -ISFCOL-, a multidisciplinary team, has developed an active learning process through which engineering students develop the skills to contribute to the challenges of society. Even though the CDIO -Conceive, Design, Implement, Operate- initiative has characterized the development of a product, process, or system as the main purpose of engineering, initiatives like ISFCOL have adapted that approach so that they can articulate it with the participative approach required to allow the projects of social impact to generate positive results in the communities.

Therefore, this paper aims to use the poCDIO framework (observation + community participation + CDIO) to analyze a case study in rural areas of Colombia where a collective process of active learning is generated, taking engineering education beyond the classroom and allowing participation and co-design to be its main axes.

The poCDIO methodology (Arias et al., 2016) seeks that groups like ISFCOL articulate the interests of different stakeholders to search for solutions for problem issues so that a net positive impact is generated in the target communities. This group emerges from the necessity to connect vulnerable communities in clear need of improving certain life conditions, with engineering professionals and students that will support the development of diverse solutions based on their disciplines. For this, ISFCOL, an alliance between Universidad de los Andes and Corporación Universitaria Minuto de Dios – UNIMINUTO, has designed a systemic methodology for the development of participatory approaches in engineering problem-solving for Colombian communities (Ramírez et al., 2012).

Given the context of inadequate management of natural resources, the group has sought to co-design solutions that fulfill the criteria of viability, low cost, innovation, and, especially, social impact linked to the problem issues, with the help of the target community. One of these problem issues, related to the regional mismanagement of water, enables the integration of popular knowledge with the technical know-how of engineering education, leading to the design of solutions technical and socially pertinent.

Following the above, this paper is structured as follows: (1) The theoretical framework describing the Active learning process and poCDIO context for ISFCOL; (2) The methodology for co-designing engineering projects with a social impact; (3) A case study that displays the application of the methodology in the context of the education of high school students, who are experiencing the problem of shortage of the water resource; (4) Results analysis; and finally, (5) All main learnings and conclusions, as well as suggestions for future endeavors.

2. Theoretical Framework

A. CDIO

CDIO is an engineering initiative that seeks to spread the fundamental principles of engineering education. It was conceived towards the end of the 20th century at the Massachusetts Institute of Technology -MIT- after the industry detected that engineering professionals lacked multiple skills required to perform effectively in real-life engineering situations. This circumstance is generated due to the intensive focus on the science approach in engineering education. Therefore, the practical approach has been put aside, disregarding the main mission of the engineer: to build products, processes, and systems that contribute to humanity's improvement (CDIO, n.d.a).

Engineering as a practice is based on the skills that an engineer must have to be able to develop the lifecycle of a product, process, or system. This lifecycle is structured in four main stages: conceive, design, implement, and operate, as follows:

- Conceive: to define the needs of the clients, considering the technology, strategies, and restrictions to develop concepts, techniques, and business plans.

- Design: to create the design building the plans, sketches, and algorithms that describe what is going to be implemented.

- Implement: to transform the design into the product, process, or system including its manufacturing, coding, testing, and evaluation.

- Operate: to use the product, process, or system implemented to define the value that will be delivered to the clients, including its maintenance.

The adoption of the CDIO framework has been shown to significantly enhance student-centered learning by promoting active and collaborative approaches in engineering courses. For example, Julius Fusic et al. (2022) found that integrating CDIO principles with active learning techniques improved both cognitive and kinesthetic skills among students, resulting in a more effective and engaging educational environment.

In the CDIO frame, an engineer must be able to conceive, design, implement, and operate complex value-added engineering systems from an individual position of reflection in a modern, teamwork-based environment. For this purpose, engineering learning must be supported in three blocks of knowledge, skills, and attitudes: technical knowledge and reasoning, personal and professional skills, and interpersonal skills (Crawley, 2001).

These blocks are related to the characteristics defined by the Accreditation Board for Engineering and Technology -ABET-, an organization recognized as the main world reference in quality standards for applied sciences, computing, engineering, and technology programs. According to ABET (2016), engineering programs students must be prepared for the practice of engineering. To this end, the last stages of the academic curriculum must be strongly marked by designing experiences that allow the student to apply the knowledge acquired during the early stages of his/her studies while facing the restrictions imposed by real-life problems. Therefore, according to ABET (2016), engineering students are expected to have among others, the ability: to apply knowledge of mathematics, science, and engineering; to design and conduct experiments, as well as to analyze and interpret data; to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; and to function on multidisciplinary teams. They should also have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

To consolidate these skills within the curriculum, CDIO Initiative (n.d.b) established 12 standards required for an engineering program to guarantee an effective learning experience. One of the clearest teaching strategies for implementing the 12 standards is to adopt a Project-Based Learning -PBL- approach, in which the course is structured around the development of a real project (Kohn et al., 2018). For instance, integrating PBL with the design thinking process can enhance students' technical knowledge while increasing their engagement and ability to solve real-world problems (Naik et al., 2019).

For example, the CDIO Knowledge Library presents a case study of a two-semester course that took place at MIT Lincoln Laboratory of the Department of Aeronautics and Astronautics, which intended to develop a vehicle that could facilitate the calibration of high-pressure antennas in space missions (Hansman, 2009). The project was proposed by the U.S. Federal Government and by several aerospace companies that were having high expenses related to radar calibration in their space missions and were looking for a less expensive calibration system. Besides the technical skills, the students faced the need to develop other skills that could provide a solution to a real-life engineering problem, such as critical thinking, resources and time management, team working, and oral and written communication, among others.

In the context of the ABET accreditation for Universidad de los Andes, in 2010, ISFCOL decided to adopt the CDIO frame as the basis for developing projects with social impact. However, in the practice, there were troubles incorporating the non-technical dimensions of technology that forced the organization to include an “observation” stage as a prelude to the “conception” stage, as well as the community participation as a transversal axis for CDIO implementation. ISFCOL renamed this approach poCDIO (Arias et al., 2016).

The first reason for including the observation stage is the fact that problem situations that are related to social issues, such as poverty, insecurity, and inequality, among others, have a complexity level that cannot be solved through pre-defined algorithms (Aldana & Reyes, 2004). A second argument comes from the work of Humberto Maturana, where he argues that the statement of the problem or research question depends on who is stating it or who is the situation’s observer (Segal, 2001). Therefore, students should start considering the following premises when they are going to define the design criteria of any solution (Ramirez et al., 2011):

- The problem situations are transdisciplinary.
- The statement and description of the problem situation depend on who is causing it and who is observing it.
- The problem situation derives from the relations among the different parties involved.
- The understanding of the problem should be regarded as a system itself.

Given the above and looking to broaden the technical dimension spectrum in the Conceive stage, ISCOL included methodological observation activities that facilitated the use of tools with a social component such as Observation (Kawulich, 2005) and fieldwork, to understand the social, cultural, and political believes from the community's point of view.

ISFCOL also incorporated a participation approach into CDIO as the main axis of the engineering projects with social impact (Kohn et al., 2018). Thus, the development of participation spaces was included in the CDIO strategy, where the participation of the community is integrated, depending on the stage and the power and influence relations between the actors involved (Arias et al., 2016). This approach implies that besides the engineering and social sciences skills, it was required to promote the development of management abilities in the students, for them to be able to design participation spaces that are consistent with the skills, knowledge, and resources of the key actors involved. The main contributions and difficulties of incorporating social impact projects as the basis for the development of learning processes in engineering through poCDIO can be identified in the case study that will be introduced later.

Having introduced the methodological context of poCDIO has allowed engineering research to be articulated with community participation. For instance, applied research has been developed in different contexts such as rural aqueducts, water management with rural youth, and green enterprises (Ramirez et al., 2019) with managers committed to society and the environment. In all these cases a co-design environment was systematically prepared with the different communities, having successfully archived their objectives, for example, reducing the irrational consumption of water or developing green enterprises with an impact on the communities (Acero et al., 2019).

B. Participation in the Learning Process

For Brendehaug (2013) the concept of participation, as well as other concepts such as environment, power, revolution, and science, has a broad array of interpretations and notional elements, as it is not only a mental construction but also a social one and is, therefore, dynamic and subject to discussion. However, participation might be understood as a process that integrates the different collective and individual social subjects (with their needs, interests, and specific points of view) into the decision-making process, regarding an environmental, economic, political, cultural, or social action aimed to modify their direct surroundings, whether they are urban or rural.

For example, in countries like Brazil, participation is related to terms such as "politics", "democracy", and "progress" because they require certain types and forms of participation to express their intentions and move forward. In Uganda and other countries, participation becomes a complex (and ambiguous) combination of different cultural and social interaction styles that seek both to reach a consensus and the sustainability of the processes. Hence, Newig et al. (2008) point out that project managers should inform if their participatory processes seek to gather information, obtain acceptance, or generate synergies, because, regardless of the intention, the stakeholders must know which will be their roles and level of participation in the initiative or project.

Any social participation process must explicitly state its intentions before the different stakeholders, such as students, families, workers, social organizations, shareholders, and suppliers, among many other possible actors that will be affected by the process. This helps in the creation of a trust relationship that is mandatory for developing a proposal, project, or program whose goal is to enhance new opportunities for the communities. According to Martin et al. (2003), participation has, among others, the following characteristics:

- To be a direct path for social subjects to get involved in the decision-making process related to a specific aspect of their lives.
- It implies the transference of power to popular sectors, giving them the possibility to exert a systematic influence on the development of society.
- It is a mechanism for socializing power and a means of fostering collective and individual abilities.
- It contributes to the increase of the individuals' involvement with their organization.
- It becomes a bridge between organizational efficiency increase and individual personal growth.
- It gives the individuals the possibility to take part, perceive their acceptance by others, and recognize themselves in the result of the activity.

In this way, participation is not only the equivalent of giving a voice to the community, but also the method to transform that voice into tangible actions that, on one hand, allow the systematic display of the individual abilities, and on the other, promote quality in the decisions, equality in the relations, mitigation of conflict, and sustainability of ideas (Arias et al., 2016)

It is important to keep in mind that every attempt at participatory work is connected to a specific community and therefore the social projects must anticipate and work on issues that concern its biophysical complexity (relief, environmental conditions, biodiversity). Also, as it is a socially built space (a space where historical, economic, social, cultural, and political situations are happening daily), the relations of power, belonging, and empowerment between the individual and the territory must be taken into account (Sosa, 2012). Likewise, in any urban, rural, local, or regional territory, there are coexisting scenarios for participation, communication, learning, and teaching such as the family, school, workplace, church, etc. After the family, school is the most important scenario for participation and learning in the social development of children and young people. Consequently, participatory projects should be promoted in educational contexts, fostering thus interest and a sense of belonging for a group, a territory (country, city, or region), an idea, or a project of their own (Brendehaug, 2013).

Here, the perspective of community participation in the context of engineering would require that the activities and knowledge acquired in the classroom have some relationship with activities and projects that are carried out in real scenarios, as this allows future engineers to work collaboratively with people outside their academic community, which in turn leads to more productive learning experiences for the students. It is important to point out that this is not the only valid view of teaching and learning in engineering because the wider the range of useful perspectives, the more successful the students' learning processes will be (Allie et al., 2009).

Therefore, educational environments are favorable spaces to promote participatory projects whose intention is to generate networks and synergies to positively impact the territories and thus create participatory strategies and techniques, such as focus groups, guided interviews, workshops, and training, among others. These allow for the identification and appropriate channeling of know-how and popular knowledge, as well as the feelings, expectations, fears, and tensions that any social intervention triggers (Valderrama, 2012).

C. Engineering Education with Social Impact

The concern of universities to achieve a competitive quality education encourages engineering faculties, among others, to think of a contextualized education, i.e. to offer future engineers teaching-learning scenarios that allow them to develop skills to understand and respond to the uncertain and ever-changing environment they face. Likewise, according to Bissett-Johnson, & Radcliffe (2021), engineering education is increasingly looking for all technical solutions to be contextually sensitive and responsive to the social, cultural, and political aspects of the location. This contrast of scenarios creates new and exciting possibilities for engineering students, as the technical aspects of engineering could have greater synergy with the creativity of design and its operation in real contexts. This also offers a great opportunity for the so-called "new engineer", who must respond to the challenge of the technical and sociocultural tangible and intangible aspects of a problem (Beder, 1999; Pritchard & Baillie, 2006). Therefore, the training of the new engineer demands to rethink traditional teaching approaches every day and to look for social scenarios whose problematic issues allow multiple solutions to be proposed, more in line with the problems encountered in the real world (Silva et al., 2014).

Thus, an urgent call is made from universities to re-signify the meaning of classrooms, since the classroom as a social and daily space is a scenario that becomes significant for both students and teachers (Morán et al., 2009). Strong connections are made between place, personal life, and the rest of the world, ranging from one's history to the future, and helping to anchor a sense of personal continuity in a rapidly changing society. In this sense, future professionals should understand that the classroom is not only a physical space where knowledge is exchanged and certain experiences are developed, but also a fabric of relationships that make knowledge possible. In classrooms, not only the interests of teachers and students are addressed, but also the interests of those who are part of the research, i.e., the communities with their countless needs and potentialities (Arias, 2013).

While it is important to understand the social meaning that classrooms have, it is also relevant to understand the strong connection that must exist between the designs of products and services, among others, that emerge in these classrooms or laboratories, with the reality of the prevailing context. Hence, design theorists Sanders & Stappers (2008) propose a "Design for a Purpose" discipline, both shifting the focus in the design discipline from the artifact alone and addressing too the complex problems of social and environmental sustainability. In this sense new engineers need to understand that it is essential to develop socially responsible solutions, i.e. solutions that are "'good' for the people (individual and local community) and 'good' for the environment, with the potential for positive social change" (Bissett-Johnson, & Radcliffe, 2021, p.6).

In this way, it is sought that the student assumes themself as a sensitive, human and engineer, a citizen responsible for others and for themself. Once the student becomes humanized about their environment, they can understand that engineering is fundamental for practically all industries in the world. From household appliances, automobiles, and homes to things that are part of human life and daily work, such as going to the movies, eating, dressing, talking on the phone, and knowing how to load a truck, among other things. These aspects would be almost impossible to understand and perform without the intervention of engineering. In this sense, designing solutions and projects requires recognizing the situational contexts to understand some problems that surely had already been "solved", but such solutions may not have been pertinent (perhaps they were not even solutions). Therefore, to move towards a socially responsible engineering education it is necessary to have critical, interdisciplinary, curious, innovative, and sensitive thinking, dimensions that allow young engineers to be able to question, propose and implement alternatives for social transformation.

In the context of Project-Based Learning, the main objective, in terms of solving an engineering problem, is to properly address the client's requirements, which are usually of a technical nature. This perspective has historically positioned the engineer as a problem solver (Koen, 2003; Kohn et al., 2018). If only the technical aspects of a problem are considered, profiling the engineer as a problem solver is accurate. However, in the context of engineering projects that have a community or social impact approach, there are other contextual dimensions on which the feasibility of any design project directly depends (Lucena et al., 2010). Such non-technical dimensions are usually related to cultural issues such as (Haviland et al., 2008):

- Religion
- Standards and perspectives of justice
- Values, priorities, and opinions
- Customs and traditions
- Art
- Socio-economic differences
- Food

Engineering projects with social impact can be regarded as initiatives that seek to contribute to the resolution of the challenges related to sustainable development. These challenges are framed in the 2030 agenda by 17 objectives that comprise global interest issues such as climate change, food security, and poverty (UNDP, n.d.) and usually have a population group or "community" in the role of beneficiary.

The lack of awareness by engineers of the non-technical dimensions that should be included in the design of products, processes, and systems during the development of engineering projects with social impact results in the prevalence of several misconceptions regarding the role of technology (Lucena et al., 2010). Among them:

- Technological development happens as a process independent of society, culture and politics: There is a gap between the technical dimension of technology and its non-technical aspect. This belief is very problematic as it places engineers as experts with absolute control over technological development, whereas the community appears as a passive member that receives a technology already developed. This underplays the social, cultural, and political dimensions of the community which will have little to no influence on the technological development.
- The community is a homogeneous group of people: From a sociological perspective, it has been shown that, faced with the complexity and heterogeneity of the communities, many engineers tend to think that they are homogeneous entities with a single voice that, therefore, will tend to have

the same single client or customer profile. This ignores the need to listen to multiple perspectives as an indispensable process for the feasible development of a technology

The consequence of the above assumptions is that the technology designed to contribute to the solution of the problem is unsustainable. For a project to be truly sustainable, considering non-technical aspects, the community must be considered as a key component throughout the process, and capacity building of the stakeholders must be sought (Gómez, García & Castaño, 2008). In this way, the engineer must redefine him/herself from a "problem solver" to a facilitator of a community-empowering process. Including this new perspective in the context of engineering, learning spaces bring the need to create conceptual and practical connections between other non-engineering disciplines, such as anthropology and sociology. To this end, the experience of PBL must widen its scope to become an interdisciplinary PBL (Basken, 2016).

In this sense, for the faculties and schools where engineers are trained in Colombia to adapt and stay aligned with the dynamics of economic, social, and cultural changes, they should look for new learning options and scenarios. Examples of this are communitarian social projects that allow engineering students to recognize problem scenarios through participatory techniques, such as social cartography exercises, focus groups, and participant observation, among others. In this way, young engineers learn to identify people's skills and articulate their knowledge and experiences with scientific and technical knowledge, achieving diverse solution alternatives for problematic situations, generating leadership profiles, and organizing work teams with specific roles and responsibilities. Moreover, they also learn how to apply the working hypothesis to a located reality. This aspect is crucial in the education process of the students as it faces them with a double challenge: on one hand, they must become the protagonists of their own learning-teaching processes; and, on the other, they must become engineers engaged with their context, able to generate not only wealth, but also equality and social justice. In this way, engineering education will also become a platform for training citizens who know how to read, analyze, and intervene in the real world ethically and responsibly (Vega, 2013).

Therefore, it is very important to support the development of leadership skills in engineering students and to encourage them to lead the organizational change required to develop multidisciplinary engineering projects, building good working teams, motivating people to participate in such projects and creating innovative organizational structures, capable of addressing problems through the accomplishment of effective work.

3. Isfcol's Co-design Methodology With Social Impact

Based on the analysis of the relevant literature done in the previous section, it can be concluded that to develop engineering projects, three concepts could be considered: i) the poCDIO methodology as an approach for developing engineering projects with the community; ii) the participation of the community as the articulating element for every stage of the poCDIO methodology; iii) the educational contexts in which the project takes place, with a view to the creation of shared spaces that benefit the communities.

This is something ISFCOL has been trying to do since its inception in 2007, connecting teachers, students, and alumni through various learning spaces, to design solutions in the context of the Sustainable Development Goals from a holistic perspective. Its objective is to contribute to the improvement of the quality of life of Colombian communities with an early development, through engineering projects that are sustainable, economically and culturally viable, and that allow students and stakeholders to develop a ocial and environmental awareness (ISFCOL, 2016).

At Universidad de los Andes, ISFCOL is structured as a series of elective learning spaces where the students can acquire, during the last semesters of their undergraduate studies, skills and abilities to cope effectively in contexts of engineering projects with social impact (see Fig. 1). The academic spaces do not contain a curricular line in terms of pre-requisites, but they do have an increased level of complexity regarding the considerations that must be taken into account when working in real contexts. Students in any of the academic spaces get directly involved in the social impact projects developed by ISFCOL, which since 2012 have involved communities in the Guavio and Sabana Centro regions, in the state of Cundinamarca, Colombia.

Also, ISFCOL's learning spaces have in common the use of the poCDIO framework as a transversal

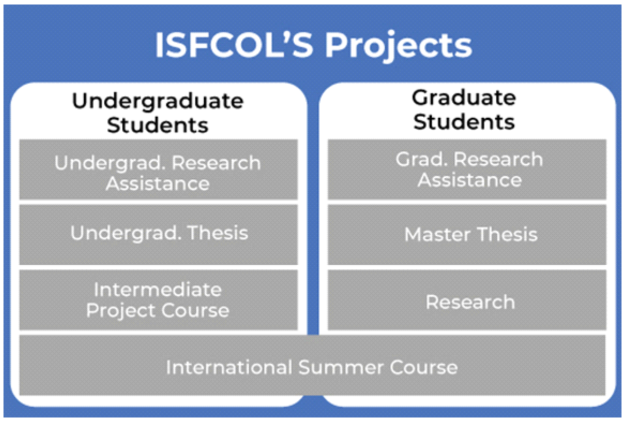

Fig. 1 : ISFCOL Learning Spaces at Universidad De Los Andes

approach to the projects developed by the students, where they begin observing the problem situation inquiring with those possibly affected, exchanging ideas with experts and researchers, conducting bibliographic reviews, among other activities. Once this preliminary observation has been made, students conceive the formulation, contextualization, and possible solution to the observed reality; this conception requires a strong emphasis on the development of creativity and innovation exercises that allow the proposal(s) to be adequate.

4. Case Study

The objective of this analysis is to assess the strengths and weaknesses of the poCDIO adaptation done by ISFCOL throughout its over 15 years of working experience. This analysis will be carried out taking the CDIO standards as a reference and seeks to contribute to future learning initiatives in engineering to effectively articulate the CDIO with the development of projects with social impact. For this, the case “Water saving prototypes in the Guavio and Sabana Centro regions” will be analyzed under the 12 CDIO standards. It was developed by ISFCOL within the framework of the project Strengthening Community Water Resource Management, by reducing its Consumption using Participatory Techniques and ICT (Information and Communication Technologies) in Guavio and Sabana Centro regions.

A. Water-saving prototypes in the Guavio and Sabana Centro regions

During 2016, the main focus of ISFCOL’s learning spaces was the project above mentioned. In this context, an inter-regional dynamic of participation was developed to generate science and technology proposals oriented to the efficient management of the water resources and thus enhance the development of capacities on science, technology, and innovation in several villages of Guavio and Sabana Centro. These capabilities were defined in the project as the abilities of students from Universidad de los Andes and schools in the region, to contribute using their imagination, creativity, and skills, to the design of mechanisms (referred to as prototypes) that could generate water savings in their homes and communities. For this, they required the application of mathematical, physical, and mechanical concepts to recreate a functional physical system. Because of this activity, two water management prototypes, which emerged from the proposals made by students of Guavio and Sabana Centro, were built.

B. Application of the methodology

The implementation of the poCDIO approach led to the participatory construction of two water-saving prototypes: a greywater filter and a mechanism that allows the collection of water from the fog, also known as a fog catcher. As already indicated, the poCDIO framework focuses on the engineering learning process in multiple participation spaces where there is a direct interaction between the engineering students and the community throughout the lifecycle of the product, process, or system. In this case, the community was composed of 10 teachers and 1500 students from rural schools in the Guavio and Sabana Centro regions that work for one year shown in Fig. 2.

The following ISFCOL learning spaces were active during the inter-regional cooperation:

- International Course: Undergraduate Engineering students took part in the conception stage of the project using their experience as a case study.
- Graduate Research Assistance: A group of graduate students worked full-time in the management of the project's participation spaces and their articulation with the poCDIO stages.
- Master thesis: A graduate Mechanical Engineering student and research assistant of ISFCOL focused his thesis on the lifecycle of water-saving prototypes.

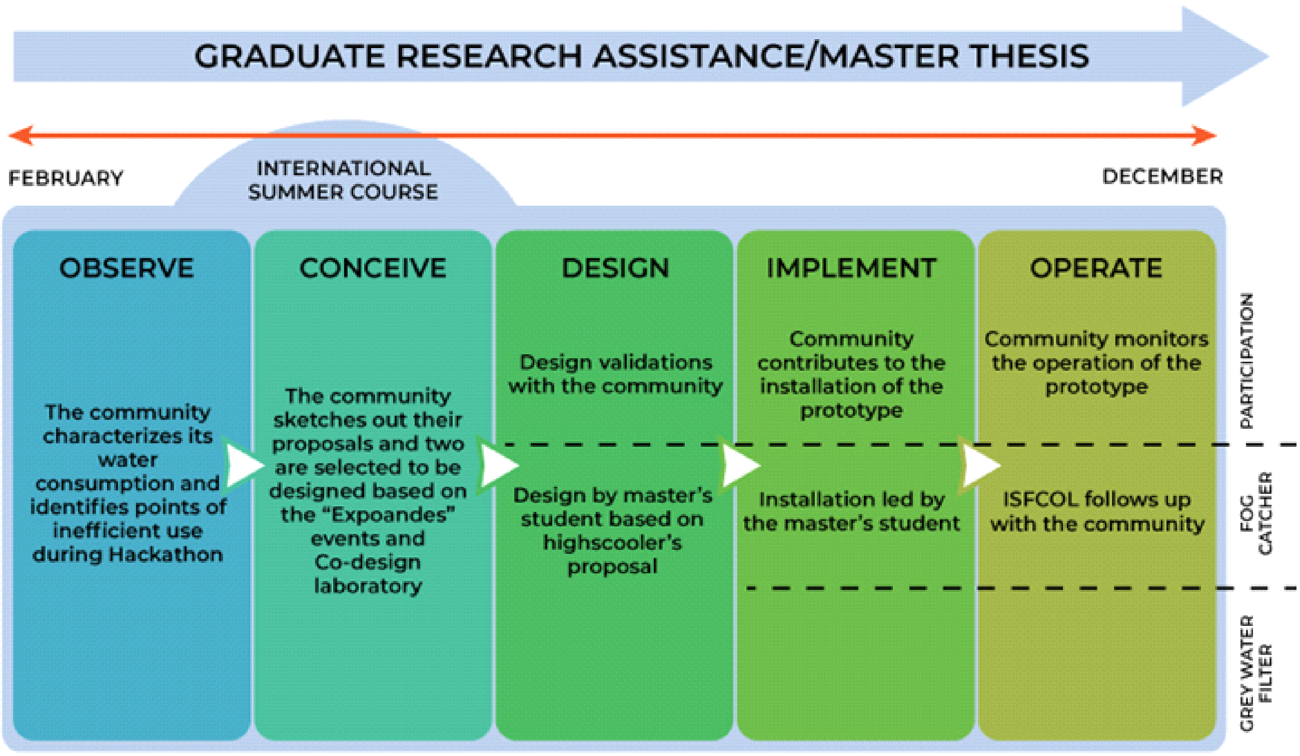

Fig. 2. Pocdio Approach For the Case Study "Water Saving Prototypes In The Guavio And Sabana Centro Regions"

1) Observe

To begin with the participation spaces around the design of the water-saving prototypes, three Hackathon-type events were held with students from all the schools involved. The goal of the events was for students and teachers in schools to make a quick exploration, through short ideation and construction processes, of proposals that could promote the water conservation. In the observation phase, schools had the mission to characterize water consumption in their homes and to propose ideas for solutions that were feasible from their contexts. In this stage, the main responsibility of the ISFCOL team of research assistants was to understand the different social, economic, and political variables of the community regarding the creation of water-saving prototypes.

2) Conceive

"ExpoAndes" is a fair of the Faculty of Engineering of the Universidad de los Andes, where first-semester students present projects developed during the semester in front of professors and businessmen. Also, the students from the schools presented their solution ideas and received feedback from engineering students and professors, as well as from external guests. After this experience, a laboratory named "Co-design in Action: green and sustainable technology" took place. During this participation space, held in the context of the ISFCOL International Course, the two prototypes to be constructed were selected considering sustainability and participation criteria: the greywater filter and the fog catcher. The role of the ISFCOL graduate research assistants during the conception stage was to synthesize the information obtained from all the participation events and transform it into design requirements.

3) Design

After the work done in the two previous stages, the design process for the two chosen prototypes began. In the context of the design process, several validation activities were carried out, both in the territory and in the Mechanical Engineering laboratories of Universidad de los Andes, where the students and teachers from the schools evaluated from their perspectives and contexts the variables that were being considered in the design and proposed others that were missing. The "design" stage, as well as the next two stages, were led by the master's student in mechanical engineering in the context of his thesis.

a) Fog catcher design

During the conception stage, five students from one school identified that a large amount of fog was generated in their municipality in the mornings. By studying their context and researching similar cases, they came out with the idea of generating a mechanism that could gather water from the fog, thus promoting the reduction of drinking water consumption for domestic chores inside their school.

Taking the above into consideration, the students proposed the design of a suburban fog catcher (see Fig. 3), or atmospheric water gathering model (Monroy, 2014), with an aerodynamic shape that could withstand the strong winds of the area and had a concave collecting layer that could catch the water drops of the heavy mist (Menéndez, 2008). Fog is a potentially high but largely neglected source of water, even though the technology that allows its collection is simple, affordable, and low-cost. The fog catcher has screens that collect water by condensing the dew particles suspended in the fog. These same screens also allow the collection of rainwater, since when these drops come into contact with the surface of the collector, they are diverted into the channels. Also, the construction, operation, and maintenance of these devices are easy to carry out, so their potential for saving water in communities with high humidity or rainfall is considerable.

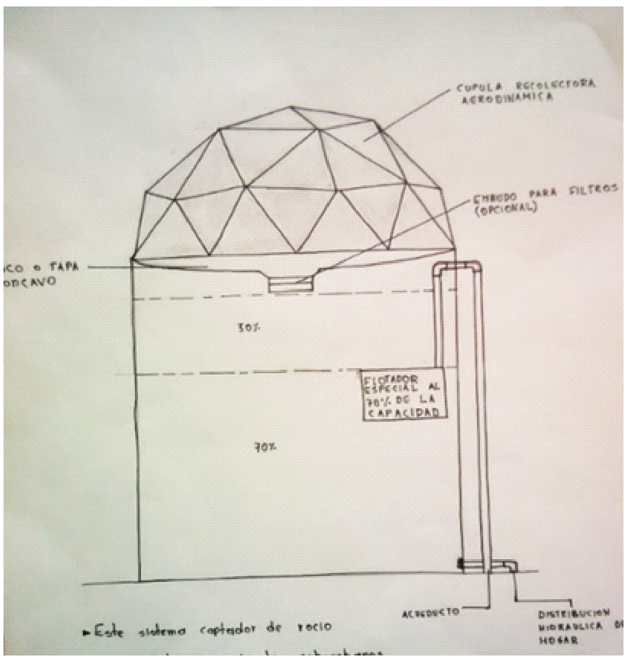

Fig. 3 : Concave Suburban Fog Catcher Designed By Elementary Students

Based on this proposal, the ISFCOL researcher and mechanical engineering graduate student elaborated a design that complied with the requirements proposed by the students and the requirements of technical feasibility (see Fig. 4), considering his research found that a concave shape wouldn't catch as many droplets as vertical panels while making the design more expensive and harder to implement by other communities themselves.

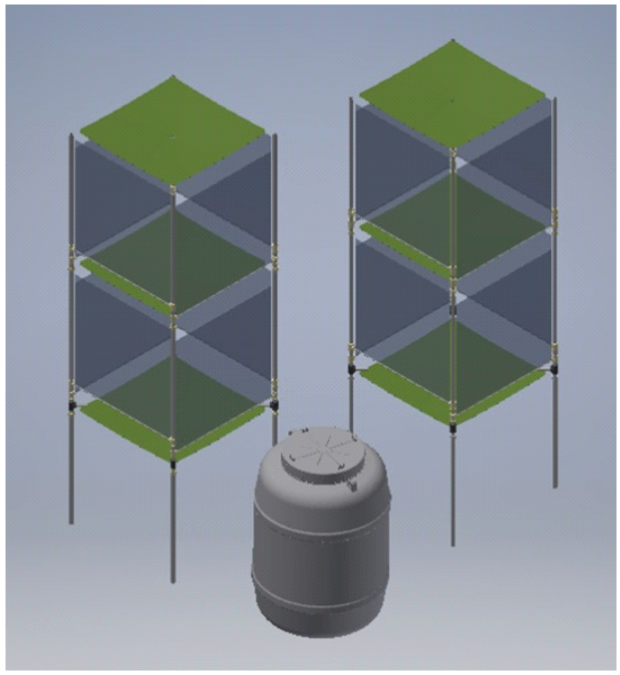

Fig. 4 : Suburban Fog Catcher Proposed by the Graduate Student Based on The Proposal of the School's Students

b) Washing machine greywater filter design

During the conception stage, many of the prototype ideas proposed by the college students were oriented toward the need to reduce the waste of water from washing machines in their homes by reusing it for other domestic uses. Following this premise, the graduate student designed a proposal for a greywater filter based on the analysis of already-existent technologies and the possible uses that treated greywater could have. The following is a general description of the design.

The system was built in PVC for pressurized water. The filter has three flanges and two 4-inch diameter pipes, which create compartments for the filtering layers to be used, for this case: 40 centimeters of thick sand and 50 centimeters of activated carbon. These are held in place through a stainless-steel wire mesh with

0,2 mm square orifices, placed between each pair of flanges.

The water enters the system from a storage tank, where it is pumped by a 120W water pump with a maximum flow of 23 liters per minute and a maximum headwater of 9 meters. A valve located after the pump allows pressure and flow regulation. In this case, water was pumped at a rate of 0,7 liters per minute which is equivalent to 14,5 psi; this pressure can be read from a manometer located upstream of the valve.

Once the water leaves the filter, it is returned to the initial storage tank, creating a closed circulation circuit, resulting in cleaner water. This process should be carried out continuously for approximately 10 hours to treat each washing machine discharge most efficiently. A valve located at the filter's outlet allows treated greywater collection.

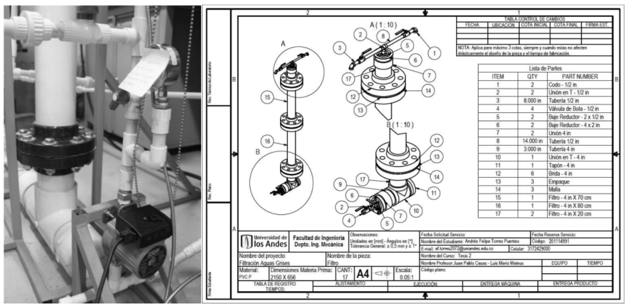

Fig. 5 : Washing Machine Greywater Filter Design

As a result of the design, it was observed that the filter could remove over 90% of soaps in the water, reducing in this same percentage the water turbidity, which generates a fluid with an almost crystalline appearance, in comparison to the water introduced. To validate the design with the community, participation spaces were developed, where students and teachers emphasized the need of evaluating the practicality and usefulness of the proposal, considering the relationship between the size of the filter and the potential uses of the filtered water. They pointed out that from a learning point of view, they considered it very important to be able to interact with real designs that promoted the reuse of domestic water and that they would be very interested in implementing the filter in their homes, as long as its size was more adapted to the space available in their homes and there was a bigger number of possible uses for the filtered water (see Fig. 5). Also examples of the co-creation spaces are shown in Fig. 6.

4) Implement

Fig. 6 : Participation Space Where the Design of the Filter Was Validated Looking Forward to its Implementation and Operation

The implementation of each of the prototypes had different development levels. In the case of the greywater filter, it was decided that the maintenance of the filter must be carried out by backwashing. This process is carried out through a subsystem of valves and pipes that allow it to divert the water of the storage tank, causing it to rise, cleaning the sand and activated carbon. A fraction of the filtered or uncontaminated water may be used for this purpose. After this process, the contaminated water resulting from cleaning the filter flows out of a pipe different from the entrance, towards the sewer system. Even though the filter is currently designed from a merely technical point of view, the filter was moved to the Padre Luna's farm, a space where its performance will continue to be tested, and where school and engineering students will have the opportunity to continue improving on the design on future participation spaces.

In the case of the fog catcher, as shown in Fig. 7, the prototype was installed in one of the schools by the students with the advice of the mechanical engineering graduate student, who after several

Fig. 7 : Participation Space Where the School Students and the Research Assistants Install the Prototype in the School

rounds of re-design required adapting the proposal to a mono-modular structure that could be assembled easier.

5) Operate

Regarding the operation of the prototypes, for the case of the greywater filter, considering that it is not an automatic system, it was decided that training was necessary either through an installation and operation manual or through a tutoring session. This is important as inadequate use of the system may damage the pump. It was noticed that the filter can treat up to 100 liters of water before clogging up. This means that it requires maintenance after approximately every load of laundry that goes through the system. 20 liters of filtered or uncontaminated water are required for this aim, meaning that the system has a water-saving efficiency of 80%. As in the implementation stage, the operation of the filter is currently designed from a merely technical perspective, and it should be articulated with the community's experience in the next academic semester.

In the case of the fog catcher, after the implementation of the prototype, the school students have provided feedback concerning its functioning, indicating that some defects in the chosen materials hinder optimal performance and that the water collected has been used for cleaning the school floors.

5. Results Analysis

The 12 CDIO standards will be used below to evaluate the case study and to provide some recommendations for future engineering education initiatives willing to adopt this learning approach based on social impact projects. The analysis will be made through the identification of the weaknesses and strengths of the poCDIO framework developed by ISFCOL.

A. Standard 1: CDIO as the context of engineering education.

In the case study as well as in the entire structure of ISFCOL, CDIO has been the framework for the development of engineering projects with social impact, so this approach is part of ISFCOL's learning spaces. It is important to highlight that throughout the inter-regional dynamics, each of the stages (including the observation stage) involved the participation of different actors, such as the undergraduate, graduate, and school students, as well as the community, which took on a role as both co-designer and user. ISFCOL facilitated the spaces that allowed the inclusion of the methodology at the school level. This level of inclusion was subject to the interest of the school's teachers, as it is not part of the school structure. As such, school students participated in the development of the prototypes, but there was not enough information available to show the ownership of the CDIO framework inside the schools. As for undergraduate students, their participation took place within the ISFCOL international course, focused mainly on the conception stage, where their role was oriented towards the accompaniment of high school students in the context of some participation spaces to define the two prototypes to be designed. While the course is focused on the CDIO approach, the learning space is limited, as are the stages that can be covered in it. Finally, the group of graduate students, in the role of research assistants, are those who were able not only to get to know the CDIO framework but also to appropriate it during the entire unfolding of the inter-regional dynamics.

While ISFCOL has established poCDIO as its framework, the level of appropriation of the students depends on the depth they reach in the learning spaces.

B. Standards 2, 3, and 4: Curriculum CDIO and learning objectives

The complexity of having to develop spaces for effective participation makes the dynamics of projects take greater priority than those of engineering education. It is important in this case to find a balance where the project and the participatory approach are always considered the basis on which impacts on education are being generated, otherwise, the poCDIO initiative is reduced to a project development methodology, with little evidence to show the impact that social project-based learning generates on students. ISFCOL is characterized by the creation of its own contents and curricula based on the project that it is currently developing.

This approach has some advantages and disadvantages. Regarding the advantages, it allows certain flexibility in terms of adapting the learning spaces to the project. This flexibility is necessary for the context of projects with social impact, as it is complex to standardize learning spaces when the community (and therefore all non-technical dimensions) may change between academic periods. However, the fact that the ISFCOL project is the central axis of the learning spaces makes the monitoring of the objectives and goals to be achieved by the students -from the point of view of the skills to be developed- take a back seat. For the case study, the development of metrics to evaluate the capabilities of all the students who participated (colleges, undergraduate, and graduate) was not considered, although the results make the impact of the learning spaces in the students perceptible. The complexity of having to develop effective participation spaces makes the project's dynamics outweigh those of engineering education. Hence, it is important to find a balance, where the project and the participatory approach are always considered the basis for generating impacts on education, otherwise, poCDIO will become a project development methodology, unable to evidence the impact on students of social project-based learning.

C. Standards 5, 6, 7, 8, 9, and 10: Learning and teaching environments:

Diversity and innovation in learning spaces is the greatest contribution that exists when adopting the learning approach based on social impact projects. Engaging students directly and explicitly in projects where their participation has an effect as decision-makers in complex environments, generates a unique experience in the context of engineering education. It is also important to highlight that going through most of the learning spaces guarantees a difference in the professional profile of an engineer.

It is evident in the case study the multiplicity of learning spaces that the students livein, where the teaching is given from a practical and almost personalized approach. Regarding the ISFCOL International course, the learning spaces were given in the classrooms of Universidad de los Andes and in the community where they could interact directly with the participants of the inter-regional dynamic. In the case of the research assistants and mainly the graduate student in mechanical engineering, they were faced with complex dynamics where it is possible to achieve a much broader learning experience than those obtained in purely academic or project environments where only the technical dimensions are considered as design requirements. It can be concluded that interacting with the community is the most enriching experience around engineering as a practice. However, in logistical and organizational terms, this leads to a greater level of complexity in the management of the spaces, and so it is suggested that the teaching or management team define the generation of logistical and community work capacities as a priority.

D. Standards 11 and 12: Evaluation

As can be seen, the poCDIO approach and the several strategies designed by ISFCOL to articulate it under the CDI stages, have generated some challenges when evaluating ISFCOL as an integrated engineering education program. During the case study, based on the traceability of the process, it can be shown that the greatest contribution is to ensure that the CDIO stages are merged with community participation and that, in turn, it is possible to develop engineering prototypes with a higher level of ownership and sustainability. However, due to the multiplicity of approaches and the different levels of management available, impact assessment and its framing within the faculty of engineering is complex. It is necessary to seek the integration of the learning spaces under the same line of objectives that are articulated at the level of measurement and verification with the learning objectives of the faculty (ABET, in the case of Universidad de los Andes). The evidence and diffusion of the results in an articulated way, can potentiate the expansion of the impact of initiatives not only at the faculty level but also at the university level. However, it is important to highlight that such scaling up is important once results and activities indicate a clear added value in social impact project-based learning.

Conclusions, Lessons Learned And Future Work

Several interesting findings were presented to conclude in this section. The first is related to the poCDIO methodology and the second to the proposed technology. The participation of the community allowed the design of the proposal to be carried out with the direct beneficiaries of the solution. The young people of the rural community themselves presented their ideas and proposals and were working hand in hand with engineering professors in the University's laboratories. Undoubtedly, this represents a direct link of how the technological proposal has a direct proposal from the community that will use it, which facilitates the appropriation of the knowledge developed in the schools involved. Regarding the technology proposed by the school students together with the university, although it does not represent a technological innovation, it does generate an important solution for the school, which can be replicated in other institutions. In this sense, it is highlighted that the technology designed contributes to the learning process of rural youth and provides a focused solution in terms of water management.

Also, through the CDIO standards, it is possible to conclude that the social impact project-based learning approach given by ISFCOL (poCDIO framework) has, as its greatest strength, the enriching experience that it means for students interacting with communities throughout an applied engineering project. The need to include non-technical dimensions in the design of an engineering prototype allows for the development of management and community work skills in the context of the life cycle of products, processes, and systems. It soulf be noticed that the effectiveness of the CDIO framework in enhancing both technical and interpersonal skills among engineering students has been demonstrated in multiple contexts. For example, a recent longitudinal study found that sustained implementation of CDIO over several years led to measurable improvements in students' technical competence, creativity, and teamwork abilities, as well as positive educational outcomes and satisfaction (D, A., C, J., & S J, T., 2025). These findings reinforce the value of adopting integrated, practice-oriented frameworks like poCDIO for preparing students to meet the evolving demands of engineering education and professional practice.

As the main disadvantage of the poCDIO approach, planning and coordinating the project might become take too much time and effort, taking the monitoring and evaluation of the competencies developed by the students in the background. In this case, it is important to find a balance between the curricular structure of educational spaces in engineering and the transversal and complex process of an engineering project with social impact. Achieving evidence of the impact -in terms of competencies and learning that students experience thanks to their participation in the spaces designed by ISFCOL- is a key aspect to guarantee the relevance of this approach in the context of engineering education. This should be central in future research.

A project, such as the co-design of water-saving prototypes in the Guavio and Sabana Centro regions, highlights the need to promote the conservation and efficient use of natural resources while recognizing that local knowledge and participation constitute an important aspect of sustainable development, that promotes participative and self-managing organization in the community around essential problems such as water saving and responsible consumption. Likewise, the participatory processes generated throughout the project allow the understanding that there are several ways of community organization and participation and that the development of management and coordination capacities between stakeholders implies the reconstruction of social relations from the grassroots, around common interests and objectives.

The implementation of educational engineering projects with social impact requires not only the active participation of several involved parties but also implies searching and facilitating innovative ways for students and stakeholders to exchange knowledge, so it can be translated into a solid input that contributes to improving the environments and conditions of the inhabitants of the target region. In this way, a permanent "learning to learn" and knowledge application attitude can be promoted to understand and transform the realities of the people involved.

As such, the analysis of the design process of two water-saving technologies developed over the course of a year by ISFCOL evidences the impact that engineering has on contemporary society by managing to work in an articulated manner with the situated reality of two middle schools. Some of the specific competencies developed by the engineering students during the poCDIO framework approach were: the ability to find engineering solutions in a holistic way to diverse situational schemes for the integral development of individuals, and the articulation of the contributions of the different areas of engineering with other disciplines and with the processes and activities of the students of the regional schools, respecting their knowledge and the conditions of their environment. It is also important to highlight the ability to think interdisciplinary, and the capacity to be sensitive to the diversity and multiculturalism of the participating communities.

The aforementioned competencies show that engineering education should promote more teaching-learning scenarios and approaches that manage to permeate personal, experiential, and academic dynamics, both of future professionals and of the communities in which they participate, so that future professionals assimilate the responsibility, ethics, and social impact that their professional practice implies.

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