# How do Engineering Students Design Projects with Social Impact?

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## ABSTRACT

In Colombia, poor management of the water resource creates water-related problems. These problematic situations require sustainable engineering solutions developed by professionals with the ability to recognize global needs, teamwork and the impact of their solutions on the future of humanity. In this sense, to reinforce the processes of quality in the training of engineers, a methodology has gradually been conceived that has given rise to a whole learning movement called Ingenieros sin Fronteras- Colombia. A team of professors, students and alumni of several programs of engineering have complemented the CDIO proposal with observation and participatory phases. Due to CDIO approaches have proven to be a powerful tool for developing professional skills by creating a formative identity through active learning, the training process in undergraduate and master courses has been enriched based on the oCDIO proposal. In this article, we present the learning methodology with which groups of students perform an engineering solution design with the ambition of impact on society. This methodology was implemented in the course of Industrial Engineering from 2012 to 2016. Results show that this methodology allows students to develop (1) professional skills related to communication and problem-solving, and (2) feasible engineering proposals that go beyond traditional approaches, and (3) the methodology promotes flexibility, autonomy, initiative, and active participation.

## KEYWORDS

Participation, Observation, Sustainability, Standards: 1, 5.

## INTRODUCTION

Engineers play a significant role in society, where their technical solutions have a high impact on the design of social and environmental systems. We are facing a crisis inside engineering practice, which emerges from applying technical knowledge that does not affect life, nor institutions, nor what happens in the daily life of the communities (Cech 2014). For example, the percentage of people in poverty in Colombia is 27.8% and the percentage of people living in extreme poverty is 7.9%. In addition, the increasing

inequality in this country plays a key role, reaching 0.535 on the Gini coefficient in 2015 (World Bank 2016). In this way, it is pertinent to investigate mechanisms or artifacts to teach/learn socially responsible engineering and that, through an adequate structure, achieve societal goals in the short and medium term.
Therefore, our world requires professionals with the capabilities to innovate, work together, understand complex situations and generate feasible solutions (Nussbaum 2005)(Nussbaum 2005)(Nussbaum 2005). Engineering students are increasingly interested in contributing to the design and development of these effective solutions for social problems (Beever and Brightman 2016). Understanding how engineering solutions can generate community change for the public good is important for professors (Leal Filho and Pace 2016, chap. 6), researchers (Lemons et al. 2014), professionals (Gómez Puente, van Eijck, and Jochems 2014), and students (Weber et al. 2014). The problem remains on that engineering programs, since their consolidation after the Second World War, have been taught in a deductive way (Goldberg 2012) This has privileged the sciences within engineering (Goldberg 2008), where professors approach first to the required theory, followed by typical problems of textbooks and finally, sometimes, real-world applications. As King (2012) points out, this structure needs profound changes that allow an engineering education focused on professional practice, autonomy, and deep and experiential learning. These changes can be summarized in three primary features. First, the knowledge and practice of engineering cannot be limited to a single field but allows the integration of other disciplines and pieces of knowledge (Sheppard et al. 2006). Second, engineers must recognize that their solutions are immersed in an intentional process that affects other systems that are complex by nature (Gallegos 2010). Finally, this integration allows to put on the table the social dimensions of the practice of engineering, hidden behind a technical façade for a long time (Eizenberg and Jabareen 2017). The challenge is, therefore, to connect engineering education and positive social change.

Therefore, the present article summarizes one possible approach to this challenge. In this experience, three main characteristics were evaluated. First, the use of methodologies which connect theory with practice by incorporating knowledge into real-life situations. Second, the importance of professional skills for the design of the technical solutions for the public good. Finally, the use of technologies during the experience to improve students learning experience. This methodology was applied in the EWB Engineer without borders Colombia course, where students designed solutions for different social problems. This paper is divided into four sections: a brief theoretical review that introduces the concepts of professional skills, CDIO learning, and engineering with social impact. Second, a presentation of the methodology used in the course and the assessment methods used. Third, the authors include a description of the qualitative and quantitative results of the experience. A final discussion presents several conclusions that generate relevant questions about the use of this kind of approaches to engineering education.

## RESEARCH QUESTION

Given the background presented above, this study wants to explore the following research question: What is the impact of implementing socially oriented projects for engineering practice on the students?

## THEORETICAL FRAMEWORK

### *CDIO context*

As CDIO methodology recalls, an innovative approach for developing skills on problem-solving through projects. Specifically, the use of CDIO provides students with the necessary tools to deal innovatively and flexibly with complex problems within a society. The strengths of the CDIO approach are summarized in table 1.

Table 1. Strengths of the CDIO approach. Based on Edstrom and Kolmos (2014)

| Characteristic | CDIO perspective |
|---|---|
| Definitions | The CDIO Standards: 12 standards ranging from design, implementation, and evaluation. |
| Curriculum | An integrated curriculum based on CDIO Standards. |
| Discipline | Discipline-led courses and an integrated learning experience. |
| Engineering Projects | Design-build experience. |
| Change Strategies | Recognition of deep understanding of disciplines and involvement of stakeholders outside academia. |

In this case, EWB Colombia developed an approach to CDIO projects in five phases, the oCDIO methodology. The additional phase, observation, will be an opportunity for students to create strong relationships with the community, and interacting with them to understand their problematic situations (Arias, et al. 2016); meanwhile, the other phases (Conceive, Design, Implement and Operate) remain the same. Applying this methodology, students generate prototypes that are the result of a systematic analysis of the problematic situation, using technical knowledge, teamwork, and innovation. However, research on the effects that the application of CDIO on professional skills (Lewis and Bonollo 2002). and the use of socially-based approaches of CDIO is still inconclusive.

### *Social impact and participation action research (PAR)*

Since the last decades of the 20th century, several research fields, particularly psychology, education, and engineering, have been having great changes that set significant differences in the ontological, epistemological, ethical, and methodological dimensions of how to approach community work (Langdon and Larweh 2015). Until the mid-twentieth century, social impact research was strictly framed into a quantitative focus, led by natural sciences or hard sciences (Lleras 1996), using positivist, coherent characteristics with the subject-object relation, experimentation, objectivity, proof, validity, and reliability as indispensable conditions(Fals-borda 1987). As an alternative for social approaches, using hard sciences stands the action research, specifically participatory action research. PAR allows projects and practitioner to achieve accurate feedback and adjustments for the proposals (Mackenzie et al. 2012). Furthermore, PAR eases institutions contribute to the community as part of their social responsibility, open to real problems and real solutions, and generate processes of teaching and research involving all stakeholders (Hernández, Ramírez Cajiao y Carvajal Díaz 2010).

## STUDY CONTEXT

### *Course overview*

Engineers without Borders (EWB) Colombia designed a learning space where engineering students' work becomes relevant by interacting directly with vulnerable communities. The projects are based on guidelines that students, professors, practitioners and volunteers on EWB Colombia must understand, develop and share. These guidelines or objectives point to important characteristics of socially responsible engineering and solution-based thinking. These objectives are:

- To recognize the contribution of engineering in improving the life quality of communities.
- To identify the specific problems of vulnerable communities and the opportunities for intervention from engineering.
- To apply science and technology knowledge in projects that address issues in vulnerable communities.
- To work in multidisciplinary teams for the conception, design, and implementation of innovative solutions to social problems.

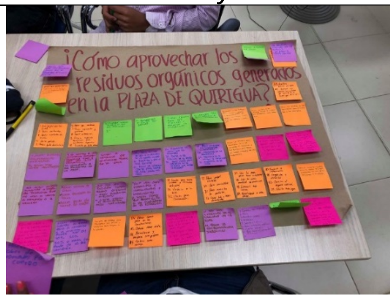
With these objectives in mind, the course mid-career EWB course. This course was integrated on the curriculum of the industrial engineering program as the course of engineering design and an alternative for implementation of their knowledge in the second half of the career. In this course, which is not mandatory, students work on groups of two or three students to solve a real challenge together with a community using explained in the next section. This course is offered to students of six to the seventh semester, and during around five months students work to implement a solution to the specific challenge. The final task includes a presentation to the community members and external experts, who evaluates the solutions not only in terms of the technical aspects but also on the level of involvement achieved. Several of these projects are developing in following semesters.

### ***Design of the methodology and phases***

In this regard, the theoretical proposals outlined above and the objectives of EWB Colombia have been integrated to provide a working methodology to work with vulnerable communities. The following table 2 provides a description of the methodology that was performed.

Table 2. oCDIO Context

| Phase | Description | Some Examples |
|---|---|---|
| Observation | The student requires factual evidence (such as indicators, situations, and experiences) to improve their knowledge of the problem. This is a phase where the engineer is linked, as stated at the beginning of this phase, at an early stage that will allow you to delve into the collective design with the community. |   |

| | | |
|---|---|---|
| | | To understand problematic situations WITH the community |
| To Conceive | The articulation with traditional engineering methodologies is when, after having evidence of variables and their relations, a process of initial conception of ideas starts. This phase must lead to the future co-construction of a solution. | <br>To conceive real solutions to real problems |
| To Design | Participatory spaces are designed, where ideas knowledge, interests and local resources translate into designs and innovative actions that provide creative solutions. | <br><br>To co-design (students + community) |
| To Implement | The students and the community developed activities that contribute to the solution and give an answer to the co-design | <br><br>The implement of 1) Transformation of fog in water in a rural context; 2) |

| | | |
|---|---|---|
| | | recollection and purification of rainwater in a rural context. |
| To Operate | Actions are monitored and justified to see both if the project contributed to changing the environment and quality of life of people. This phase requires ongoing monitoring where it is seen that not only the technical solution is taking effect, but also the co-participation in all phases has generated value added in the full process. | |

The participatory component, drawn from PAR, is transversal to the oCDIO phases, meaning that each one of them should be developed together with the community. That is why it becomes important that learning is not given exclusively in college classrooms but directly in challenging contexts.

## METHODS

### *Subjects*

The participants of the study were 56 students who enrolled in the engineering courses of Universidad de los Andes (a large private university in Colombia) and Corporación Minuto de Dios (a large regional university in Colombia). In this course, students were involved in service learning, active learning activities and project-based learning to co-create with a community a solution to a water problematic situation. The posters of some of the courses of the last years are presented in Figure 1.


Figure 1. Images of examples of version of the courses from 2014 to 2016

To accomplish this purpose, the researchers design a survey where they can determine: Student's perceptions of the course methodology and how this course was useful for their academic or professional lives. Student's perceptions about the contribution of EWB Colombia courses to their professional skills. The chosen professional skills are based on Markes' (2006) research on the skills that employers value in engineering students, the assessments of Mohan, Merle, Jackson, Lannin, and Nair (Mohan et al. 2010) for professional skills within engineering curricula and the professional skills derived from ABET's evaluation of engineering programs (Reich et al. 2015). Therefore, fourteen professional skills were selected and evaluated using a Likert-scale perception questionnaire[1]. Different socio-demographic characteristics of students participating in the study (gender, age, and occupation). In addition, the academic level of the students when they enrolled in the course (undergraduate or graduate) were considered. Furthermore, informed consent was provided at the beginning of the survey, where participants know about the objective of the survey and the possible risks of answering it. The survey had 46 questions, with three open questions. Finally, the survey was upload to Google Forms© to be available in an online format. The survey was sent by email to 360 students who took the courses between 2012 and 2016. The response rate was 15.5%, with a total amount of 56 responses[2].

***Description of the process***

During the observation phase, the students did the workshops in several high schools of Guavio Region, in Cundinamarca. Before the first visit to the community, they did a review of the town, as well as their economic and natural sources, so they were aware of the context. During the visits, the students worked with the students and the producers of the region. From these inputs, the students diagnosed that this region has good access to water, but there was a misconception of abundance that led to a huge misuse of the resource. Furthermore, some people in the town were open to embracing innovative solutions and most of them count with good connectivity to the internet.
On the conceiving and designing phases, the university students proposed several solutions based on the information collected and the engineering tools they had learned so far. After that, they went back to the school two times to develop workshops with the students, aiming to collect more information about the potential users of the solution, get feedback on their initial idea (or ideas) and keep on developing the idea together with the community, so it could fit both their needs and expectations.
Finally, the concept of La Liga del Agua was born: considering that students and the community, in general, want to learn how to use of their water resource, a gamified online environment was developed. This platform was designed as an interactive space where participants can learn about their consumption and good practices for water resource management. On the platform, the users should enter daily information on their consumption by giving the water consumption information of their water counter.
The game consisted of several levels that increase their difficulty and where they can according to their performance. To get from a level to another, the platform users should answer some questions related to the water (water cycle, consumption, saving techniques, pollution, global warming, etc.). The users could compete against their Facebook friends and other unknown people around the globe.
This platform was implemented in nine towns of the Guavio region for around three years, with outstanding results of 11% water saving on each household, on average, and more than 2000 participants.

***Findings***

From the 56 engineers and engineering students that answer the survey, 38.2% were female and 61.8% male (in concordance with the population of the courses). 81.8% of the respondents are between 21 and 26 years, while 5.4% are between 30 and 35 years and 1.8% are outliers with 19 and 49 years. 76.7% of the respondents stated that they are currently studying and/or working; from them, 23.3% are only studying, while 31.7% only work and the remaining 21.7% perform both activities. No significative differences

[1] A translated version of the questionnaire is available in the following link: https://goo.gl/Uh2tcy.

[2] The data should be available by request.

between groups were found during the analysis. Regarding the perceptions of the different activities developed in the courses, it was found that 92.7% of the respondents perceived the EWB courses as important or very important for engineering students training. In addition, more than half of the participants agreed that the theoretical concepts on which the courses are based are useful for their professional practice. According to the course's curriculum, students should develop a project along the course, working in teams. 61.9% of them say that was relevant for their professional development. Overall, 92% of respondents said the EWB Colombia course in which they participated was interesting, 72.7% consider that the course is useful for the professional life and 83.6% added that courses like this should be included in the curriculum of the engineering programs. Some of the students consider the courses:

- "Me permitió observar y analizar otros tipos de negocios desde una perspectiva mucho más responsable" (It allowed me to observe and analyze other types of businesses from a much more responsible perspective)
- "Tuve un espacio de aplicación real de mis conocimientos, siento que fue mi primera experiencia profesional" (I had a real application space of my knowledge, I feel it was my first professional experience).
- "Entendimiento del poder de la ingeniería en las necesidades de los sectores en Colombia" (Understanding the power of the engineer in the needs of the sectors in Colombia)

Based on the perspective of the professional skills, three of them stands out as the most important skills developed on the course. First, 85% of the students consider that their negotiation skills were improved during the course. Second, 90% of the participants consider that they solve a problem creatively more frequently after being part of the course. Lastly, the communication skills (both oral and written) was improved in 100% of the responses. This result is interesting because is the first time these skills were assessed in a community engagement course, showing the power of the interaction with a real problem to build upon the professional skills of the students. According to the opinion of the students, the impact on professional skills was:

- "Principalmente ayudo a fortalecer mis habilidades de comunicación. Al ser un proyecto netamente práctico con personas dueñas de negocios de diferentes capacidades económicas y sociales te exige un mayor nivel de comunicación para lograr tus objetivos." (Mainly the course helped me to strengthen my communication skills. Being a clearly practical project with business owners of different economic and social capacities requires a higher level of communication to achieve your goals.)
- "Me ayudó a ver que como ingenieros tenemos que involucrar a las comunidades en las soluciones que estamos diseñando y no caer en la falacia del experto." (It helped me to see that as engineers we must involve communities in the solutions we are designing and not fall into the fallacy of the expert).
- "Brindo herramientas transversales a la ingeniería que de otra forma no se habrían dado." (Provide transversal tools to engineering that otherwise would not have occurred.)

## CONCLUSIONS

The use of a social perspective in engineering education is not new (Al Lily 2013; Abaté 2011). This perspective of engineering teaching has been focused on the ethical implications of engineering practice and the inclusion of the social justice (Leydens and Lucena 2014; Baillie et al. 2011; Kabo and Baillie 2009). However, this approach and the use of oCDIO context courses and its relationship with service learning has a huge opportunity to learn about it. Most of the engineers and engineering students that participated in the survey stated that the courses were interesting and useful for their professional development. Furthermore, a high proportion indicated that social-oriented oCDIO courses as the ones offered by EWB Colombia should be part of the engineering curriculum. It was probed that sharing experiences with the communities affect the way respondents evaluate the courses' contributions towards the development of professional skills. Engineers that are working or doing post-graduate studies, on the other hand, valued more positively the contribution of the courses to their professional skills, especially those related with work management, working on groups and creative problem-solving. Additionally, regardless of the context, most of the respondents pointed out the EWB Colombia courses foster their ability to solve engineering problems and the participants pointed out this professional skill development is a response to the oCDIO approach of the courses. This study reveals the need for further that links theory and practice in engineering education. Even when some empirical research has been developed in the last years, integrative and comprehensive approaches should be designed and implemented in engineering schools to achieve sustainable solutions with social impact. This methodological proposal is one of the infinite possibilities that allows the involvement of students and the community through engineering practice. This "hands-on" approach suggested by EWB Colombia allows engineering students to connect with the reality and the context under study, get first-hand information from the stakeholders and conceive solutions that are pertinent and adequate for the problem they are trying to tackle. Employers and academia must recognize the importance of these results to prepare engineers with the needed abilities to face the task that 21st century proposes. Finally, this study provides results that can be valuable in the design of the curricula in engineering programs, where major changes reside.

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