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Education for Sustainability Using PBL on an Engineering Course at the National University of Colombia

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***Abstract*—**This article describes the implementation experience of Project-Based Learning (PBL) in an engineering course of the Universidad Nacional de Colombia, with the aim of strengthening student skills necessary for the exercise of their profession under a sustainability framework. Firstly, we present a literature review on the education for sustainability field, emphasizing the skills and knowledge areas required for its development, as well as the commitment of the Faculty of Engineering of the Universidad Nacional de Colombia, and other engineering faculties of the country, regarding education for sustainability. This article covers the general aspects of the course, describes how students team were formed, and how their experience was during the first semester of 2017. During this period two groups of students decided to develop their course project aiming to solve a problem regarding a Non-Governmental Organization (NGO) that works with head-of-household mothers in a low-income neighborhood in Bogota (Colombia). Subsequently, we show how sustainability is involved in the course, how tools are provided to students, and how activities are developed as to strengthen their abilities, which allows them to incorporate sustainability in their projects while also working on the methodology used to develop said projects. Finally, we introduce the results obtained by the students who sent the prototypes of their projects to the community they were working on and the conclusions reached by them regarding the course experience.

***Keywords*—**Sustainability, project based learning, engineering education, higher education for sustainability.

I. Introduction

HIGHER education and sustainability are very closely related dimensions that synergistically provide feedback to each other. Novo said in 2006 that there is a direct two-way relationship between higher education and sustainable development, for although education is a fundamental human right, dominant educational systems are the ones to determine the type of society and individual which prevails, hence determining the degree, form, and especially, the aim of the intended development to be attained [1].

School curricula have to teach how to build new coexistence models based on a citizenship capable of critically analyzing the errors of our own aspirations as a biocentric species, absorbed in myopic and unintelligent ethics [2]. Curricular sustainability must be understood as Geli proposed in 2002: a continuous cultural production process aimed at training professionals committed to a permanent search for the best possible relationships between society and nature, taking into account the principles of justice, solidarity, and equity, applying universally recognized ethical principles as well as respect for diversity" [3]. If we intend the university to have the dual social function of training new generations in a model of integral sustainability (synchronic and diachronic solidarity) [1] and to contribute to a lifestyle change in current society, a new theoretical-methodological framework under the paradigm of sustainable development one that substantiates and specifies the educational proposals for the adequate training of teachers becomes necessary [1] The problem is the scarce real presence of sustainability in higher education, which hinders its true integration into university curricula, creating obstacles such as the poor sustainability culture of many university teachers, the use of traditional methodologies, the curriculum saturation in undergraduate studies, the absence of a tradition among teachers regarding the collective reflection around these problems [4].

This article describes an experience of the inclusion of sustainability in an engineering undergraduate course. We present the generalities of the course and a specific experience with two working groups that developed their projects during the first half of 2017; the results of the projects and the opinions of the students regarding the course are presented as well.

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II. Literature review

Sustainable development must become the paradigm of the whole educational system so that different perspectives are present in the learning exercise [5]; in this way, we acknowledge that higher education institutions around the world participate in different ways in the promotion of sustainability. Higher education has a very particular and specific function: to graduate influential citizens who value their environment and who are aware that they have a responsibility to help sustain it [6].

Universities are looking for new ways to include environmental and economic management, as well as to address social issues [7]. Rogers, as cited by [8], ratifies the position of different authors by restating that a sustainable campus must include educational and operational elements in its design [8]. Additionally, measuring instruments must be designed as to establish the benefits achieved when students become involved in campus sustainability initiatives [9], and thus attain a transformation. For this transformation to happen, they must be aligned with the vision of sustainable development, the skills and attitudes of people in the system, as well as the characteristics of the system itself [5].

Education is the main transformation agent for the realization of sustainable development [10] and according to Bauer, as cited by [8], for sustainable development to be effective it must permeate every aspect of the university [8]. This is due to the fact that, on occasion, higher education institutions constantly focus on their educational activities, neglecting their economic, environmental, and social role as well as the possibility of introducing sustainable development in the region [11]. [6] starts from the question, what are the learning principles for sustainability and how do these projects relate to student learning outcomes and education theory? He affirms it is possible to separate what students learn about sustainability during their higher education experience, starting from what they valued during the same period. Most teaching and assessment processes in higher education focus on knowledge and understanding skills rather than the affective outcomes of values, attitudes, and behaviors. Affective learning refers to values, attitudes, and behaviors and involves the student on an emotional level. Cognitive learning is more related to knowledge and its application. Thus, he states that it is possible to create an argument about how the essence of education for sustainability is a search for affective results [6]. On the other hand, [12] emphasizes the importance of integrating sustainability in higher education programs. Universities have the means to teach tomorrow's decision-makers how social interrelations, economics, and the environment determine our destiny and our success or failure to achieve long-term prosperity for all humans on Earth [12].

Most people in the university receive little education on sustainability and environmental issues, unless they specifically took part in the subject or it was of personal interest [13]. Educators should increasingly focus on multi-disciplinary and multigenerational approaches to help their students, of all ages, to become increasingly qualified [14]. Practical aspects of sustainable development may also include collaboration with companies as well as working with local communities to help promote future innovation for social development and preservation of resources [15].

Education for sustainability (ES) inherently involves the idea of implementing programs that are locally relevant and culturally appropriate. All sustainable development programs that include ES must take into account the local environmental, economic, and social conditions. As a result, ES will take many different forms around the world [16].

ES can help change the attitudes and behaviors of people as consumers, producers, and citizens in the carrying out of their collective responsibilities and duties [13]. Reference [14] argues that if we are not convinced that the long run is something that must be addressed from education, research, and extension, the information about the challenges related to global warming, loss of diversity of species, poverty, and AIDS, will not be effectively translated into actions to make a difference in the short and long term.

Despite the growing interest in ES, and the acknowledgement that education and constructive capacity are key to bringing societies to a shift towards sustainable development [17], there are still many challenges for the successful integration of education for sustainability in engineering due to its complexity and the relative novelty of the sustainability theme in the engineering community [18].

Different approaches should be considered to include the main aspects of sustainability in university curricula in a coherent way. A multidisciplinary and interdisciplinary approach is also necessary because sustainability encompasses and goes across several technical and scientific areas [13], [19], [20].

New forms of training which can move beyond the boundaries of traditional disciplines are needed, aiming to provide world-class interdisciplinary teaching in the university context [13]. A greater effectiveness is necessary to assist teachers and students in the understanding of the economic, ecological, and social-ethical dimensions related to sustainability, not only for present but also for future generations [14].

Sustainability is a transdisciplinary field where engineers cooperate with other disciplines, granting greater importance to the ability of engineers to communicate with other areas and stakeholders without losing disciplinary quality [21]. Engineering has certainly not been at the vanguard of sustainability, and important changes are currently being made in various engineering institutions [22]. The sustainability revolution is likely to be a conscious operation, hopefully guided by the best science available. One of the most important priorities currently is the need to integrate the concept of sustainability into engineering programs [7], since it is possible to anticipate an increase in the demand for engineers with high competences in clean production technologies and integrated environmental management [23].

Azapagic and Adeyeri argued that major institutions in the United States have recognized that sustainable development must have a leading role in education and engineering practice [24]. In this regard, it could be said that sustainable development is the new great challenge for the 21st century engineers; however, it has to be said that they have also been the creators of many environmental problems in the past [22]. Thus, engineers have the task of translating the theoretical principles of sustainable development into everyday industrial practice [7].

III. Commitment of the Faculty and Faculties

In 2016, the authors developed a workshop with deans from different Colombian engineering faculties at the meeting of the Colombian Association of Engineering Faculties, ACOFI, where they worked on the incorporation of elements of sustainability (among others) in their respective faculties. At the end of the workshop, the participants decided to release a statement, which was written with the assistance of the authors, reflecting their commitment in a more political and public tone. The following is the translation of the statement read at the closure of the meeting: The engineering faculties of the country, committed to sustainable development in the framework of peace. The deans of the Faculties of Engineering met in Cartagena de Indias within the framework of the International Meeting of Education in Engineering (EIEI), ACOFI 2016. They discussed the role of

the faculties with regard to the new development scenarios in the country, the problems arising from climate, social, political, economic, and cultural changes, and phenomena such as environmental pollution, drought, floods, food supply, drinking water, negative effects of engineering works, resource scarcity, inequity, basic sanitation, deficient infrastructure, and corruption, among others. They also discussed the political changes required in the country, the current situation as shown by the results of the plebiscite, and the difficult political situation of uncertainty, which can lead to an increase in the historical gaps already present in the country. The engineering faculties associated in ACOFI are committed to the construction of a sustainable world, an ethical, resilient, equitable society, based on the training of citizens and engineers committed to an ethic of self-care, care for others, and care for their environment. We offer all of our capabilities by reaffirming our willingness to build and support together strategies and policies that allow the consolidation of a peaceful, sustainable, and developing country. Regarding the results of the plebiscite last Sunday, October 2, the engineering faculties call on the various political actors to cast aside the polarization and strive for a real way to overcome the conflict. The bases of the Nobel Prize stipulate that it should be given to a person who has done the best or the most work in favor of fraternity between nations, the suppression or reduction of armies, or in the participation and promotion of peace and human rights congresses in the immediately preceding year. We acknowledge and salute the work that the government and the negotiating team have done and congratulate President Juan Manuel Santos for the award he has been given. Finally, we invite our academic communities to stay informed and to continue being an active part of the expression and participation mechanisms, strengthening the bases of scenarios which allow for the improvement of the quality of life and, in turn, the possibility to satisfy the needs for future generations.

IV. Incorporation of Sustainability in a Course at the Faculty of Engineering of the National University of Colombia

Modalities and dimensions of sustainable development that must be taken into account in project development were proposed, gathering from literature, by [25]. These are later incorporated in the Workshop on Interdisciplinary Projects of the Faculty of Engineering of the Universidad Nacional de Colombia. Aware of the commitment made by the engineering faculties, it was decided to set the implementation of sustainability in the Interdisciplinary Project Workshop - TPI of the Faculty of Engineering of the Universidad Nacional de Colombia. During the first half of 2017, the strategy for the implementation of education for sustainable development in the TPI presented by [26] is complemented and renamed ”implementation scheme of education for sustainability.” The scheme incorporates the skills to be developed in students and emphasizes the components of each dimension of sustainability that are expected to be involved in the development of student projects.

Skills to develop:

- Teamwork
- Communication
- Working with local communities
- Integration
- Synthesis
- Critical thinking
- Systemic thinking skills
- Cooperation with other disciplines
- Communication

The elements from sustainability that were included are based upon those defined by [26]:

- Social Dimension:
  - Ethics
  - Justice
  - Equity
  - Culture
  - Values
  - Democracy
- Environmental dimension:
  - Natural resources
  - Green techniques
  - Water management
  - Recycling
  - Mobility
  - Environmental impact
- Economic dimension
  - Material economy with finite growth
  - Non-material economy with positive growth
  - Policies
  - Stakeholders
  - Management

A. The Interdisciplinary Projects Workshop - TPI course

The course is part of the disciplinary or professional training component of all the undergraduate academic programs of the Faculty of Engineering of the Universidad Nacional de Colombia. The course syllabus introduces its characteristics and objectives, which are presented below.

The course seeks to foster in students:

1) The development of teamwork as well as a collaborative and supportive spirit, in order to favor integral development, promoting individual and collective rights to differences in terms of belief, thought, gender, and culture.
2) The development of strategic thinking and higher order mental abilities; conceptual and experimental capacity; aesthetic and creative sensibility; ethical, humanistic, environmental and social responsibility; and the ability to pose, analyze, and solve complex problems, generating autonomy, critical analysis, propositional ability, and creativity.
3) Work of interdisciplinary nature as a strategy for the construction, formulation, and development of a project. Graduates of the Universidad Nacional de Colombia will be prepared to work in disciplinary and

interdisciplinary teams integrated in a vast local and international communication network, as well as to use cross-sector tools and expertise acquired in a specific area of knowledge, carrying out valid adaptations and applications in other areas.
4) A relevant assessment system to project-based learning
5) The development of soft skills such as negotiation; communication; empathy and relationship skills; leadership; knowledge management; time management; and resilience

1) Structure of the Course: The course is structured in four phases

1) Set-up Phase. In this phase the rules of the game are made clear, the syllabus is introduced, and work teams are organized aiming for their synergies. Key issues such as teamwork, negotiation and communication; interdisciplinarity; sustainability and ethics in the projects are worked on; and the techniques for project formulation required depending on the field, modality, and approach of the project are reviewed. Duration: 4 weeks.
2) Preparation or Inspiration Phase. Project contextualization is emphasized during this phase, recognizing and identifying precedents and the context of the problem; dimensioning the problematic situation and the actors or interested parties within the project concept; obtaining information on the state of the art of the problem and the opinion of experts. This is the way to approach a pertinent solution, by promoting interdisciplinary work, emphasizing the strategic stage, and enhancing the team work, communication, and negotiation soft skills. All of this, while simultaneously recognizing and assimilating interdisciplinary proposals to approach a solution. The interdisciplinary exercise and critical and complex thinking is what should inspire the proposed solution to the project. Duration: 3 weeks.
3) Formulation / Implementation Phase. This phase highlights the tactical skills and focuses on the tactical and operational stages with the analytical methodologies to choose, propose, and develop the best solution within the different project alternatives and modalities depending on the field, mode, and approach of the project. Particular emphasis is placed on, among others and depending on the project mode the different studies such as technical, legal, organizational, market, risk, environmental, financial, etc.; also on the definition of objectives, indicators, deliverables, and schedule organization. Additionally, the key aspects for project management and implementation in the aforementioned modalities are highlighted. When the projects bring up a well-defined solution with adequately based studies, then the realization or implementation can be carried out in this phase. Duration: 7 weeks.
4) Final or Presentation Phase. The emphasis here is on the communicative competences to ”market the solution”, by showing a solid formulation and a relevant solution, with arguments stemming from the strategic, functional, and operational areas. The argumentative and synthesis communicative abilities when presenting a project are highlighted. Duration: 2 weeks.

2) Training of the work teams: During the week before the start of the classes, the students who are enrolled in the subject are requested to propose a project idea or come up with a problem to solve which can be related to any of the topics mentioned in the following paragraphs. The first day of the class, students are divided into topic groups and then they are requested to perform a one-minute pitch where they present their idea to their classmates and two or three professors who act as jurors. At the end of the session, the jurors select a number of finalist ideas to be presented in a plenary session on the second day of classes. The number of ideas selected in each area depends on the number of students enrolled in each one of them. On the day of the general presentation, the students whose idea was selected will present the pitch again, this time to all students who are enrolled in the course (approximately 180). In addition to the presentations of the students (about 50 ideas), it is possible that others members of the community, students, teachers, or external guests present their ideas or problems to solve. These additional ideas are approximately 10. After the presentation of the projects, the students register into the one that attracted them the most, forming the work groups following these conditions: maximum seven students per group, a minimum three different academic programs, and, in as much as it is possible, every gropd has to include an industrial design student.

3) Work teams in 2017-01: In the second half of 2017, the organization Distancia Cero was introduced, bringing along the proposal of three challenges. Two of these consisted of the development of a social business model based on the transformation of materials (plastic and paper) for head of household mothers belonging to the Pocalana foundation, located in the Mochuelo Bajo neighborhood of Ciudad Bolvar. The Mochuelo Bajo neighborhood is located less than 600 meters away from the capital city garbage dump called ”Doa Juana”, which causes health problems and worsens the living conditions of the neighboring inhabitants. The members of their community have limited economic resources and some are dedicated to the collection of recyclable material as a means of income. In addition, there are foundations such as Pocalana, which works with head of household mothers and accompanies them in the development of productive processes.

4) The TPI Projects: Fourteen students enrolled in two of the projects proposed by Distancia Cero to be developed with head of household mothers; their academic programs are listed below:

- Electrical engineering
- Electronic Engineering
- Mechanical Engineering
- Mechatronics Engineering
- Chemical engineering
- Industrial design

One of the authors of this article was chosen by the students as the mentor of the groups.

B. Sustainability Tools at the TPI

In order to incorporate the elements of sustainability, a set of activities to be developed with students have been selected; these are described below.

C. The Farmer's Story

For the first session where the two groups of students meet with their teacher-mentor, the teacher does not let any student enter the classroom. Later on, the first student enters and the mentor reads the farmers story; then he asks the student to tell the story to the next person, who in turn must do the same with the third student and so on until all 14 students enter the classroom. In the end, the original story is compared with the story of the last student who entered the room. The story of the farmer is widely available on the internet in spanish as "La historia del granjero" and is told as follows: A farmer in the west of Extremadura placed a thin roof over his barn. Shortly after, a howling wind sent it flying, and when the farmer found the roof twenty kilometers away, it was bent and shrunken, impossible to repair. A friend and a lawyer told him that the Ford Automobile Company would pay him a good price for the scrap and the farmer decided to send the roof to the company to see how much he could get out of it. He packed it in a large wooden box and sent it to Avils, Asturias, clearly writing the return address so the Ford Company knew where to send the check. Twelve weeks passed and the farmer had heard nothing of the Ford Company. Finally, when he was about to write to them as to find out what was going on, he received an envelope from them. It read: "We do not know what hit your car but we will have it fixed by the fifteenth day of the next month." After the activity, and as suggested in the source website, a reflection on the importance of communication, the way of understanding information, and the distinct importance subjectively given to different elements of the message, is brought up by the mentor. The distortion of the message can happen due to the message not being clear or due to keeping incomplete information. A debate is held with the students on the importance of ensuring a good communication process from the sender to the receiver and how information depends on the interest and interpretation given. Hence the importance held by the entire working group being vigilant for the indications and the practical need to attend to all sessions for the purposes of project development. Some aspects that must be taken into account during the exercise are:

- Lack of meaning of the message and the context
- Difficulty to remember a considerable number of ideas in a single message
- The presence of distracting elements
- The difference between remembering anecdotal aspects and crucial aspects

D. Definition of the Problem

In order for the students to understand that the definition of a project must come from the identification of a problem and not from the proposal of a solution, some of the following methodologies are implemented. First of all, there was a meeting between the students, the foundation, and the head of household mothers to establish their needs and the basis for a joint creation process. Other activities were developed with the information obtained during the visit. Six Times Why: Students are asked what the problem is; upon receiving the answer to the question, they are asked why that is a problem (first why), and again, upon receiving the new answer, they are asked why that could be framed as a problem (second why). This continues until six questions why are asked, each with their corresponding answer. This allows students to understand the causality of the problems and later on enables them to identify the root or the issue, while giving them the elements to modify and fine-tune their proposal of a solution. Methodologies such as the CATWOE, the VESTER matrix, and the construction of the problem tree are applied, concluding with a new version of the initial problem.

E. Contextualization and Teamwork

In order to contextualize their problem, students are asked to develop the PESTAL matrix, which examines the Political, Economic, Social, Technological, Environmental, and Legal aspects related to their project. In this way, they obtain the framework that allows them to establish the general and specific objectives of the project they will carry out. The importance and necessity of teamwork is highlighted through the so-called Einsteins Riddle, which is developed with the students, with a small twist. Each student receives only one of the clues to solve the riddle (if there are more clues than students, any leftover clue is publicly shared), motivating them to work as a team, involving their negotiation and communication skills to achieve a common goal: the solution of the riddle. After the activity, the importance of communication is discussed with students based on the following questions:

- What was the common goal?
- Was the common goal achieved?
- What allowed or prevented you from achieving the goal?
- What is the importance of teamwork to achieve a common goal?

Now, having defined the problem and the objectives, the students are ready to start their projects, in which they must take into account the aforementioned dimensions of sustainability. The following is the initial idea proposed by the students, the definition of the problem, and the objectives set by each one of the groups:

F. Group 1

- Initial question: How to generate a social business model based on recycling and plastic processing for the Pocalana Foundation and the head of household mothers of the Mochuelo Bajo neighborhood in Ciudad Bolvar?
- Problem identified by the group: The lack of a business model based on plastic recycling which would allow head of household mothers of the Pocalana foundation program in the Mochuelo Bajo village to generate economic resources.

- General objective: Proposing a social business model based on the use of plastics that can be implemented by the Pocalana foundation for the economic benefit of the head of household mothers.

G. Group 2

- Initial question: How to generate a social business model based on recycling and paper transformation for the Pocalana Foundation and the head of household mothers of the Mochuelo Bajo neighborhood in Ciudad Bolvar?
- Problem identified by the group: The challenge the Pocalana foundation faces in order to improve the quality of life of the head of household mothers associated to the foundation, by means of a business model based on paper recycling.
- General objective: To create a social business model for the Pocalana foundation, so that the head of household mothers in the Mochuelo Bajo neighborhood, associated to the foundation, receive additional income from the production of two products derived from recycling and paper processing.

H. Idea development

Students work on business models and the product design to be delivered to the foundation. When they have a concrete proposal, they carry out another visit to validate the ideas and receive feedback with the mothers. They make the relevant adjustments and prepare the final version of the business models and product prototypes. During a final visit, they deliver these to the community; bringing the academy closer to society.

I. Result delivery

Mothers say they are satisfied with the students work and feel they have the groundwork to start their business from recycled materials.

The students deliver to the mothers a business model which includes the following information:

- Executive Summary
- CANVAS
- Corporate identity manual
- Product Manual
- Scheme outline
- Service scenarios and responses
- Description of the business environment
- Ethnography of the clients
- Competence study
- Technical description of products and services
- Prototypes
- Space Design
- Machinery and equipment
- Analysis of the organization
- Quality control
- Product prices
- Communication and publicity
- Products datasheets
- Distribution strategies
- Financial plan

Additionally, the students provide the first prototypes resulting from plastic and paper processing to mothers.

J. Final Presentation of the Course

The students made a final pitch-like presentation showing the results of their projects. After the evaluation by the group of jurors, the two groups are placed among the 6 best projects of the semester out of a total of 28 projects.

K. Student Comments

In the last session of the course, the students were asked to evaluate the development of the subject, their comments were:

- The project we carried out has a future, it is important to provide continuity for it
- The University should be involved more in this type of projects; this allows it to fulfill its social function. The next semester it should create a space for the mothers to show their products
- The number of people in the working groups is quite large. It is very difficult to work, each person has a different pace of work and the schedules of each member create a problem to establish meetings
- The work with the foundation is very good, it helps to build society, and you can hardly see the mission of the University
- There should be more teamwork in Wednesday classes. Less lectures and more workshops
- Too much time is spent on planning and too little for implementation, this should be reversed. Among other [reasons], because the inspiration stage is smoother and when the hard work begins, there is a lot of academic pressure coming from the other subjects. There is not much time for trial and error with the prototypes
- It is a very romantic methodology. You should not move it out from the academy
- Projects associated with organizations are already biased towards a solution
- The activities developed in the mentor sessions allow the fear of speaking to be broken and confidence is built-up. The dynamics that were carried out were important because one does not always know how to work in teams. The course was adapted according to the needs of the project. For every exercise, we made pre-deliveries and received feedback.
- The drills were useful. [It is] important to acquire the additional commitment instilled by the teacher; there was an interesting communication that helped.

V. Conclusion

- The methodological proposal strengthens the presence of sustainability in the Faculty of Engineering, incorporating it into the curriculum.
- Education is recognized as a transformation agent to achieve sustainability in all dimensions. Assisting in the

change of attitudes and behaviors of students strengthens the training of professionals who work in the framework of sustainability.

- The integration of the concept of sustainability in engineering programs means a challenge that implies a change in traditional schemes. The project-based learning methodology is a path for the successful integration of sustainability in engineering in accordance with the commitment made by the deans of engineering faculties of building a sustainable world. Additionally, the methodology presented contributes to the training of engineers committed to an ethic of care, for themselves, others, and their environment.
- The proposed scheme adjusts the implementation of sustainability in the Interdisciplinary Projects Workshop course by incorporating the skills to be developed in students and emphasizing the components of each dimension of sustainability
- Thanks to the implementation of the proposed scheme, the students were able to develop the following aspects:
  - Teamwork
  - Communication
  - Working with local communities
  - Integration
  - Synthesis
  - Critical thinking
  - Systemic thinking skills
  - Cooperation with other disciplines

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