EMBEDDING SUSTAINABILITY IN THE CURRICULUM AT THE ENGINEERING SCHOOL OF THE UNIVERSITY OF CHILE

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Abstract: The present paper presents two manners in which, by utilising the existing structures, sustainability is being integrated in the engineering degree programmes at the University of Chile. The first approach consists of including sustainability topics, principles and methodologies within the first two and a half years of compulsory courses; while the second one, entail the creation of two Minor programmes which can be undertaken by the students within a voluntary scheme. Additionally, this work describes the change process towards sustainability in teaching, and the main challenges found along the road. Moreover, in order to quantify the gap between the current and desired curriculum status in terms of sustainability incorporation, some context-specific assessment metrics are proposed.

1 INTRODUCTION

In December 2002, the United Nations General Assembly proclaimed the UN Decade of Education for Sustainable Development, emphasizing that education is an indispensable element for achieving sustainable development (DESD -United Nations, 2005-2014). Universities play a significant role in promoting the concept of sustainability in different avenues, such as new educational programs, research, cooperation with other entities and the use of demonstration projects. In fact, education for sustainable development has been on the agenda of many engineering faculties since 1990’s (Segalas et al., 2010).

Much progress has been made over the last decade in developing ways to introduce the concepts and issues surrounding sustainable development to engineering students and to challenge them to think about sustainability-related problems in different ways (Fenner, 2013). However, while education for sustainability literature shows there have been calls for embedding sustainable development content throughout engineering curricula (Allen et al., 2010), there has been little of strategic and systemic integration (Byrne et al., 2013).

One approach to introducing sustainability concepts to engineering education is incorporating sustainability-related topics directly in the curricula. Such mechanism has been implemented by many universities; see for example the case of the University of Nottingham Engineering Faculty. In another approach, the engineering undergraduate curriculum can incorporate a professional specialisation, for example the Energy, Sustainability and the Environment specialisation at the University of Cambridge. A third case worth-mentioning is to create a whole new academic unit dedicated to sustainability-related topics, for instance, the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology. In regards specifically to Minors in Engineering Schools, a wide range of such programmes can be found worldwide. To mention a couple: Minor in Sustainability Engineering at the Binghamton University – the State University of New York – and also a Minor in Sustainable Engineering at the Columbia University in the City of New York.
The issue of sustainability in higher education from the learning and institutionalisation processes point of view has been revised in (Wals, 2013). A major reflection in this work is the classification of “bolt-on” and “built-in” approaches. The first one consists of adding new courses and modules that have elements of Education for Sustainable Development, whereas the second one corresponds to integrating sustainability in existing studies and research programmes as well as in staff development. As the “built-on” responses seem to be becoming extinct, in the change process presented in this paper the “built-in” approach has been selected. International evidence has shown (Wals, 2013) that most of the universities that engage in sustainability are universities that have a focus on education, rather than on research. In the case of the University of Chile, its main focus is on research, and experience has shown that it has been an important challenge to open space for the introduction of sustainability at the Engineering School.

The main purpose of the paper is to present a field experience in embedding sustainability in the curriculum at the Engineering School of the University of Chile, and also identify the gaps yet to be accomplished, which is discussed in light of the international analysis and scholar evidence. The remainder of this paper is organized as follows. In Section 2 a description of the engineering curricula at University of Chile’s Engineering School is presented. In Section 3 initiatives for introducing sustainability contents in the first two years of the engineering curriculum and in each Department is discussed, whereas in Section 4 the two minors are described, which includes the main aspects of the design process and structure proposal. Finally, section 5 summarizes the main conclusions of this work.

2 ENGINEERING CURRICULA DESCRIPTION

The engineering studies at University of Chile last six years. The main specialisations comprise mechanical, industrial, computer science, civil construction, electrical, chemical, mining, and biotechnology engineering. The first two years are set as a core programme in mathematics, physics and computer science. This two-year programme is denominated Common Plan, and the courses are described in Figure 1.

![Figure 1: Common Plan](image)

In Figure 1, each row represents a semester, and the academic year has two semesters. Lines with arrows indicate courses requirements. Every course has the same time dedication of 10 hours per week, which consist of 4 hours of teaching, 3 hours of assistant-guided classes and 3 hours of personal work. Additionally, there are Integral Formation courses for English and humanities. Students must take four of these courses, and the total dedication in this case is 5 hours per week.

In third year students choose their field of specialisation and most of the courses they take are given by a specific Department (called Department Courses). The two following years, starting in semester 5, will fulfil the requirements to acquire the Bachelor Degree. A general outline is presented in Figure 2.
Similarly, in Figure 2 each row represents a semester. Basic Formation courses are defined by each Department, and correspond to those considered to be significant for the understanding of the discipline. Starting in the sixth semester, there is a sequence of five courses dedicated to Minors (Minor Courses in Figure 2). Two of them take place in Semester 7 and the other two in Semester 8. In the engineering curriculum at the University of Chile there are around 20 Minors available, and they can be completed by students as long as they comply with the Minor course requirements. The students also have the possibility not to engage in a Minor and, alternatively, take those five courses according to their own election freely.

3 INTRODUCING SUSTAINABILITY IN THE COMMON PLAN AND DEPARTMENTS

The Office of Engineering for Sustainable Development (OESD) was created at the Engineering School of the University of Chile a year ago. Its vision corresponds to incorporate sustainability as an enhancing element of the students’ formation, and therefore focuses on the following dimensions: teaching, applied research, operations and organisation of the Campus, and outreach. One of the initiatives driven by the OESD has been to identify which courses are either focused or related with sustainability, which is highlighted in the course catalogue with green and yellow leaves, respectively. As further work, the OESD intends to categorise the courses that and neither focused nor related with sustainability, but those which have been modified to concisely include activities, certain content or exercises related with sustainability, which should be indicated in the course catalogue with a white leaf.

In regards to teaching, several efforts have been made through engaging in one-to-one dialogue and brainstorming sessions with professors of the Common Plan. The achievements and work in progress are listed below:

• A brief introduction to sustainability definition and principles will be soon included in the Introduction to Engineering II course;
• In the Computation course, the students have been given last semester an assignment which consists of calculating the second scope of the Campus carbon footprint. This activity is expected to be repeated the subsequent semesters;
• A Sustainability Workshop is being offered for second year students. They are obliged to choose one workshop of around twenty five courses available, which are related to a variety of engineering and sciences’ specialities;
• An experiment with solar cells will shortly be incorporated in the Experimental Methods Lab;  
• In the Chemistry course and since last semester, content regarding reducing-reutilising-recycling has been added, in the context of mass balance equations in the Mining Industry;
• Complementary reading material related to Hydroelectric Power Generation has been included in the Newtonian Systems Lab, and an exercise with wind turbine prototypes is currently being designed;
• A compulsory class was added last semester in the Electromagnetism courses, with an emphasis on energy efficiency.
If a target of a 100% of the courses within the Common Plan are expected to incorporate sustainability activities – and the mathematics courses are assumed to be not feasible to modify because of their theoretical nature – then 6 out of 11 courses incorporate sustainability-related topics, exercises or principles, with a reach of 54.5%.

The efforts to incorporate sustainability in the curriculum have not only been narrowed to the Common Plan. It has been possible for the Office of Engineering for Sustainable Development to work with interns of different engineering careers in order to include sustainability topics, principles and methodologies within their corresponding Department.

For example, in the Industrial Engineering Introductory Course, students are typically asked to develop social projects throughout the semester, and since last semester, wider sustainability projects have been contemplated in the course projects. Furthermore, the interns have sent e-mails trying to contact each professor of each course at the Industrial Engineering Department, in order to discuss with them the most appropriate way to include sustainability in their courses – with the directions and study material provided by the Office of Engineering for Sustainable Development. The same procedure has taken place with the Chemical and Biotechnology engineering Departments. On the one side, the students engaged and particularly the Office of Engineering for Sustainable Development has seen a reasonable degree of progress within those Departments, which could be estimated in a 10% success percentage. On the other side, the magnitude of the effort of contacting the professors on a one-on-one basis, having creative meetings with them and coming to an agreement, providing the complementary material, and monitoring that the changes are actually being implemented in all the Departments of the Engineering School has been perceived as unmanageable for a two-persons OESD.

In order to objectivise the incorporation of sustainability in each Department curriculum, an index measuring the percentage of the compulsory courses that can be classified as focused, related or modified towards sustainability is proposed. So far, it is only possible to identify the focused and related courses, as the modified courses have not yet been marked with a white leaf. Each Department curriculum has been revised, and the results are shown in Table 1.

<table>
<thead>
<tr>
<th>Career</th>
<th>Number of Compulsory Courses</th>
<th>Courses Focused or Related with Sustainability</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Engineering</td>
<td>18</td>
<td>7</td>
<td>39%</td>
</tr>
<tr>
<td>Geology</td>
<td>21</td>
<td>7</td>
<td>33%</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>23</td>
<td>7</td>
<td>30%</td>
</tr>
<tr>
<td>Biotechnology Engineering</td>
<td>23</td>
<td>4</td>
<td>17%</td>
</tr>
<tr>
<td>Industrial Engineering</td>
<td>18</td>
<td>3</td>
<td>17%</td>
</tr>
<tr>
<td>Mining Engineering</td>
<td>19</td>
<td>3</td>
<td>16%</td>
</tr>
<tr>
<td>Geophysics</td>
<td>10</td>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>22</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>18</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Computer Science Engineering</td>
<td>14</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Physics</td>
<td>8</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Mathematical Engineering</td>
<td>11</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Astronomy</td>
<td>8</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 1: Number of Compulsory Courses per Department and Number of Compulsory Sustainability-Classified Courses per Department

We have estimated that, in this preliminary stage of deployment, a desired minimum percentage would be 25%.
4 MINOR PROGRAMMES

In the present chapter the design process and structure of the Minor in Renewable Energy and Engineering for Sustainable Development are described.

4.1 Minor in Renewable Energy

The Minor in Renewable Energy was conceived with a flexible organisation, and students may choose four courses from a given list and the fifth is free at their election (they may pick any course given in the entire Faculty). So far, the list of courses is as follows:

- electricity generation with renewable energy,
- introduction to meteorology and oceanography,
- principles of geothermal energy,
- introduction and applications of solar energy,
- renewable energy with biomass.

The average number of students taking Minor courses per semester is above 100, being the Minor with higher demand in the School of Engineering so far. It is important to emphasize that due to the success of the Minor, there is a number of new courses that may be incorporated in this list in the future. Here we describe the existing courses that are currently being offered in the curriculum.

A. Electricity Generation with Renewable Energy. The aim of this course is to provide basic knowledge of the various technologies for generation of electricity out of renewable energy. It will provide course participants with an overview of the most significant renewable energy resources, concepts and technologies to generate electricity in a sustainable fashion. In addition it will describe the foundations for sustainable energy usage. Students will be able to recognize, understand and evaluate the different renewable energy resources available today and in the future.

B. Introduction to Meteorology and Oceanography. This course provides an integrated vision of meteorology, oceanography, and environmental science, which is oriented towards the need to understand the interactions between the ocean (superficial), atmosphere (lower), and land, and how these interactions influence the earth weather system on many different time scales. The course is oriented towards the identification of potential areas with renewable energy such as solar, wind and tidal. It is also in the scope of this course the design of measurement system in order to do the sizing of energy resources.

C. Principles of Geothermal Energy. In this course the exploration of geothermal resources, including geological factors, and a description of the different conversion technologies used for energy production are presented. The course covers efficiency of power production from geothermal resources, economic aspects and provides practical examples. The main objectives of the course are to understand the thermodynamic principles used for energy production from geothermal resources, to know the fields of application of the different technologies, their advantages and their drawbacks.

D. Introduction and Applications of Solar Energy. The course consists of a study of Solar-thermal technologies for generating both electricity and heat from sunlight. The principles, manufacturing technologies, efficiencies, advantages and limitations of various solar-thermal technologies are considered. The students should be able to design a manufacturing plant as well as practical installations of various solar-thermal components in a cost effective way. The different solar-thermal systems will be introduced with the basic heat transfer and thermodynamics principles that apply. Both bulk electricity generation and smaller stand-alone systems will be covered.

E. Renewable Energy with Biomass. This course provides an understanding of biomass production systems including agricultural and forestry. Students will learn to assess the potential and limitations for energy from biomass from different sources. The content will include: Introduction to biomass; Basic principles of thermodynamics and energy transport; Energy transformation in the land-use processes;
Introduction to genetic engineering and metabolic engineering; Thermo-chemical transformations. Combustion, gasification, pyrolysis; Physical and chemical transformations; Bio fuels, biodiesel; Bioethanol/bio butanol. In order to give the participants hands-on experience, knowledge of the interaction between the technologies, sustainability criteria and the need for distributed energy solutions, a small scale project is proposed in a final assignment.

4.2 Minor in Engineering for Sustainable Development

The origin of the idea of a Minor on sustainability is a directive given by the previous Dean of the Engineering School to the head of the OESD. The Minor would be implemented by putting together a set of courses, which could be offered as a Minor in Engineering for Sustainable Development. This indication responds to a very sensitive need expressed by engineering students to incorporate sustainability concepts and contents into the curriculum. It was seen as an opportunity to introduce the sustainability concepts in a way which posed less resistance and barriers to implementation.

In order to set the task force, a group of professors were invited by the Head of the OESD to an initial brainstorming session to commence designing the Minor. The Engineering School Teaching and Pedagogical Area promotes a competence-based approach in the training of engineers, therefore they recommended the Minor in Engineering for Sustainable Development should integrate a similar methodology. The Area also suggested integrating students in the working sessions, in order to be able to embrace from the beginning of the design process the students’ thoughts and recommendations. Accordingly, students involved in environmental student groups were invited to participate in the design sessions of the Minor. As a result, the task force in charge of designing the Minor was led by the Head of the OESD and the whole team was composed of 10 Professors, 3 Professionals and 4 students.

In terms of the design process of the Minor, five monthly working sessions were organised by the Head of the OESD. These sessions would typically last two hours and have a couple of objectives to be discussed and agreed. It is worth mentioning that vertical authoritarian leadership styles where not commonly observed throughout the sessions, which contributed greatly to the depth of the discussions and to achieving consensus. This process has followed a social learning approach (Barth and Rieckmann, 2012), and as a result, become individually and collectively more competent. The key outcomes of the working sessions were a list of competences students should have by the end of the Minor, the structure and courses of the Minor, and the responsible teams of the various tasks. The competences students should have by the end of the Minor are the following:

- the student links sustainability to complex systems analyses, in its social, environmental and economic dimensions;
- the student assumes sustainability as a professional attribute related to critical thinking and responsibility;
- the student integrates complexity and sustainability educational tools in the practice of its own field of specialisation;
- the student discusses, promotes, and proposes sustainable solutions to its local environmental.

The previously described competences have determined the definition of the structure of the Minor – which has 45 credits. The structure of the Minor aims not only to introduce basic sustainability contents and topics, but also to permit students to specialise in their own fields of interest, and to experience the complexities linked to sustainability through a practical workshop. In terms of methodological approaches (Littledyke et al., 2013) argue that wide consultation, consensual agreement and collaborative practice have been viewed as important to achieve collective views and coordinated action for education for sustainability. The overall structure of the Minor is shown in Figure 3.
Figure 3: Structure of the Minor in Engineering for Sustainable Development

Firstly, there is a mandatory introductory course to Engineering for Sustainable Development, which purpose is to introduce a common background in terms of engineering and sustainability to the students. There is a wide range of new forms of learning in ESD programmes (Wals, 2013), including trans- and interdisciplinary learning, social learning, project-based learning, gaming, computer simulations, distance learning, backcasting, case-studies, policy-laboratories, problem-based learning, bootstrapping, values education, ecological footprint analysis, experiential approaches, reflective journal writing. In our case, we have adopted among others interdisciplinary learning, project-based learning, values education, and the ecological footprint analysis.

Secondly, three elective courses must be chosen from a pool of approximately 15 courses offered by the various Engineering Departments within the Faculty. These elective courses comprise subjects such as climate systems, environmental engineering, environmental economics, sustainability in construction, innovation for sustainability, sustainability in mining, social project evaluation, and renewable energies. This initiative also led to the creation of two new elective courses in the undergraduate programme. The Minor ends with a practical project where students propose a sustainability intervention to their surroundings. The design of this workshop followed the ideas of (Segalas et al., 2010) in the sense that sustainability courses at technological universities should focus their content on the social and institutional aspects of sustainable development, and apply a constructive and community-oriented pedagogical approach.

In order to assess the Minor Programmes’ impact, Table 2 exposes the number of students who have undertaken them in the period 2009-2014. In the case of the Minor in Renewable Energy, every course is included, whereas in the Minor in Engineering for Sustainable Development, only the compulsory introductory course is presented as it has been launched during the second semester of 2014.

<table>
<thead>
<tr>
<th>Course</th>
<th>2009/1</th>
<th>2009/2</th>
<th>2010/1</th>
<th>2010/2</th>
<th>2011/1</th>
<th>2011/2</th>
<th>2012/1</th>
<th>2012/2</th>
<th>2013/1</th>
<th>2013/2</th>
<th>2014/1</th>
<th>2014/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Generation with Renewable Energy</td>
<td>0</td>
<td>50</td>
<td>64</td>
<td>25</td>
<td>18</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>23</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Introduction to Meteorology and Oceanography</td>
<td>16</td>
<td>76</td>
<td>87</td>
<td>53</td>
<td>89</td>
<td>45</td>
<td>52</td>
<td>54</td>
<td>62</td>
<td>69</td>
<td>66</td>
<td>60</td>
</tr>
<tr>
<td>Principles of Geothermal Energy</td>
<td>0</td>
<td>0</td>
<td>52</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>46</td>
<td>0</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Introduction and Applications of Solar Energy</td>
<td>0</td>
<td>0</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>52</td>
<td>0</td>
<td>48</td>
<td>0</td>
<td>58</td>
<td>0</td>
<td>64</td>
</tr>
<tr>
<td>Renewable Energy with Biomass Introduction to Engineering for Sustainable Development</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>26</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>126</td>
<td>242</td>
<td>98</td>
<td>107</td>
<td>123</td>
<td>122</td>
<td>127</td>
<td>131</td>
<td>154</td>
<td>111</td>
<td>184</td>
</tr>
</tbody>
</table>

Table 2: Number of students who have undertaken Minor Programme Courses (2009-2014)
After the first period of settlement, which we consider from 2009 to 2010, Table 8 reveals that the number of students enrolled in these courses fluctuates between 100 and 150, approximately. If we keep in mind that yearly the number of students entering to the School of Engineering is around 800, we can estimate that over 25% of them have interest in these sustainability-oriented Minors. Furthermore, if we take into account the new course Introduction to Engineering for Sustainable Development, offered the second semester of the year 2014, those percentages could rise over 45%.

5 CONCLUSIONS

As the Minor initiatives have been promoted with a wide support and participation of the students, the design process along with the implementation have received an enthusiastic answer from the whole Faculty. These first years of implementation have shown that both of Minors, in Renewable Energy and Engineering for Sustainable Development, have had full inscriptions, which also suggests that the students are very keen on acquiring both conceptual and methodological knowledge in sustainability. In fact, a preliminary estimate of the interest in this courses indicates that over 45% of students in the School of Engineering have clear interest in sustainability-oriented Minors. Likewise, it has been possible to incorporate sustainability-related topics, activities and principles in 54.5% of the Common Plan Courses, and at the moment 23.1% of the Departments are successful in having more than a quarter of their courses focused or related with sustainability. Therefore, it could be concluded that the Engineering School at the University of Chile is moving forcefully towards embedding sustainability in the curriculum.

For future work, reaching the 100% target of sustainability incorporation in the Common Plan, expanding the same mechanism for the Basic Formation Courses, prioritising the current work in those Departments which have a large number of students and have not extended the 25% target of sustainability incorporation in their curriculum, implementing the white leaf mechanism for the modified courses, and ameliorating the assessment and impact in students’ education and literacy in sustainable development, is proposed.

References