Active Learning Based Sustainability Education: a Case Study

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Abstract

The fundamental role of engineering in modern societies demands not only technically specialized engineers, but also global cultural cognizance, personal and professional ethics, together with sound transversal skills and responsiveness for sustainability issues. An enriching learning context provides engineering students with opportunities to proactively seek knowledge and technical proficiency at their unique pace, and monitor and master their own learning process. Active Learning undoubtedly enables an enriching learning context, where technical and transversal competences can be widely exercised and developed. However, when looking at the development of sustainability competences within engineering degrees, they can be: (1) straightly patterned into the curricula; (2) loosely coupled or arbitrarily schedule amongst a number of degree courses; or (3) essentially absent. This paper provides an analysis on the development of sustainability competences in the Industrial Engineering and Management (IEM) programme of the University of Minho, Portugal. Supported by student report content analysis, this paper explores the widely documented IEM interdisciplinary Project-Based Learning (PBL) methodology, at University of Minho, which has been applied over a long timeframe, and denotes, at least to a certain extent, to be a suitable learning methodology for the development of technical and transversal competences for the envisaged professional profile. Fink's Taxonomy was used in the discussion and reflection of the reports results relating to the sustainability issue.

Keywords: Education for Sustainability; Active Learning; Project-Based Learning; Engineering Education.

1 Introduction

The sustainability is in the order of day and universities are doing their best to integrate sustainability in their curricula. Engineering Education (EE) curricula have been a concern, given the profession influence in society (UNESCO, 2010). Guidelines for Engineering Education provide insight in common goals and perspectives on how to best address current and future challenges. Initial findings point out that these guidelines strongly suggest the adoption of alternative learning methods, such as student-centered learning with emphasis on synthesis and transdisciplinarity and a strong tie between theory and practice, and the reinforcement of aspects that are key to a comprehensive professional practice, such as those of protection of human values and the preservation of nature, amongst others.

In this sense and with Bologna process in progress (European Ministers of Education, 1999; Eurydice, 2010), a group of IEM teachers decided to implement Project-Led Education (PLE) (Powell & Weenk, 2003) in 2004_2005, an active methodology based on concepts like Project-Based Learning (PBL) (DeFillippi, 2001; Graaff & Kolmos, 2007) in the first year of Industrial Engineering and Management (IEM) programme (Lima et al., 2007; Alves et al, 2012). PLE is an active learning method, as it involves student in their learning (student-centered) as opposed to passive methods where the teacher is the center of the classroom, trying to transmit knowledge. Sustainability is the kind of knowledge that cannot be transmitted, students need education and not only knowledge, they need actions, they need to be involved in order to learn and learn how to learn.

This goal of this paper is to present how the Industrial Engineering and Management (IEM) degree of the University of Minho integrates sustainability in the curriculum. Sustainability has been the project theme during eleven editions of IEM projects of the first year. Through PLE student report analysis the authors of the paper show that PLE is a suitable method to educate sustainability to engineers, at least in this case study.

The paper is structured in 6 sections. After introduction, it presents a brief review about how universities have been integrating sustainability in EE curricula. The methodology used for obtaining results is presented in section 3 and the context of the study in section 4. Section 5 is the core of the paper and presents the findings: sustainability components in IEM projects. Section 6 presents final considerations.

2 Integrating sustainability in Engineering Education curricula

Sustainability is the key term of Education for Sustainable Development (ESD) decade. This decade was launched in 2005 by Resolution 57/254 of the United Nations General Assembly and is now reaching its end [2005-2014] (UNESCO, 2005). ESD is particularly important in engineering education and must include societal, environmental and economic aspects in order to educate socially responsible engineers, as they are key elements in society. Consequently, Engineering Education programs must be reoriented to sustainability. In order to do this, UNESCO (1997) has been for a long time alerting for the need to break barriers and compartmented knowledge between disciplines, promoting interdisciplinary and sharing values between them in order to educate for a sustainable future.

Efforts from accreditation programs have been made to include criteria related to sustainability such as in ABET accreditation system (2011): i) an ability 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; ii) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context and iii) a knowledge of contemporary issues.

Additionally, the European accreditation system (EUR-ACE, 2008) adds the following criteria: demonstrate awareness of the health, safety and legal issues and responsibilities of engineering practice, the impact of engineering solutions in a societal and environmental context, and commit to professional ethics, responsibilities and norms of engineering practice as some of transferable skills for European Engineering students. Educational systems from other regions and countries had been also aware for this need (Alves et al., 2013). Moreover, in Europe, it was signed a declaration in 2005 by more than 300 universities, the COPERNICUS Charta, launched in 1993, to provide general guidance to integrate sustainability in higher education promoting the integration in European universities (Hansen et al., 2013).

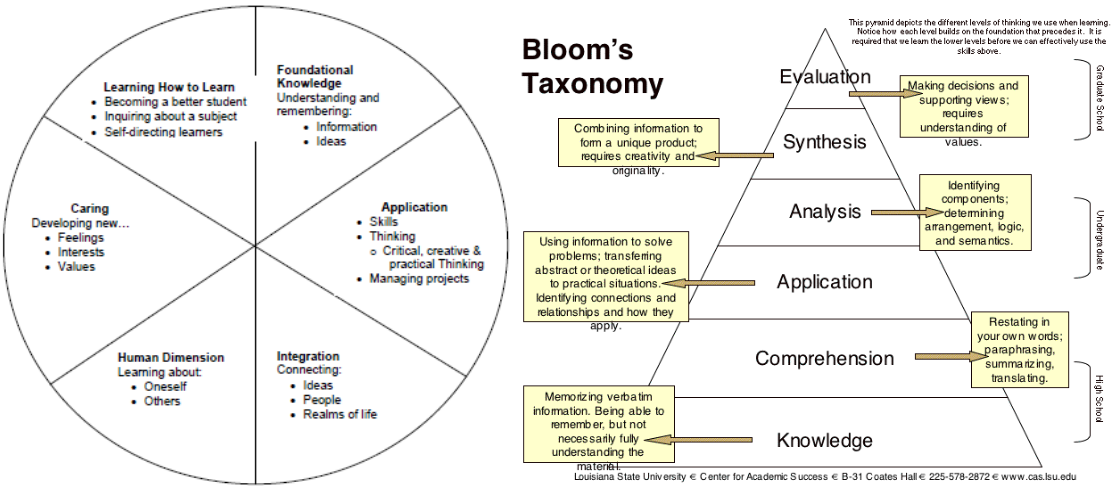
In spite of these efforts, it seems they appear as isolated criteria, without a clear link to ESD. Furthermore, many engineering education programs were changed at different universities, but without a clear ESD agenda. This was confirmed by Colombo et al. (2014) through a review of 170 papers published in a fifteen year period [2000-2014] in some well-known EE conferences proceedings and EE journals. The Decade of Education for Sustainable Development (DESD) was not clearly mentioned, particularly in the last ten years.

Numerous Engineering programs at USA institutions incorporate sustainability issues. So, many programs were implemented in a deregulated way that US institutions felt the need of a benchmarking of these programs. Therefore, a project that involved three institutions: University of Texas at Austin, Carnegie Mellon University, Arizona State University and one governmental agency U. S. Environmental Protection Agency (EPA) was developed (Allen et al, 2008) to, among others objectives, identify accredited engineering programs at US institutions that incorporate sustainability concepts into engineering curricula. From this project resulted four categories of how sustainable engineering (SE) is integrated in courses: 1) Sustainable Engineering (dedicated sustainable engineering courses), 2) traditional Engineering courses with sustainable engineering content, 3) cross-disciplinary courses offered jointly with a non-engineering department, and 4) Sustainable Engineering Technology courses which addressed technologies viewed as enabling for sustainability (Murphy et al., 2009).

Independently of a new course or restructure of a traditional one, this process implies changes in the educational paradigm. These changes must reflect a new kind of education and focus on acquiring and developing sustainability competences by active involvement of students in the learning process. Learning methodologies suitable for such development are based on active learning, cooperative and participatory activities that use student-centered approaches like Problem and Project-Based Learning (PBL) (Powell & Weenk; 2003; Prince, 2004; Graaff & Kolmos, 2007), service-learning projects through NGO like Engineers without Borders (EWB) or projects with support by governmental agencies like EPA (Bosscher et al., 2005; Pines

& Gallant, 2006). According to the last UNESCO report (2012) *"Teaching and research are placing a new emphasis on real-world challenges to sustainability in the communities that surround campuses."*

Zhang et al. (2008) appealed to a change process more disruptive and appeal to a different taxonomy. These authors present a project that, according to them, enables engineering faculty to more easily incorporate sustainability approaches into curricula through a proposed transformational learning practice and peer- to-peer networks. In order to do this, they incorporated and leveraged Fink's taxonomy (2003) of significant learning in their textbook and the course design. Figure 1a) shows Fink's view levels: Foundational knowledge; Application; Integration; Human Dimensions; Caring and Learning How to Learn. These authors referred that Blooms six level taxonomy (Figure 1b)) is no longer enough to the transformational learning practice.



a) b)

Figure 1: Taxonomies: a) Taxonomy of significant Learning (Fink, 2003); b) Taxonomy of Bloom

These levels are interactive in a spiral and significant learning results require all of these different kinds of learning, faculty as coach and mentor, student-centered and peer-to-peer networks. To achieve this, the learning methodologies referred above are vital for the transformation learning.

3 Methodology

The research presented in this paper is based on a case study that was developed at the Industrial Engineering and Management degree programme of the University of Minho. IEM teaching-learning methodology is based on Project-Led Education (PLE). Eight editions that took place between 2006/2007 and 2013/2014 academic years were analysed by the authors of this paper. Two of these authors have been actively involving in PLE as teachers, tutors and coordinators. Data collection consisted on final project reports written by each group, which were then analysed. This included a discourse analysis for each report, searching for all possible approaches to sustainability and related concepts. Also, as co-authors have been involved in PLE they interacted, assisted, monitored and assessed all activities and final products delivery by the students so they also contribute for this paper with them impressions about project developed. For each project edition, findings are summarised.

Conclusions were categorised according to Fink's taxonomy: 1) Foundational knowledge: How was knowledge developed related to sustainability 2) Application: Were issues related to sustainability applied to product and process, 3) Integration: Were sustainability questions related to contents in different disciplinary areas 4) Human Dimensions: How were relationships in the groups, including enthusiasm about the project team as well as social implications of the product and the process 5) Caring: This category includes feelings and values, so refers to social and environmental commitment of professional 6) Learning how to Learn: Working methods of the group, including curiosity and proactivity.

4 Context of the study

The Production and Systems Engineering Department of the University of Minho has a decade of experience in promoting the Project Based Learning (PBL) methodology in the M.Sc. degree in Industrial Engineering and Management (IEM). The PBL method is applied to IEM freshmen (first year) right from the first semester (IEM11_PBL), and widely explores teamwork and interdisciplinary by addressing semester-wide projects. This method has been applied at most courses that are included in the semester, which are called Project-Supporting Courses (PSCs). The IEM11_PBLenabled PSCs are General Chemistry (GC); Calculus C (CC); Introduction to Industrial Engineering (IIE) and Computer Programming 1 (PC1). For the 2013/2014 academic year a fifth course was also added to these, i.e. Linear Algebra. This represents a real and consolidated collaboration of a number of lecturers from four distinct departments pertaining to two different schools, i.e. the school of engineering and the school of science.

The IEM11_PBL class (about 48 students in total) is normally divided into six teams. The teams remain the same throughout the semester, while a tutor monitors the progress towards an original solution for the proposed challenge. Each team is expected to interact with all teachers and the remaining teams in several occasions, namely through public presentations, reports, the extended tutorial and the prototype demo, whose overall discussions fundamentally show coherence on the choices made and development of solid PSC backgrounds. Although a general theme is proposed at semester start, each team endorses specific visions on how to specifically tackle the challenge. This results on a number of different approaches taken by the teams. The teams are purposely issued with enough freedom to follow their own track, while assuring that the project objectives and learning goals are achieved. All aspects of the project are compiled in a comprehensive Student Guide, namely objectives, assessment details, milestones, PSCs expected learning outcomes, etc. Table 1 presents a list of the IEM11_PBL milestones. The guide is electronically distributed to each single student at the semester start.

Table 1: Milestones for IEM11_PBL (2013/2014 edition)

Milestone	Timing	Requisite
1	Week 2	Pilot Project presentation
2	Week 6	Project progress presentation
3	Week 11	Extended tutorial
4	Week 14	Intermediate report
5	Week 16	Final report & prototype delivery
6	Week 17	Final presentation & discussion

5 Sustainability education in IEM PBL

5.1 Project themes

A recent study from Moreira et al. (2011) on the importance of the project theme in IEM_PBL unveils that a specific project theme has an impact on students motivation on the project, and particularly when there is: (1) a clear relationship with the professional reality of an Industrial Management and Engineering graduate; and (2) a clear focus on sustainability or energy and environmental concerns. Since motivation drives behavior, and recognizing that industrial practice is increasingly both tied-up and driven by a sustainability agenda, the themes of the projects have been carefully selected to introduce a number of issues akin to sustainability. This requires students to actively pursue information, be knowledgeable and proactively design product and system solutions that are environmentally sound, promote social equity and improve value while minimizing resource use and waste generation. Teams actually have not only to pursue such sustainability endeavor, but also present and construct a convincing argument, to both their student colleagues and the PSC teachers, around their unique proposal to tackle the challenge. Table 2 presents a list of the PBL themes developed over the last eight academic years on the IEM11_PBL. One can observe that the chosen themes form a comprehensive set of issues, relevant within the context of sustainability and are prompt for multidisciplinary perspectives, such as the ones that relate with waste generation and recycling, oil spills, potable water availability and de-carbonization of fuels and transportation systems.

Table 2: IEM11_PBL multidisciplinary projects: editions and themes.

Academic Year	Project theme
2006/2007	Specification of a fuel cells production system
2007/2008	Desalination of sea water
2008/2009	Production of batteries for an electric car: specification of the battery and its production system
2009/2010	Use of organic waste for the production of bio-alcohol
2010/2011	Air_2Water: specification of a portable device for production of drinking water from air humidity
2011/2012	Clean-up and recovery of crude oil from sea spills
2012/2013	Specification of a disassembly line for recycling of WEEE (waste electrical and electronic equipment)
2013/2014	Design of a more sustainable packaging and specification of the production system

5.2 Sustainability concepts and contents

The sustainability rationale, the main challenges and a number of key enabling concepts and tools are briefly introduced in a short module (4 hours of contact and about 8 hours of autonomous work) entitled "Topics of Industrial Ecology" on the Introduction to Industrial Engineering (IIE) PSC. Also, the context of sustainability focused in the specific theme of the project is lightly introduced in GQ.

The IIE curricular unit represents 5 ECTS which corresponds to a total of 140 hours of work. This provides a general overview of key aspects of Industrial Engineering, each of which representing a short module, e.g. historical review on production management, project management, team work, production management terminology and production dynamics, techniques to represent production systems, prototypes of production system and Industrial Ecology. Each one of these modules of IIE have one or more corresponding Curricular Units (in the remaining 4 and a half years of the IEM degree), which tackle the topics in more breadth and depth. Most of those Curricular Units are compulsory, but a small number are optional. The corresponding curricular unit to the Industrial Ecology module is optional and is positioned on the 5th and last year of the IEM degree.

The "Topics of Industrial Ecology" module introduces and discusses models for human development, historical progress, two systems for measuring human development progress, and explores the concept of sustainable development and its pillars. It then introduces key variables that markedly impose a footprint on development, i.e. human population, energy system and impacts on environment (emissions and climate change phenomena and use of natural resources). It then introduces key concepts on impacts deriving from the industrial activity, distribution, and product use and discard stage, highlighting the importance of using full life cycle perspectives. The module also introduces the concepts of eco-design, eco-efficiency and eco-labelling. These lectures use multimedia resources (e.g. short videos) and individual and group interactive exercises. The teams are stimulated to develop further the subject in the context of their own project and to interact with the IIE lecturers along the way if required.

5.3 Reports analysis results

For 2006-2007, with fuel cells production as the project theme, the reports analyzed indicate different approaches to the energy generation by the students' teams. They approach different motivations for fuel cells production, like fossil fuel scarceness or non-renewable energy, their emissions and impacts, renewable or alternative energy, advantages and disadvantages. A deeper approach to sustainability issues was not perceived. All groups though proposed hydrogen batteries, but with a variation between sources. Some teams made an analysis of sustainability issues involved and others not. The considerations on the environmental impacts of the production of different energy sources were limited.

The reports on the project about water desalinization in 2007-2008 showed that the issue of scarce drinkable water is treated differently by the different teams. Some groups include human consumption in the productive sectors, whereas others present a more limited vision. Desalinization was proposed as a great solution for the water scarceness, showing a limited vision focused only on a solution achieved by the technological advances. However, there were some teams that considered the habit change as the most important. With regard to the proposed solution, some teams elaborated sustainability issues searching for localizations of "their company" that, apart from water, also offer renewable energies like solar, wind and waves. In general, and in spite the theme allowing for socio-environmental approaches of sustainability, most teams did not develop this issue well, focusing more on technical matters.

The production of batteries for electric cars in 2008-2009 raised a lot of interest of the teams and provided opportunities for a more discussion on environmental and social discussions related to sustainability. The environmental impact issues of vehicles movements as well as fuel production were largely discussed. This meant that the theme allowed for an impact evaluation more ample in the vehicle life cycle and their batteries, being worked the environmental issues since the supply energy source as their discard. A deeper approach on the environmental productive process was visible in the reports. One of the teams treated the learning issue, showing that the theme instigated a vision development oriented to the sustainability, which, in spite of not being expressed, also was understood in the other reports. The following sentence synthetizes what was observed in reports on the production of batteries:

> *This theme instigated a lot of interest in the team because represents an alternative to the problem that was raised by the atmospheric pollution. And as we cannot be radical and retrocede in the evolution, the solution is to create eco-sustainable ways in order to benefit from the same quality life without compromising our planet.* (Team 2)

In 2009-2010 the theme was the use of organic wastes for bio-alcohol production, where environmental issues of the production, and in some cases, social and different fuels (fossil, bio-fuels of first and second generation) were treated. Recycling issues were also discussed by some of the teams. However, the deeper question that would be the great focus of the work like the raw-material, relating to the direct environmental damage and indirect for being a residue, was not included by most teams. Furthermore, there are teams that did not make clear the source being a residue neither the selection of the company local related to transport. Mostly, it was observed that the project would have great discussion possibilities of the environmental damages eliminated with the residues exploration, beyond the benefits of the bio-fuel. Only one team approached this.

The production of drinking water from air humidity was the theme of the project in 2010-2011 where the main problem approached by most teams was the drinkable water scarcity, others approached the water pollution. Generally, no one approached the sustainability issue deeper. The local company selection was based on water scarcity and air humidity. The focus inversion, i.e., the dehumidification as main objective having as result the water production, beyond the environmental comfort, was not treated by any team. It was observable that this theme did not instigate the exploitation in an ample way the environmental issues. The product instigated to the outsourcing, in a way to take responsibility for the environmental impacts generated inducing the eco-efficiency measures to them. Only one team dealt with sustainability issues for suppliers, other disperse measures were from solar energy used and to improve eco-efficiency of infrastructures. Nevertheless, in general, sustainability was not worked in a deeper mode. The following sentence summarizes the idea of misunderstand of project by one team:

> *The fact of our company being an assembly company is an advantage relating to the others companies because is poorly polluted, as has a small number of machines and the used components are not toxic. In this way, our company could generate some toxic residues but in minor quantity.*

In 2011-2012 the theme was about the recovery of raw oil from sea spills and, curiously, most teams did not treat this serious cause of environmental movements as a deeper sustainability or environmental issue. The various teams worked the theme in a different way. One team worked on product and process production sustainability. It can be concluded that even the project intended and allowed for a sustainable approach, needing a specific learning mode that included a more effective theme assessment.

Design of a disassembly line for e-electronic waste such as televisions, computers and so on was the theme in 2012-2013. In this context, the teams enrolled in the theme in distinct ways, treating the environmental impacts, health damage associated to the Waste Electrical and Electronic Equipment (WEEE) and recycling. In the developed proposals, all teams included the recycling (or benefits for the recycling) of some components of the products disassembly. However, only one group treated one recycled component. Most teams did not approach the production process effluents treatment, only one team considered the materials cleanness water treatment and reuse. These two questions conduce to the need to orient the thematic being worked and do not only expect that they result by being involved in the thematic.

For the last academic year (2013-2014) the project theme was the production of a more sustainable packaging. The approaches taken by the teams were diverse; some focused on the temporary and final destination of the packaging, others on the consequences of packing for the environment, and others on the 3R issues. They chose the raw material according to 3R policy, at least, accomplishing one R, i.e., the facility to reuse, reduce or recycle. In general, it was observed that they showed more concern with attending the CU contents than with the packing environmental impacts reduction, involving all product life cycle.

5.4 Discussion and reflection

The following discussion and reflection attend to the reports analysis and the categories defined by Finks Taxonomy as referred in section 2. As so, the authors consider that according to the first level of **Foundational knowledge** and, in spite of, the various forms of the reports of teams, the distinct themes and through eight years, it was possible to observe that some basic knowledge about environmental issues and developed solutions were identified and learned. What was missing in this was a deep sustainability conceptual component, sustainable development and environmental impacts that based a strong theoretical for the projects.

In terms of **Application,** the second level, it was observed that in the prepositional development, some teams applied sustainability concepts making a good analysis of questions related to sustainability. However, this did not happen with all teams. Some used a sustainability knowledge broad approach, whereas others did not. This could happen because they are first year students. Nonetheless, students were capable of managing a project, be creative and work on sustainability issues.

The third level, **Integration,** could be recognized in some of the projects, depending on the theme and the student teams. Some themes more easily raise the integration of sustainability issues with CUs contents and provided a broad vision of knowledge integration. They also connect ideas and people by working the theme. For example, on the last academic year project the teams searched researchers and companies that they have linked with the theme. Of course, the teams' behavior was also different in the way they worked out the theme.

Three aspects could be considered in **Human Dimension,** the fourth level: 1) learning in teams is clearly presented in the reports, some teams reporting conflicts and disharmony at specific moments of teamwork showing that this competence is promoted by PBL; 2) the social and environmental facets were also promoted in PBL as observed to the theme interest by students teams, although not in all teams and not with the same depth 3) social dimension of sustainability, which could be understood in some projects, when the prepositions considered the social issues of the environment where the company would be placed and/or of the product, as well the work conditions of operators.

The **Caring**, fifth level, is a dimension that could not be clearly evaluated in the reports as imply to how effectively educate and change values and feelings in order to students become responsible socio-environmental individuals. This is a point that needs to be worked in order to such competence be assimilated by the learners.

About the last level, **Learning How to Learn**, it was visible that some teams became stimulated and searched means for knowledge construction beyond demand, e.g., they made contact with companies that work with similar products, they searched for real life problems, such as in the case of sustainable packing project, where one team developed a packing for transport of cheese, or in the case of the WEEE project where a recycling process was researched. In the teamwork, the learning process was evident, but it was also visible that more is needed to transform sustainability knowledge into competences.

6 Final considerations

Although the projects themes were clearly directed towards the development of more sustainable products and cleaner production systems, the depth and breadth of the approaches taken were diverse, and not exactly aligned with the expected learning outcomes from some aspects of sustainability introduced on curricular units. This was verified in the missing evidence in the knowledge developed through the project, varying from team to team, that could vary according the previous knowledge of the team in the project theme or tutor orientation. In this way, it can be inferred that environmental issues will not be assimilated by the students in an effective mode and with the suitable approach, only by the project theme involve it. This fact shows that a different way of work the sustainability theme is needed in order to develop the competence to environmental conscience. This is aligned and supported by the preliminary findings of the working paper from Aalborg University (Hansen et al., 2013).

The authors suggest that effort should be taken in order to adequately integrate specific course unit contents with project issues akin to sustainability. Sustainability workshops or a full course unit focused on this issue, are also possible approaches to enhance key aspects of sustainable development, e.g. environmental management, eco-design, clean and lean production. The ideal of sustainability includes caring about human beings, other beings and the natural world. Therefore fully developed professionals should reveal good levels of sensitivity, respect and ethics that remain over the profession practice. This obviously also requires education and training, the earlier the best, throughout the academic route.

Observing the project development as a whole and relating to the existent project milestones, sustainability could be worked in an intensive way in the enlarged tutorial moments. The knowledge as also sustainability integration could be worked with others CU contents. So, it could be a value-added having more enlarged tutorials during the project development and giving more opportunities to each team and teacher to see how to integrate the diverse CU contents and their relationship.

In conclusion, improvements are needed in IEM11_PBL to develop professionals oriented towards sustainability. It was verified that the project development through PBL has potential to offer this competence development required to a present and future engineer professional. So, the authors considered that in order to obtain a better result, the sustainability theme must be worked in a cross-linked way to the CU contents or strongly included by other approach (e.g. workshops) during project development. Only thus, it will be possible to train engineers focused on sustainability and train socio-responsible citizens.

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