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Making practical experience: Teaching thermodynamics, ethics and sustainable development with PBL at a bioenergy plant

Dr. Darinka del Carmen Ramirez, ITESM (Tecnológico de Monterrey)

Ph. D. Darinka Ramírez is a professor at the Chemical Engineering department of ITESM (Tecnológico de Monterrey), Campus Monterrey, Mexico. She has a B. S. in biochemical engineering at IT La Paz, M. S. in chemical engineering at Tecnológico de Monterrey, and Ph. D. in Educational Innovation also at Tecnológico de Monterrey. She teaches mainly Material Balances, Energy Balances and Thermodynamics to undergraduate students, and also Educational Innovation to virtual graduate students at Tecnológico de Monterrey. She has experience working in projects with different local industries. Recently she has been working with innovation and technology for engineering education (remote Laboratories, virtual laboratories, flipped classroom, active learning and PBL among others).

Dr. Pablo Moreno Ramírez, Universidad Autónoma Chapingo

Born in Chile in 1942. Get graduation as Agronomist at the Univrsidad de Chile in 1966. In 1969 went to Cornell University to study Agricutural Economics. Get Master degree in 1972 and started Ph.D program at the same university, In 1974 went to México to be professor at Universidad Autónoma Chapingo where I get Doctoral Degree. Sincé then he has been teaching and researching in the area of program evaluación and educational efforts to develop programs in terms of competences.

Making experience practical: Teaching thermodynamics, ethics and sustainable development with PBL at a bioenergy plant

Bioenergy is a renewable energy made available from materials derived from biological sources. Today, it is important for the world and its future as well as for engineering students that are going to work in that field or related ones. At the same time, engineering students, especially chemical engineering students, need to learn about international issues related to energy such as ethics and sustainable development, preferably in a way that is natural to understand and directly related to their field.

The aim of this paper is to present the experience of using Problem Based Learning (PBL) for teaching thermodynamics, ethics, and sustainable development by connecting this altogether with the student practical experience at a bioenergy plant.

The students visit an energy plant that converts biogas from a landfill into electrical energy. By the time students are doing their PBL, they have to figure out how to improve the process in terms of ethics and sustainable development (biogas production, CO_2 emissions, and the liquid waste that the plant produces). This allows the students to have practical experience on some topics such as thermodynamic cycles, measurements of composition at the site plant, knowing actual equipment of pumps, pipelines, and so on.

The paper describes the innovative elements added to the PBL teaching strategy in order to connect all these issues. It also presents some of the research results, such as the engagement that is achieved by students, which lead them to the writing and publishing of papers with their own ideas. We are dealing with a new generation of engineers who are used to seeing, touching, and having first-hand experience more than they did ten years ago. They are highly motivated with the things they can see and understand. The results show some of these statements.

Keywords: Innovation in engineering education, PBL, sustainable development, ethics, making experience practical.

Introduction

In the world in which we live where change and challenges to humanity are the only constant, the challenge for educational engineering should be to involve the learning of ethics and sustainable development as part of the development for a professional engineer. The relevance lies not only in what the engineer will do in his future, talking in terms of technology and pure engineering, but also in terms of the decisions he/she will make in his professional life and that will have an effect on other people, in the cities, and in the environment.

Integrating sustainable thinking is a challenge for education in engineering, but it is essential to the personal and professional development of an engineer since the demand for labor requires engineers with professional practice, knowledge, and ability to make decisions to meet every day challenges in their work field. These decisions involve aspects of Sustainable Development (SD)

[1] like: “the development that satisfies the needs of the people today without compromising the future generations”[2]. The resulting situation at the universities today is that SD integration is often limited to some specific courses (depending on the lecturers) and that there is sometimes a specific SD course, optional or compulsory[3]. Regardless of this, sustainability has become a key problem that is relevant at the university level[4].

Engineering education has traditionally been focused on the teaching-learning processes of Mathematics, Physics, Chemistry and the development of abilities and skills for solving problems that somehow integrate this basic knowledge. However, the main concern has not been on the ethic or social side of this kind of professionals. We have not been teaching to engineers its importance, at least not consciously, or explicitly, the importance it has, such as: building a conscious about the environmental and the social impact that an engineer´s decisions has over people. It is mentioned at the *American Institute of Chemical Engineering* (AIChE) that an engineer has to formally tell his employee and/or client if some decision made has a consequence that could affect directly or indirectly, in the present or future, the health or safety of other people. Therefore the work of an engineer must be not only based on knowledge but on ethical sense[5], and this will require activities that integrate building a frame of values[6]. On the other hand, according to the criteria for accrediting engineering programs[7] and that were effective for reviews during the 2013 and 2014 accreditation cycle, any engineering program must have the following student outcomes:

“(a) an ability to apply knowledge of mathematics, science, and engineering
(b) An ability to design and conduct experiments, as well as to analyze and interpret data
(c) 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
(d) An ability to function in multidisciplinary teams
(e) An ability to identify, formulates, and solves engineering problems
(f) An understanding of professional and ethical responsibility
(g) An ability to communicate effectively
(h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) Recognition of the need for and an ability to engage in life-long learning
(j) Knowledge of contemporary issues
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice“(ABET, 2012, p. 5).

If we make a checklist out of all these outcomes that are required for engineering students, most of them must be fulfilled because this is what engineering programs do, and also this involves all the instructors that participate in it. The kind of courses, laboratories, projects and activities are designed for developing a strong engineer in the field. However, the objective of this article is not to analyze all the outcomes but to focus only on the ones that refer to professional ethics and sustainable development. Thus, in this paper we are trying to incorporate two students´ outcomes established by ABET (2012) in criterion 3: outcome f) an understanding of professional and ethical responsibility, and outcome h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

Considering the previous information now the question is: How can we develop an understanding of professional and ethical responsibility in engineering education? How can we develop the understanding of sustainable development and its importance in the decisions made by an engineer? Nevertheless, the main question could still be: How can we do this within the first semesters and not just in one course or in a final project but from a lifelong learning perspective (along with all the professional student education)? Some answers could be developing some educational innovations that could represent a positive and intentional change for making better practices[8]. Some of these innovations could also help to connect the theory with the practical experience, which is very important in engineering education[9]. In this sense, this article presents and describes an educational experience that uses Problem Based Learning (PBL) with some innovations for adding the ethical and sustainable aspect in engineering education.

The PBL strategy

One of the main characteristics of PBL is that the problems that are presented to the students must be challenging, interesting, and being able to engage the student, so he will want to solve the problem. In this process the student is learning and discovering his own learning objectives besides the ones the teachers have previously designed for them. "*The challenge is to use this opportunity effectively to develop problem solving skills"* Woods and Learning (2000, p. 9)[10]. The PBL strategy has the purpose to develop a deep understanding and learning through the solution of real problems that are presented to him before the knowledge of the learning experience[11], and this happens while the students are working in teams[12]. "PBL is a learning environment where a problem is posed first before the students have acquired the knowledge" (Woods & Learning, 2000, p.9)[10].

Another important aspect to consider is that the students must be working in teams in order to develop collaborative and cooperative work through the process of solving the problem. "Research in learning (Chickering and Gamson, 1987) suggests that learning improves if students are active, work cooperatively, have clear time on task, receive prompt feedback, and are in an environment that expects success and that caters to their personal learning style" mentioned in Woods and Learning[10]. In this sense, the teachers and instructors that use PBL build a bond of trust and a learning environment that can provide dialogue and openness to the generation of new ideas[13].

The PBL that is considered in this article and that was implemented was based on the one suggested by Felder, Woods, Rigarcía and Stice[14] that considers the lifelong learning skills and problem based learning. They suggested that the learning process may be broken down into the following steps:

- Sense problem or need
- Identify learning issues
- Create learning goals and assessment criteria
- Select resources
- Carry out the learning activities

- Design a process to assess the learning
- Do the assessment
- Reflect on the learning process

The proposed PBL scenario

Designing challenging scenarios for PBL, which can be suitable for engaging the students in the problem, is not an easy task for the teacher. The scenario requires integration of knowledge, skills, and attitudes across topics; allows openness; is motivational and relevant; is similar to one we might encounter in professional practice; and promotes student activity[10].

However, the most important element considered here was that the scenario must contain "clues" that will trigger the desired search for learning objectives and in this sense, the first innovation proposed in this article is to start with a real scenario at the plant, at the real processes (alive). In this way the teacher can provide a learning environment with the real situation that can motivate and engage the student with the professional practice. In this sense, the students were taken to visit an industrial bioenergy plant that converts biogas production from the landfill into electrical energy (Figure 1).

Figure 1 Visit to the plant

Another element that has to be addressed is the need to reinforce some concepts, so the learning outcomes expected by the teacher are correctly identified, and activate prior to knowledge. In this sense the innovation we are trying to achieve, taking the students to visit a real processes at site, needs to be done with some prior activities which are: doing some investigation about the processes they are going to visit, about their professional ethics code, and about what is sustainable development. This prior knowledge will help them once they go to the plant to think about possible solutions for the processes (including the energy ones) that could lead to a proposal. This is the starting point for the PBL, there is no specific objective given to the student. This PBL is done after they learn some basic concepts including the Carnot and Rankine thermodynamic cycles, so they have a basic idea of energy transformation before going to the plant.

The third element added to the PBL is that after the students visit the plant they have to do some research, thinking, and reflection about how to improve the processes in a sustainable way, but making a decision that considers their ethics as engineers. They write a paper about this (working in teams of 4 or 5 students) and they send it to a conference or magazine for its publication. Therefore, in this final stage the students are doing research and writing an essay research. This could provide a good opportunity for doing some deep reflection about this and as a consequence a lifelong learning experience.

Methodology

This research used a mixed method[15] combining a quantitative method with unique use for the qualitative part case method since it allows us to focus on the particular study of a new situation which has no prior information. In the qualitative section the instruments used were: observing and taking notes during the whole teaching learning experience and recording every class during the semester (we used a special classroom where you can record everything), the documents such as the essays the students made for professional ethical responsibility, exams, and the final paper made for publication with their own ideas. The essay that the students made for professional ethical responsibility regarding the visit to the plant was analyzed by categories, counting the repeated of words and similar sentences made by the students[16] and studying this words I the context they were said. This can help us understand what they are thinking.

In the quantitative section the results obtained in the final exam (which corresponds to the problems relating to specific learning objectives previously set) were compared in the quantitative section of a control group (without the implementation of the strategy) against an experimental group (with the implementation of the strategy). In this section also a questionnaire on the Likert scale was used to measure the extent of learning that is perceived by students in each mentioned category. It was applied only to the experimental group that used the proposed activity. The Likert scale used was: totally agree, agree, not agree nor disagree, disagree, and totally disagree. The students were tested after they finished the PBL activity.

The Sample

Thermodynamics is a basic required course in the curriculum for all the engineering students (with the exception of civil engineering). However, the honors format is selective only for students with high grades average (above 85 on a scale from 0 to 100). Only the head of the Chemical Engineering Department is allowed to register the students that fulfill the requirement for being in a Honor's class. At this study we used 2 groups of Thermodynamics in honors format: one without the activity of PBL, and the other one with the activity of PBL. For the quantitative study we compared these two groups. For the qualitative study we only focused on the group with the activity of PBL, because here what we did was mostly observation on the sample.

The control group consists of a sample of 17 students who constitute the entire group of thermodynamics in format honors of the semester January-May 2014. The sample is 17 pupils, of whom 10 are women and 7 men. The majors whom students study are: 4 from biotechnology, 4 from chemical engineering, 4 from mechanics, and 2 are from sustainable development, 1 from food engineering, 1 from innovation and 1 from Mechatronics. This subject is taught in 4th semester as a common core for racing engineering at the Tecnológico de Monterrey.

The experimental group consists of a sample of 17 students who constitutes the entire group of thermodynamics in format honors of the semester August-December of 2014, and who applied the strategy with modifications to the PBL presented. The sample consists of the 17 students, of whom 8 are women and 9 men. A feature of this area is that it teaches students from different disciplines of engineering. The sample has students from the following careers: 2 from engineering in sustainable development, 2 from engineering in mechanics, 2 from bio-technology and 10 from chemical engineering. This subject is taught in 4th semester as a common core for engineering at the Tecnológico de Monterrey.

Learning Objectives for the PBL activity

The learning objectives planned by the teacher for the application of this PBL were: 1) the application of energy balances at an industrial plant, 2) the identification of the thermodynamic cycle that is used in the processes, 3) the development of the competence of ethics and the professional values by means of an essay about their professional ethics code and the reflection about the process itself, 4) the development of the competence of citizenship by means of the people that work at the plant and by making a proposal with social impact, and finally 5) the development of the sustainability competence focusing on the impact of industrial analysis by means of making a profit out of the solid wastes and the carbon bonus.

Discussion and Results

In order to answer the question: Did including this project increase student knowledge of relevant subject matter? We present and discuss the results of what students said about their learning, of what they did, and the quantification of some specific learning.

Results of Ethics and Citizenship

The results from the questionnaire with the Likert scale show that most of the students totally agreed with the fact that engineering solutions have an impact on the global, economic, environmental, and societal context (as you can see in color green in figure 2). They also agree that visiting the industrial plant helped them to generate ideas for improving some social and environmental conditions at the site. Finally, most of them agreed with the fact that the PBL helped the understanding of professional and ethical responsibility. Probably because engineering students care more about the technological aspect of a process, and also, this shows that the teacher has to think more about promoting this aspect before going to the plant. However, on the overall graph from figure 2, shows that the students´ perceptions are that they achieved the learning objectives planned by the teacher related to Ethics and Citizenship.

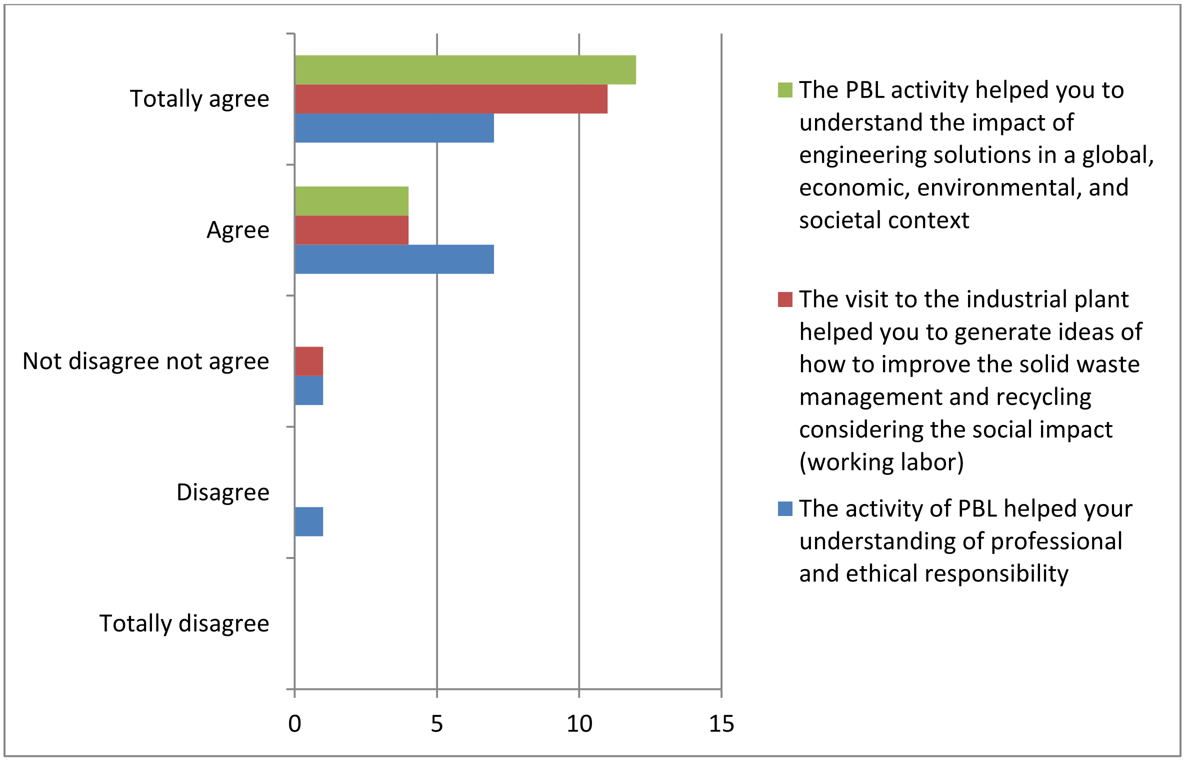

Figure 2 Results of the quantitative analysis made for Ethics and Citizenship

Results of Sustainable Development

Most of the students agreed that after visiting the plant and doing the paper they understand better the importance of being responsible with the environment (see figure 3). The paper they had to write had to be about improving the process in this sense, so they were involved in thinking and doing some documentary research in order to generate the proposal. Also, most of the students agreed that the visit to the plant helped them to understand the real meaning of carbon dioxide emissions or other emissions, carbon credits and its control. What helped for this understanding was that because the students visited the plant they were in real contact with the smell, noise and emissions that the processes could have. However, in the last category, not all of the students agreed that they did understand what SD means at the industrial plant. Regarding this comment, if we observe the graph from figure 2, we asked the same question but in other words (first sentence from figure 2), this could mean that students understand the basic concepts separately, like global, economic, environmental, society and so on, but they do not quite understand the whole concept of SD. However, the global results of figure 3 shows that the students mostly agreed having knowledge about this specific subjects related to SD.

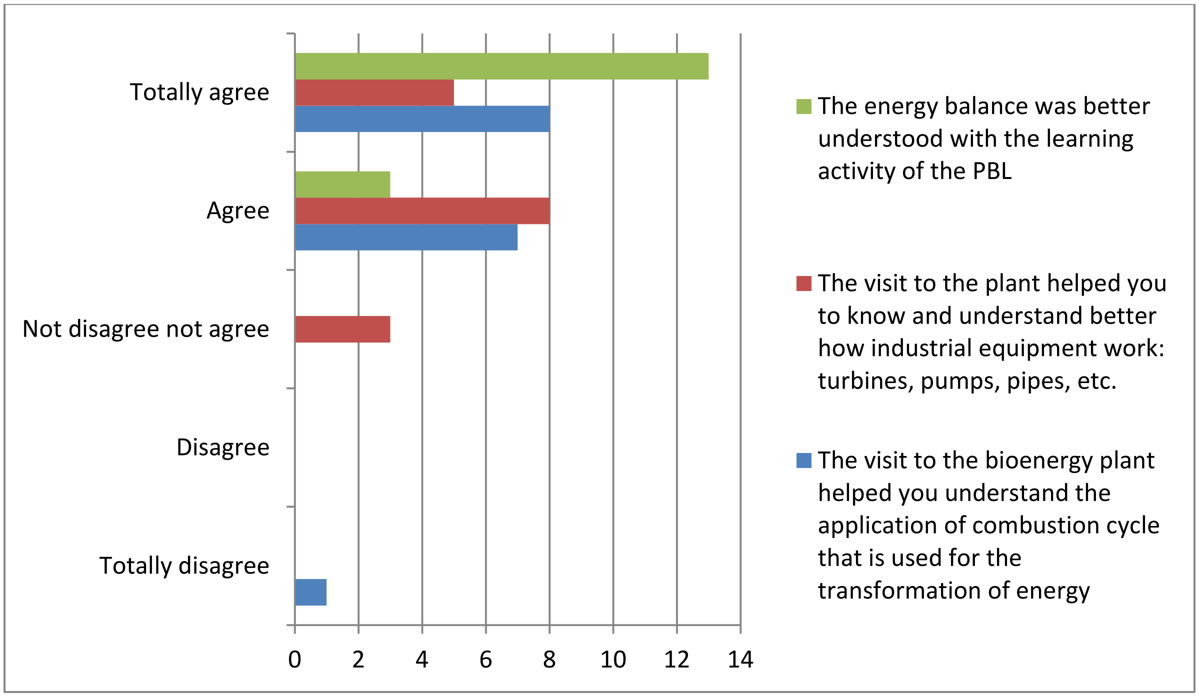

Figure 3 Results of the quantitative analysis made for SD

Some student's comments about Ethics are:
"This activity helped me understand the opportunity of being part of a socially responsible enterprise, as well as the importance of its profitability and also ethical and sustainable development". "This Project is a valuable and clear example of what you can achieve by joining educational and private efforts in benefit of our society". "Through this visit to the plant I believe I now have a different perspective and a critical thinking of what an engineer must do". "Some of the added values with this activity are that I think we can innovate in some processes for the improvement of the use of the landfills".

Some student's comments about SD are:
"Now I value the importance of the reduction of emissions from any process". "This visit helped me to understand the economic benefit that a big enterprise can do at the same time it benefits the people". "For me it was significant to learn other things and not just the ones told in class".

Results of basic Thermodynamic concepts

Although the purpose of this study was not to focus on improving the knowledge of energy itself but on the integration of the energy, ethics and SD concepts as a whole idea an as an important piece of the engineering education, the graph on figure 4 describes some of the results on specific subjects of the Thermodynamic course.

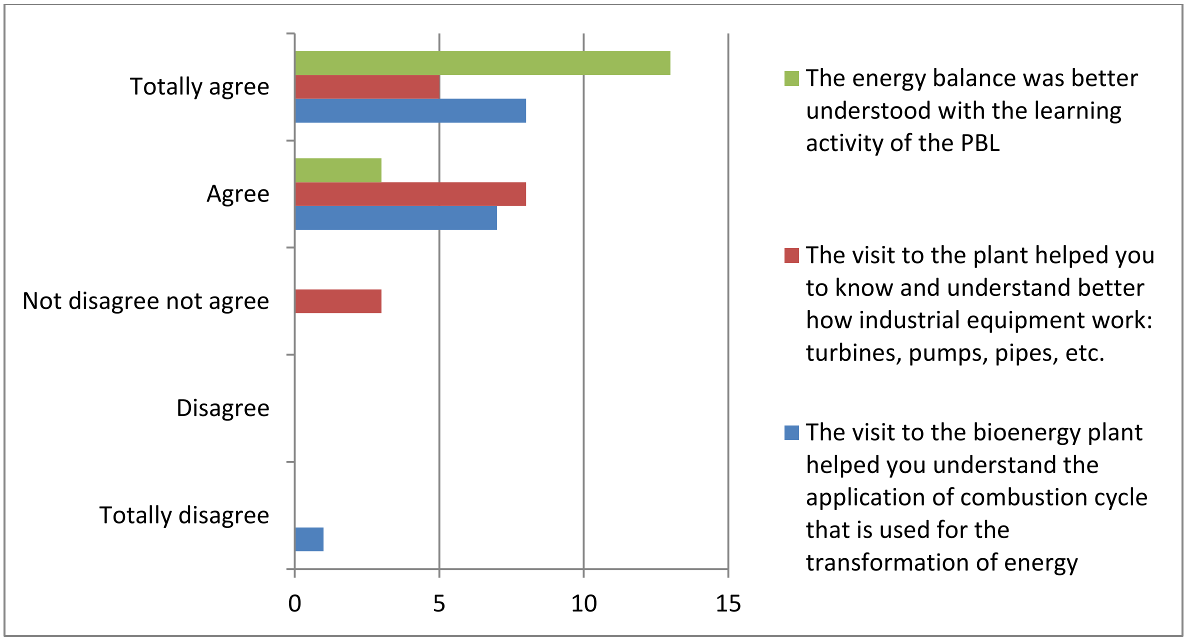

Figure 4 Results of the quantitative analysis made for some basic Thermodynamic concepts.

As we can see the students´ perception is that they did understand better what an energy balance means by doing this PBL activity, most of them totally agreed with this. This could represent that, even though engineers must do some calculations in order to solve problems, they also have to consider the context for its solution. The same happened with the second question, most of the students had a tendency to agree (30% totally agree, 50% just agree and 20% not disagree not agree) that the visit to the plant helped them to understand better the equipment used in industrial processes. Regarding the last question, some students agreed that this visit helped to understand combustion cycle, but a minority disagreed in this point.

Student´s t test

This statistical analysis is for the two samples of student's grades in their final exam, which evaluates the whole program for Thermodynamics plus the objectives presented here. The two samples were: 1) the control group that has not received the treatment, and 2) the experimental group that has the experience of learning with this PBL activity and has the treatment. Comparing both samples (control group and experimental group), and with the hypothesis *Ho* = the average is similar (meaning there is no difference with the treatment effect) then, if we reject this hypothesis (this means α must be < 0.05), then we must accept the alternative hypothesis H_1= there are significant differences between control and experimental group. With the help of SPSS (Statistical Package for Social Science) the result obtained shows that there is a significant difference between both groups because $\alpha = 0.023$. The main conclusion of this result is that the treatment (teaching with this PBL activity) did have an influence on the student's grades and learning.

Table 1 ANOVA Analysis of comparing statistically the final exam of control and experimental group

			Sum of squares	df	Square average	F	Sig.
Control group* experimental group	Inter-groups	(Combination)	437.765	1	437.765	5.741	0.023
	Intra-groups		2440.235	32	76.257		
	Sum		2878	33			

Conclusions

These kinds of activities where you can connect a real process (at site) with the concepts that students are learning in class could help to integrate in a more natural and deep way the learning of not only knowledge and skills, but also ethical and SD aspects. First, because the students are watching the real situation of the plant, and second because following the PBL steps triggers the students´ engagement in the problem and the generation of new ideas. The proof of this was the acceptance of the students´ papers sent to a conference.

Incorporating ethical values and SD to the learning processes requires an enormous amount of energy and time for the teacher that is doing this activity, but once you are there it transforms the learning experience into a more significant one, that could be a lifelong learning.

Recommendations for future work

This idea could be done with other processes, not necessarily at the bioenergy plant, the challenge is to find out any industrial plant nearby where students can go and observe in order to present an essay with a proposal for improving the processes. In case there is no industrial plant in the surroundings, the teacher can still do some similar activities at the lab or think about new possibilities for connecting something “real” with students´ learning. It is also recommended to design activities like this one, with PBL, for other courses and at different levels in the curricula in order to prepare engineers with a global vision of what the world needs today.

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