Challenge Based Learning: The Case of Sustainable Development Engineering at the Tecnologico de Monterrey, Mexico City Campus

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Abstract. Recently, The Tecnológico de Monterrey (ITESM) in Mexico has launched the ***Tec21*** Educational Model. It is a flexible model in its curriculum that promotes student participation in challenging and interactive learning experiences. At the undergraduate level, one of the central scopes of this model is addressing challenges by the student, to develop disciplinary and cross-disciplinary skills. Two institutional strategies have been implemented to reach the ultimate goal of the ITESM, to work in all careers under the Challenge Based Learning (CBL) system: the innovation week (*i-week*) and the innovation semester (*i-semester*). Here we report on the results of four *i-week* and one *i-semester* models implemented in 2016. The *i-semester* was carried out in conjunction with a training partner, the worldwide leader Pharmaceutical Company Boehringer Ingelheim. Thirteen Sustainable Development Engineering career students were immersed for a 14 week period into the strategies to solve real-life challenges in order to develop the contents of four different courses. Six teachers of the academic institution and four engineers from the Boehringer plant served as mentors. Continuous evaluations were carried out throughout the abilities examination and partial and final examinations were performed by both experts, from the company and from the University.

Keywords: Challenge based education · Sustainable development Engineering

1 Introduction

The Tecnologico de Monterrey in Mexico City (ITESM-CCM) began operations in 1973 in downtown Mexico City. The ITESM was the first University in Latin America that was associated with the Massachusetts Institute of Technology, Carnegie Mellon University and Yale University in the form of a consortium. According to the Academic Ranking of World Universities 2016 [1] and the AmericaEconomia Intelligence 2017 [2] the ITESM is ranked as the second best university in Mexico in general terms but

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the best valued by the labor market due to the skills and competences acquired by the graduated students. A key role in this achievement has been played by The School of Design, Engineering and Architecture at the Graduate Student Division (EDIA), now known as the School of Engineering and Sciences (EIC), which bases its educative growth strategy on a concept that integrates the use of technology, creation and management of innovative companies, business linkage and applied research. Inside the EDIA, the Sustainable Development Engineering (IDS) program aims to prepare skilled professionals in sustainable development taking into account that this area is considered as strategic for almost all governments.

Recently, ITESM has launched the *Tec21* Educational Model, a flexible model in its curriculum that promotes student participation in challenging and interactive learning experiences. At the undergraduate level, one of the central scopes of this model is addressing challenges by the student, to develop disciplinary and cross-disciplinary skills. Challenge Based Learning (CBL) promotes the development of skills in students [3, 4]. This model exposes students to situations of uncertainty and in some cases failure tolerance in order to develop their resilience [5]. This is a concern for students in the colleges of engineering, as they are required to have the ability to think critically and solve problems as outlined in the Accreditation Board for Engineering and Technology Inc. (ABET) criteria. Besides the development of disciplinary skills, with this pedagogical approach student motivation toward learning, for their connection to the environment it is encouraged. At the same time, during the process of solving the challenge of innovation, collaboration and multidisciplinary work is encouraged [2].

Here we report on two important ITESM efforts to develop and cross-disciplinary skills in students through experiential learning experiences. The Innovation Week (*i-week*) and the Innovation Semester (*i-semester*).

2 Experimental Design

The general purpose of this research was to investigate the use of Challenge Base Learning in two formats:

Firstly, the undergraduate students of several careers at EDIA were auto enrolled in a one-week intensive period called *i-week*. Four *i-week* subjects were offered at EDIA: ELARA Challenge, PROFEPA Challenge, Ziklum Challenge, and Xochimilco Challenge. A minimum of 15 students (all undergraduate) were enrolled in each of the challenges, no classes were given during the whole week to allow the students to focus on the *i-week* activities. A minimum of three expert teachers (lecturing related subjects) were in charge of the design of the challenge and all its associated activities. The *i-week* was divided into three steps: getting involved (reading, planning the activities and determination of the schedule of actions), development (carry out the planned activities, innovating actions), and discussion and conclusions (where all students compare their results and may improve the conclusions of the others).

Secondly, a 14 weeks/4 months in duration challenge-based-education period, or *i-semester*. Thirteen IDS students were enrolled into what we called Pharmaceutical *i-semester*. Six teachers of the academic institution served tutors of the students, of which four were in charge of each one of the four courses the *i-sesmester* consisted of. This experience was carried out through the participation of a training partner who in this case was the pharmaceutical company Boehringer Ingelheim (BI).

The general purpose of the research was to investigate the use of CBL in the undergraduate students of the Sustainable Development Engineering career at EDIA of ITESM-CCM.

3 Results and Discussion

3.1 The *i-week*

Activities are published four to six weeks prior to the *i-week* and students get involved full-time in a challenging experience they have chosen. The activities during the *i-week* are aimed at: enrich training and competency profile student experiences through innovative and challenging learning, develop disciplinary and transversal competences and promote collaborative and multidisciplinary work. A total of 50,000 students in 26 professional ITESM campus as well as more than 3,000 teachers supporting the development of more than 1,800 projects were involved. Students chose one activity among the options which were offered any campus, including projects with companies or local, national or foreign organizations. At EDIA of ITESM-CCM, samples of projects offered were (each challenge was carried out with a minimum of 15 students):

1. ELARA Challenge. ELARA is a Mexican telecommunications company offering a wide range of products and services in Mexico, Latin America and the US, among which, a wide telephony, pay TV, Internet, data transfer and interconnection network are offered. The challenge consisted in designing an electrical and electronic system that would allow to bring communication to isolated communities in the country, where no electricity is present. One key step of this challenge was the implementation of solar panels to provide enough energy for all the required devices.
2. PROFEPA Challenge. It was led by personnel of the Federal Attorney for Environmental Protection (PROFEPA) where 40 students were approached to the work of monitoring and evaluation of the Attorney General. A specific challenge was to review a company for a week detecting procedures to protect the environment and compliance with current standards.
3. ZIKLUM Challenge. This challenge was carried out in conjunction with the Ziklum Company, an enterprise that recycles more than 5,000 tons of Tetra-Pak containers a year. This prevents around 150 million containers go to garbage dumps. The challenge consisted in designing new lines of treatment of Tetra-Pak containers to open new production lines.
4. XOCHIMILCO Challenge. Xochimilco is a World Heritage City declared by UNESCO in 1987, specifically due to the very productive agriculture system called Chinampa, a pre-Spanish ancient knowledge that has survived throughout the times, this system is placed on a lake that serves as a reservoir of aquatic and aerial species giving a unique and exceptional feature. However, due to the fact that Xochimilco is embedded in Mexico City, there is a great risk of losing its identity by population

and urban growth. So an awareness campaign based on knowledge is necessary. Therefore a challenge was established in finding the way to get the message across to preserve the Chinampas that give identity to the population of Xochimilco.

In all cases, the *i-week* fulfilled the goal to approach the challenged based learning technique to all the students of the campus and helped to establish the more complex strategy: the *i-semester*.

3.2 The *i-semester*

3.2.1 School Setting and Students

A research study on the teaching strategies and the impact on the learning experience was carried out. Research was conducted in the fall of 2016 with 14 weeks/4 months in duration. Thirteen IDS students (8 males and 7 females) from 2nd (Freshman, 1), 4th (Sophomore, 6), 6th (Pre junior 3), 7th (Senior, 3) semester were enrolled in a 4-course credited "*i-semester*" CBL experience. Students were grouped in 4 teams (3–3–3–4 format).

3.2.2 Instructional Design

Participant teachers were trained during the summer 2015 in a 20-h course in which the teachers discussed strategies suitable to implement teaching techniques appropriate to the CBL in order to become mentors or coaches more than teachers of a normal classroom, since the objective is to cover the subjects of the courses through the resolution of challenges. The teachers met with BI staff to determine the challenges to be solved. It is important to note that the challenges were decided on the basis of the professional skills a graduated Sustainable Development Engineer must have, therefore the following challenges were established:

(A) Comprehensive pruning and solid waste management inside the production plant of BI.
(B) Disabling dangerous category waste such as blisters and other packaging of medicines.
(C) Use of residual food oil in the BI cafeteria to make some useful fuel.
(D) Determine the amount of methane produced in the wastewater treatment plant and establish strategies for its use or disposal.

BI participated with 4 Engineers responsible of the areas where the challenges took place and one assessor that monitored all the activities; on the other hand, ITESM-CCM participated with 6 teachers (4 responsible of each course and two assessors that monitored all the activities). BI staff and the ITESM-CCM assessors had two regular meetings a week, one teachers-BI staff only and the other one in the presence of students to monitor the developments of the resolution of challenges. Students spent 4 to 6 h immersion at the BI-Plant (2 miles away from the ITESM-CCM) from Monday to Thursday and a total of six hours Friday sessions corresponding to every single course (1.5 h each) with a specific mentor. One of the properties of the challenges is the uncertainty, this feature forced the students to have at least one 4-h session a week to visit libraries, other experts or field trips to acquire more knowledge to solve the challenges.

3.2.3 Data Collection Procedure

The analyses reported herein focused on the performance of the 4 teams, two partial and one final examination of each of the four courses, three oral presentations of the developing of the resolution of the challenges (examined by both BI and ITESM-CCM staff), and two student satisfaction surveys given at the mid and at the end of the semester answered anonymously that did not count toward the grade for the *i-semester*. The courses by which this CBL *i-semester* strategy was credited were: (a) Sustainable products and services, (b) Environmental and Sustainable research project (c) Environmental management and (d) Cleaner production and industrial ecology.

3.2.4 Analysis or Performance

Students spent approximately 280 h at the BI plant and 110 h of mentoring at the school. Performance was analyzed based on exam scores and rubric-driven examination of oral presentations regarding developments of the resolution of challenges. All exams contained a maximum of 100 points. Descriptive statistics are given in Table 1. As it is shown, the standard deviations indicated that the exam scores were widely dispersed amongst the mean for all three exams but not when oral presentations were examined. It must be noted that the results shown in Table 1 are 20 to 25% higher than the traditional academic lecture courses. These results indicate that the contents of the four subjects were reviewed in full by means of the resolution of challenges and the students fulfilled to 100% the syllabus contents of every course.

Table 1. Descriptive statistics for CBL-format 4 different course (N = 13 students)

	Partial exam 1	Partial exam 2	Final exam	Oral presentation 1	Oral presentation 2	Final presentation
Mean	87.5	89.3	85.9	88.9	92.1	94.6
Median	89	92	89	92	94	96
Standard Deviation	6.07	7.12	8.12	4.15	2.6	2.14
Maximum	100	98	97	96	98	99
Minimum	72	74	75	80	90	90

3.2.5 Analysis of Experience

Students and BI-Staff experiences were analyzed through the surveys. Students were asked two open-ended questions to rate their CBL experience. Question 1 asked students to write the best features of the CBL strategy. Four themes emerged from the students, as shown in Table 2, interaction and the exposure to real-life challenges were the top two themes that were mentioned. To have a professional experience was also mentioned, it is important to note that having a training partner is difficult as many of the companies have their goals focused on the production and business, as the competition is everyday stronger, therefore it is difficult to spend time from the company's human resources in the formation of students or to establish a Challenge-based not a Project-based or Practical-based program. Question 2 asked students to write the worst features of CBL strategy, two main themes emerged from responses. The first thing to arise was the time of the course, it is important to note that the solution of the challenge is not the most important aim under CBL, the goal is to learn the contents of the four subjects throughout the solution of challenges. It is common to hear that the time is short as the students get increasingly interested in the challenge. On the other hand the nature of a challenge is the uncertainty, some methods to solve may not be always available, and it is quite a lot of work to search sources of relevant knowledge, this is in line with the fact that the time spent at the library searching for sources was also one of the themes mentioned.

Table 2. Emerging themes for the "best thing" and the "worst thing" question on CBL strategy (N = 13 students)

Rank	Theme (Best)	Theme (Worst)
1	Interaction	Short time
2	Real-life challenges	Exam preparation
3	Professional contact	No clear order on topics
4	Innovation	Too many books for consulting
5	Applied concepts	Self-learning

4 Concluding Remarks

Challenge Based Education is a key model for teaching Engineering, in the case here described, sustainable development engineering is a recently created area that emerges from a requirement of the development of many companies that need to implement solutions with new ideas coming directly form the academy. Students should be exposed to new course materials to be able to solve the real-life problems and teachers must be ready to learn the state-of-the-art tools to implement innovative solutions. This method was developed with the purpose of improving the ability of engineering students to solve new problems and transfer knowledge from one context to another.

CBL is a pedagogical technique that has been incorporated into areas of study such as science and engineering, and demands a real-world perspective because it suggests that learning involves making or acting student on a subject of study [6, 7]. CBL forces the students to be reflective and flexible thinkers who can use knowledge acquired to take action. Thus CBL triggers the interest of students by giving practical meaning to education, while developing key skills such as collaborative and multidisciplinary work, decision making, advanced communications, ethics and leadership [8].

The Tecnologico de Monterrey will implement as soon as in three years, institutional programs of Education based on challenges for all the careers, implying a great challenge for both teachers and students. The approaches mentioned in this article are two experiences that have to be taken into account for the design and programming of the following programs of study.

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