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Project-Based Learning Applied to Distillation and Absorption Education: Integration Between Industry and a Chemical Engineering Undergraduate Course

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In this work, a successful methodology of Project-Based Learning (PBL) applied to distillation and absorption process education in an undergraduate course on Diffusional Transfer Unit Operations (DTUO) is presented. What is considered essential for the success of the program is the interaction between the discipline and industry. In the presented case study, 10 student teams developed virtual plants for a pulp industry and proposed solutions for given problem statements. Firstly, visits were made to one of the industrial sites of the partner pulp industry to present the educational plan for the process engineer's team that would support the educational project. Furthermore, in these visits, distillation and absorption operations in the plant that would be addressed in the program were selected. Once the industrial cases were chosen, problems statements were established and previous simulations using Aspen Plus@ Simulation Software were performed in order to check the suitability of the selected cases for an undergraduate course. From the initially selected case studies, 03 plants were selected for modelling considering the availability of the thermodynamic properties of the feed components in ASPEN PLUS@ database. Furthermore, before the first contact of the students with the pulp case studies, during the first two months of the course, concepts on distillation and absorption were presented to the students, so that they were able to solve simple problems by manual calculation and computer simulation. As soon as the students started their work to propose solutions for process problem statements, they were assisted by the discipline lecturer and assistants together with process engineers in order to direct the students to the best problem solutions. To assess the knowledge and skills acquired by students along the conduction of the projects, continuous feedback was established and oral presentations were given by the students to an examining board composed of lecturers and chemical engineers. Students' feedback on the methodology and their learning was evaluated through a survey. It was possible to conclude that the pedagogical practices developed were effective in establishing a positive and affective relationship between the students and unit operations concepts. Results showed a solid learning of the fundamentals on distillation and absorption. In addition, other skills and competencies such as capacity for solving problems and team work were stimulated during the program.

1. Introduction

Modern theories on engineering education have indicated that students have different learning styles, meaning some are more comfortable with theories and others with observable phenomena (Felder& Brent, 2005). Therefore, it is important that students have contact with a blend of abstract concepts and concrete information (Felder & Silverman, 1988). Instructors should mediate the learning process, presenting theories and mathematical models together with facts, data and projects with active participation of students.

There are different ways to establish a creative environment that allows integration between theoretical concepts and practical aspects, together with development of students' team work skills. Samsuri et al. (2017) experienced a successful case of combining Cooperative Learning into the Problem-Based Learning (PBL) approach in "Introduction to Engineering" course for first year students. Dym et al. (2005) cited the report of

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the American National Science Foundation (1997) “Systemic Engineering Education Reform: An Action Agenda” as a call for engineering education reform. This report emphasized the importance of teamwork, Project-Based Learning (PBL) and close interaction with industry for effective education.
In this context, the objective of this work is to present a methodology of education on Diffusional Transfer Unit Operations (DTUO) for undergraduate courses, applying techniques to meet the needs of different learning styles of chemical engineering students. First, during the so called ¨Development of the students’ repertoire of knowledge¨ period, concepts on distillation and absorption were presented to the students via 50 min expository lectures, followed by activities developed by the students. After a two month preparation period, students obtained their repertoire to develop Virtual Plants of a pulp production process through PBL.
According to Leite (2012), pedagogical decisions planned and developed by instructors impact on affective relationships established between subject (students) and the object of knowledge (course contents). In this work, it was observed that the decision to integrate industry into a chemical engineering undergraduate course led to significant motivation for students to progress their projects. This was considered the main goal of this methodology. As a consequence, the learning process for unit operations involving mass transfer such as distillation and absorption was shown to be effective. In addition, students have improved their knowledge of process simulation software. Finally, other skills and competencies were stimulated during the PBL process, such as teamwork and the capacity to transfer what has been learned in DTUO to other disciplines.

2. Methodology

The methodology has been divided into 3 parts: 2.1) the formal discipline structure, 2.2) Development of students' repertoire of knowledge, 2.3) Project-Based Learning (PBL), integration with industry.

2.1 Formal course structure

The undergraduate course on DTUO at the Chemical Engineering School of State University of Campinas totals 90 hours load within a semester (eighth semester of 10) and consists of a group of approximately 50 students. The formal content of the course is shown in Table 1. Although the focus of this paper is on distillation and absorption operations, one can observe strong relationships between the topics shown in Table 1. It is important that lecturers encourage students to integrate what has been learned.
In this work, in terms of technical knowledge, the main objectives of the course were that students should be able to: 1) design industrial equipment for separation of homogeneous mixtures until the basic project phase and 2) evaluate the influence of operating variables, such as flow rate, temperature, pressure and feed composition on purity and recovery of components in the process output streams.

Table 1: Formal content of the course.

1. Introduction	**3. Absorption**
	3.1 Solubility of gases in liquids
	3.2 Rated-based method for continuous contact
	3.3 Absorption and stripping in countercurrent flow
2. Distillation	**4. Liquid-liquid Extraction**
2.1 Vapor-liquid equilibrium	4.1 Liquid-liquid equilibrium
2.2 Flash distillation	4.2 Mass balances in ternary systems
2.3 Mass and energy balances	4.3 Single-stage equilibrium extraction
2.4 Distillation of binary mixtures	4.4 Countercurrent flow extraction
2.5 Multicomponent distillation	4.5 Countercurrent flow extraction with extract reflux
2.6 Stage efficiency and overall efficiency	**5. Solid-fluid contact operations**
2.7 Use of commercial simulators	5.1 Solid-fluid equilibrium
2.8 Sizing of trayed towers and packed columns	5.2 Adsorption
	5.3 Leaching
	5.4 Drying
	5.5 Crystallization

2.2 Development of students' repertoire of knowledge

The student’s knowledge considered to be sufficient for attending the DTUO course is mass and energy balance calculations, phase equilibrium calculations as well as calculation of the global mass transfer coefficient. Due to variation in levels of knowledge within the 50 students, 08 hours of revision classes were given based on assessment conducted in the first class. The revision classes focused on vapor-liquid and liquid-liquid equilibrium calculations and mass transfer concepts. Mass and energy balances were performed in the practical exercises given alongside the course.

During the first two months of the course, concepts on distillation and absorption were presented to the students via a structure of maximum 50 min of expository lectures, followed by activities carried out by the students with continuous feedback established between lecturers and students. The excessive use of the technique of expository classes must be rethought and replaced by other techniques more effective for the learning process (Masseto, 2012). Here, expository lectures were given only to provide the repertoire of knowledge on DTUO. They consist mainly of oral presentations with insight from practical experience, but also include films and presentation of papers. It is important to note that many students in the classroom are receptive to an industrial or research lecturers' experiences since they can see practical application of the theoretical concept. This is especially important for concrete learning style.

The active part of the classes was performed with students working in pairs, so that they could share their knowledge and ideas. The activities carried out by the students consisted of manual calculation to solve simple problems and computer simulations for: 1) comparison of the manually obtained results with simulation results and 2) solving more complex cases.

Starting the program with simple problems, for example by using graphical solution methods, is considered essential for later use of simulation tools by the students. Examples of simple problems solved manually are binary distillation using McCabe-Thiele method or multicomponent distillation using Fenske-Underwood-Gilliland method. More complex problems solved in the classes have normally involved separation of multicomponent feedstreams, with one or more columns, and in some cases involving recycle streams. Through the use of simulation software students were stimulated to carry out sensibility analyses for establishing optimal process operating conditions. As an example, students simulated the separation process of ethylene oxide from the reaction stage output stream. Students simulated the reaction stage in the previous semester within the chemical reactors course, therefore it was possible to integrate knowledge.

The familiarity of students with computer simulation is emphasized, as the development of virtual plants has been increasingly important for the needs of the chemical industry. According to Hazwani et al. (2017), modeling and simulation can help with the description of the system and the choice of the optimal control strategy in industrial plants. Approximately 20% of the course is dedicated to computer simulation.

2.3 Project-Based Learning (PBL), integration with industry

Project preparation

Initial visits were made to one of the industrial sites of the partner pulp industry in order to present the educational plan to the process engineer's team that would support the educational project. Here it is important to mention that engineers were motivated to participate in the educational project since the partner company has a formal program of approximation with the university. In these visits, distillation and absorption operations in the plant were also selected to possibly be addressed in the program. Once the industrial cases were selected, problem statements were established and previous simulations using Aspen Plus® simulation software were performed by the lecturer in order to check the suitability of the selected cases for an undergraduate course. From the initially selected case studies, 03 plants were selected to be modeled considering the availability of the thermodynamic properties of the feed components in ASPEN PLUS® database and degree of detail of the plant technical documentation. The cases were: 1) Absorption of gases from a recovery boiler tank, 2) methanol recovery plant, 3) steam condensate treatment plant. Problem statements were then prepared containing the problems to be solved together with plant information such as simplified flow charts, details of equipment construction and process operation conditions. Figure 1 illustrates the complexity degree of the case studies. It is shown a simulation flowsheet of the steam condensate treatment plant designed by one of the students team.

Project development

Problem statement documents were distributed to the students, who formed 10 teams that varied in size from four to five members. There were no specific directions about how the students should be organized within the groups. Each team was responsible for proposing new solutions for one of the problem statements in the 03 preselected industrial processes. The only restriction imposed was that teams should propose solutions through the development of virtual plants in simulation software.

As soon as the students started their work, they were assisted continuously by the discipline lecturer and 02 assistants together with process engineers in order to direct the students to the best problem solutions. The assistance to the students included the visit of a pulp plant engineer for answering questions about the industrial process. Appropriate choice of models of thermodynamic properties must be made to obtain reliable results using computer simulation. Operating conditions to be considered are temperature, pressure and composition of the streams, as soon as the nature of the properties of interest. During the course of the

project, students decided on the thermodynamic property models to be used according to the article of Carlson (1996). It provides practical tips and techniques in an accessible way for undergraduate students.
Besides the continuous feedback established between lecturers and students during the course of the projects, to assess the knowledge and skills acquired, oral presentations were given by the students to an engineering examining board. One student from each team was randomly chosen to present the projects and the other members were allowed to complement the presentation. Teams also submitted final reports of the activities with the proposed solutions. Teams' final score was established considering both presentation and final report.
The students' perception regarding the methodology and their learning was evaluated through a form, with the 09 items shown in Table 2, completed by students at the end of the course. Likert-scale type was used to measure individual perceptions ranging from 1 (strongly disagree) to 5 (strongly agree).

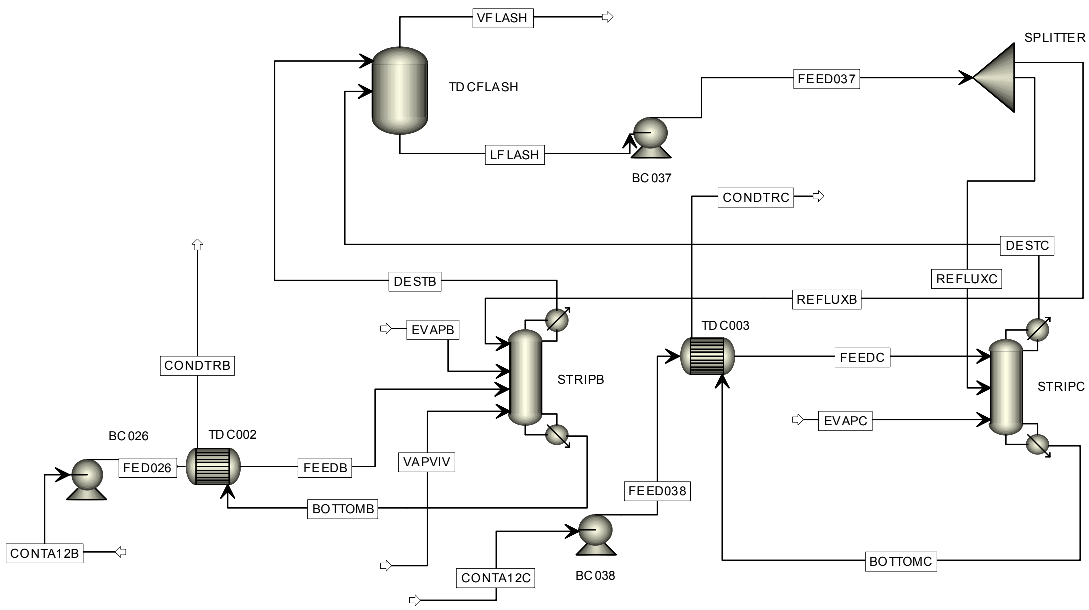

Figure 1: Example of a steam condensate treatment flowsheet designed by one of the students team.

Table 2: Statements of the students' perception survey[1].

	Statement
1	The project contributed to my learning on Diffusional Transfer Unit Operations (Distillation, absorption, etc.).
2	I prefer the methodology of active learning (in which the students conduct activities inside and outside the classroom), when compared to the methodology of only lectures given by the instructor
3	The running of projects in partnership with industry should be continued for the next semesters of this course.
4	Technical fundamentals provided by the instructors during the classes were sufficient for conducting the projects.
5	Infrastructure (of computers, software, books, access to periodicals) was adequate for conducting the projects.
6	Projects helped me to develop skills and competences (ability to argue in favor of an idea or investment, teamwork, etc.) necessary for my career as a Chemical Engineer.
7	The projects contributed to improve my knowledge in process simulators such as ASPEN PLUS@.
8	Through the projects it was possible to integrate knowledge with other disciplines of the Chemical Engineering course.
9	The technical knowledge on Diffusional Transfer Unit Operations that I acquired through the project conduction will be useful for my professional life as a Chemical Engineer.

[1]Likert-scale type used to measure individual perceptions: 1 strongly disagree, 2 disagree, 3 neutral, 4 agree and 5 strongly agree.

3. Results

Figure 2 presents the results of the survey on the learning process mediated by the PBL approach, based on industrial cases. It was clear that students recognized several benefits of the adopted educational practices. There was a large prevalence of answers strongly agreeing or agreeing with the statements presented in Table 2, which affirmed positive results reached at the end of the course. For all the statements shown in Table 2, less than 7 percent of the students disagreed with the positive benefits. No answer of strong disagreement was received.

It seems the adopted practices of mixing theoretical concepts and practice were able to approximate the subject (students) to the object of knowledge for practically all classroom learning styles.

According to the results presented in Figure 2 for statement 5, students considered the infrastructure of computers and access to periodicals etc to be adequate. It is important to note that throughout the classes and project, a computer room with more than 50 machines with Aspen Plus@ installed was available

Evaluating statement 4, students agreed that technical fundamentals provided in the course were sufficient to carry out the project. This may be related to the special attention given to the initial preparation period for the formation of the students' repertoire of knowledge.

Analyzing together the results of statements 1 and 7, it was observed that according to students' perception, PBL contributed to the learning for DTUO and improvement of process simulator knowledge. Assessing of final reports and oral presentation confirmed a solid learning of the fundamentals of distillation and absorption, including concepts of thermodynamic modeling, Murphree efficiency and the difference between vapor and gas, etc.

When students were asked whether the practice of conducting projects in partnership with industry should be continued for the next semesters of this course (statement 3), only one student disagreed. It shows the high level of the motivation when there is a relationship between an industry and an undergraduate course.

Statements 6 and 9 are related to how students see the contribution of the project to their future career as chemical engineers. It was noticed that in addition to the technical concepts on DTUO, they considered the activities helped in the development of personal abilities and skills, such as teamwork and ability to argue in favor of an idea or investment.

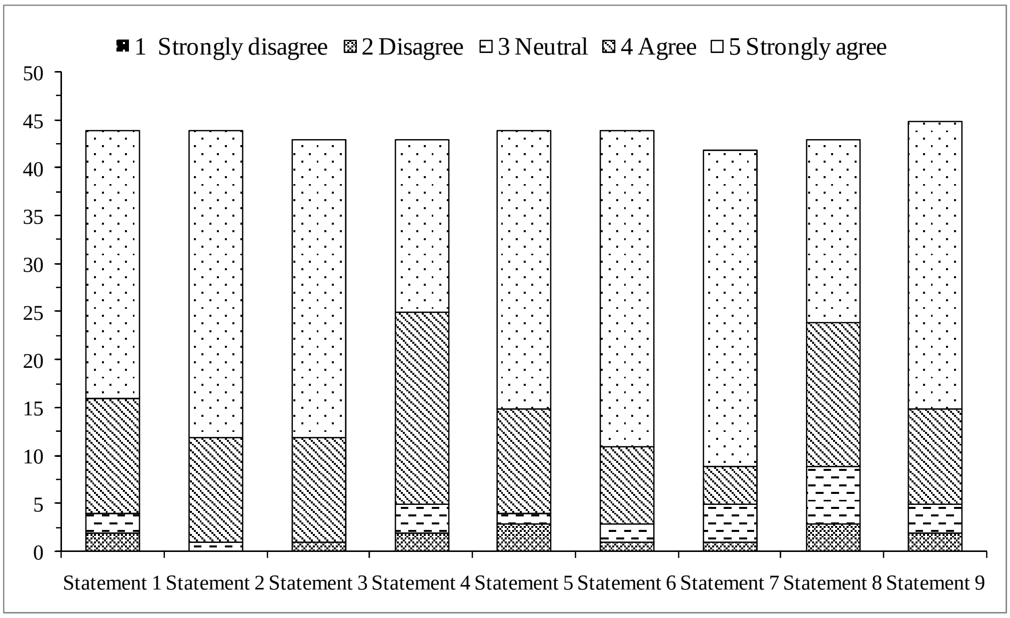

Figure 2: Level of Agreement or disagreement with the Statements shown in Table 2.

4. Conclusions

The developed educational practices of approximation between an industry and an undergraduate course were effective in establishing an affective relation between the students and unit operation concepts for all learning styles. A high level of motivation was observed in the students to construct virtual plants for proposing solutions for the industrial cases.

The result of the survey conducted with the students has shown that, besides the technical concepts on DTUO, students recognized activities helped in the development of personal abilities and skills, such as teamwork and the ability to argue in favor of an idea or investment.

Acknowledgments

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