STRENGTHENING ENGINEERING SKILLS BY MEANS OF PROBLEM SOLVING ORIENTED COURSES IN HIGHER EDUCATION PROGRAMS

Elisabet Capón-García¹, Edrisi Muñoz², Konrad Hungerbühler¹

¹ Department of Chemistry and Applied Biosciences, ETH Zürich (SWITZERLAND)
² Centro de Investigación en Matemáticas A.C. (MEXICO)

Abstract

New generations of engineers will face an increasingly complex reality and will need to drive society and technology towards a sustainable development. Hence, it is extremely important to educate highly qualified professionals with well-founded engineering skills. Therefore, the spirit of reflective reasoning and constructive criticism must be present in high education programs, thus promoting the acquisition of creative engineering thinking and skills to face problems found in the industry. This contribution presents the educational experience in real problem solving oriented courses in two engineering disciplines, namely software and chemical engineering. Specifically, the course structures are presented, and a repository of case studies is provided. From a methodological perspective, several complementary approaches are applied to foster interest and to support students to acquire engineering skills in problems solving, namely contextualizing the problem, connecting the concepts, setting clear objectives, practice of the scientific method, and managerial oriented activities, such as information exchange, writing reports, the participation in work teams and preparation of presentations integrated in the dynamics of the class, foster interdisciplinary skills.

Keywords: Problem oriented courses, Higher education, Engineering skills.

1 INTRODUCTION

Engineers make use of knowledge of mathematical and natural sciences, such as, biology, chemistry, physics and earth science, gained by study, experience and practice is applied with judgment to develop strategies for optimize the use of materials and forces of the nature for a specific benefit. Hence, in order to support engineer’s activities, the application of scientific and engineering knowledge and methods combined with technical skills are required.

The teaching task is a highly challenging and motivating activity because it offers the opportunity to lead new generations of engineers towards sustainable development of society and technology. It entails a significant amount of work, including structuring course contents, establishing assessment criteria, preparation of the material for the courses, organizing lectures and practical case studies, as well as supervising the learning process of students, among other activities. Indeed, teaching is a continuously evolving assignment, which requires a high level of responsibility and commitment, flexibility and adaptation to new methodologies and upcoming trends and concepts stemming from both academia and industry.

This work presents the experience as a teacher in the Process Simulation and Flowsheeting course. This course provides students with process modelling and optimization skills, based on systems thinking and the perspective of systems problem solving, which could be considered as a valuable ingredient in the academic training of chemical engineers and industrial practice. Thus, the current syllabus is enriched and strengthened by the incorporation of methodological skills for modelling, simulation and optimization based on troubleshooting thinking.

To educate highly qualified professionals, with well-founded skills in chemical engineering, who can successfully develop their careers either in the industry or the academia. Even more, I would like to transmit the spirit of reflective reasoning and constructive criticism, thus keeping them away from compulsive memorization and automatic acceptation of established knowledge. In my opinion, teaching goes beyond presenting and transferring knowledge, it is about promoting the acquisition of creative engineering thinking and skills to face problems found in the chemical, pharmaceutical, food and other process industries.

The basis of a successful learning environment consists of fostering the participation of students and their involvement in their learning process. Since the professional career is a decision that students
take freely, in principle it could be assumed that they are motivated and eager to learn how becoming
good chemical engineers. However, teachers can contribute to consolidate and guide their motivation
by respecting and tutoring personal preferences of students for a given topic. Hence, I consider highly
important to be understanding with students’ requirements, a good observer and communicator, fully
devoted to people, and to feel passion for the academic growth of the subjects.

2 METHODOLOGY

The learning objective according to constructive alignment theory of the Process Simulation and
Flowsheeting is to simulate and critically evaluate process flowsheets in the chemical industry
(applying chemical engineering principles and simulation tools). Such main objective can be further
structured in several objectives, namely:

- Analyze the structure and properties of process flowsheets
- Integrate previously acquired chemical engineering principles for chemical process systems
- Evaluate the feasibility of existing and new process flowsheets
- Assess the performance of plant-wide chemical processes
- Optimize chemical process (sub)systems

From a methodological perspective, several complementary approaches are required to foster interest
and to support students to acquire engineering skills in problems solving:

- Contextualize: It is necessary to set the whole subject and each individual learning unit in a
  context for highlighting its actual meaning, scope and interest for students as chemical
  engineers. In this line, the presentation of relevant news, real industrial situations, pictures and
  videos of chemical processes among other resources could be helpful to illustrate the context.

- Connect: The concepts behind process simulation and optimization are grounded on principles
  from other areas such as reaction engineering, process separation, transport phenomena,
  thermodynamics and mathematics. Hence, it is of utmost importance making presentations of
  new topics, as structured building blocks within the chemical engineer profile. Such goal could
  be established by proposing problems and case studies, which require principles, knowledge
  and tools that should have been acquired in other subjects of the curriculum. Similarly, it would
  be helpful to present the syllabus as a list of themes to be discussed as well as a road-map
  course which clarifies the relationships among the different topics to be mastered. In this way,
  students can visualize how the current course is based upon previous acquired concepts as
  well as how it is connected to subsequent courses and future applications. In my personal
  teaching experience, I have also found that interaction with the students during lectures and
  exercise classes creates an environment that helps to keep their attention, and it is highly
  beneficial to illustrate through realistic scenarios the kind of questions that can be addressed
  with the skills that they are developing.

- Set objectives: It is important to inform students about what they are expected to learn and the
  skills that they are going to develop. Thus, these issues constitute the framework for
  establishing a coherent assessment process to be used in the course. This framework should
  provide the class with a clear and consistent grading system and assessment schedule, and
  should be designed to provide timely feedback about the achievement of the goals. In this
  sense, it is also valuable to propose a long-term project course, where they can progressively
  incorporate the concepts presented in the course and improve their skills. I experienced that
  promoting continuous work tended to reinforce the constructive process of learning. For
  instance, while supervising teams of students pursuing the simulation of the dynamics of a
  separation operation in a project along the semester, I observed that students felt more
  committed to the content of lectures and strived to learn and apply new concepts and skills
  earlier.

- Practice: In order to embrace new concepts and skills, it is highly important to use them by
  means of exercises, case studies and projects. I have observed that students strived for
  understanding the material presented in the lectures, when they had to face exercises and
  semester tasks. Hence, the presentation of attractive and realistic exercises is an asset to
  motivate students. Even more, in the area of process safety, design and operation, chemical
  engineers usually develop their own models and apply algorithms embedded in mathematical

6565
software, or commercial simulators. Hence, the inclusion of software tools for reaching engineering decisions is a key issue in the education of chemical engineers. Likewise, in-site visits to the industry are highly valuable for motivation, since students come into contact with industrial reality. To take the most of industrial visits, my task consists of preparing exercises and case studies for acquiring and developing skills inspired in actual process plants. In addition, it is highly valuable to introduce students to the scientific method and its realization in the process systems engineering. This goal can be achieved in the context of the project course, by proposing tasks related to literature review, systematic observation, hypothesis formulation, solution procedure and testing, validation and results analysis.

- Management: In this sense, managerial oriented activities, such as information exchange, writing reports, the participation in work teams or preparation of presentations integrated in the dynamics of the class, foster interdisciplinary skills of students which are highly important for their professional careers.

Next, the experience of adapting the learning activities during the first four lectures of the course is presented.

3 RESULTS

The structure of the four lectures as well as the feedback on the learning activities organized for each lecture are discussed next.

3.1 Day 1

3.1.1 Structure

Fig. 1 presents the structure of the first day of the lecture. In that day, 32 students showed up and participated in a set of learning activities. First, the goals and motivation of the students are requested. Next, the course portal is shown by the lecturer. Then, the applications of the course knowledge is requested and disciplines involved in this course are listed. Finally, a problem solving activity is introduced. The lecture closes with a so-called Cognitive Ability Test (CAT), in which the students have the opportunity to explain what they liked most and what they liked least of the first lecture.

3.1.2 CAT results

Fig. 2 and 3 show the preferences of the students towards the learning activities of Day 1. On the one hand, Fig. 2 shows that most of students liked the fact that they could get to know their classmates (20%), the group work (18%), the practical activity related to problem solving (18%), and the fact that it was an interactive lesson (13%). On the other hand, students were not satisfied with the time distribution and the course pace (24%), the introduction about the course background (19%), that they considered that they did not learn anything specific (16%), and that it was too interactive (12%).

![Figure 1. Lecture structure.](image.png)
3.2 Day 2

3.2.1 Structure

Fig. 4 presents the interactive sequence of the second day. On that day, the students had to prepare the poster related to the problem-oriented task introduced in day 1. Next, there was a block including the theory about degrees of freedom. Finally, a challenging exercise on a practical exercise is presented so that students can use the presented theory in a real example.

3.2.2 Lessons learned

Fig. 5 presents the lessons learned during the teaching activity in the second day of the course. Specifically, it is necessary to have prepared an alternative if the digital means considered for the course eventually fail. It is crucial to have a strong and interesting consolidation of the learning activities, so that the students acknowledge the newly acquired skills. In addition, the students need to
put the course into context and create a nice atmosphere in the classroom. From a structural perspective, it is a good idea to build from an initial question, and pose a clear objective, which likes to pieces back and forward. It is also to show the connections and explain the reasoning so that students can understand the engineering thinking. Finally, from an organizational point of view, it is important to be clear about the timing and stick to it, have a rule of 1 slide for 3 minutes, and stress only important things. Additionally, written questions need to be posed clearly and in an appealing structure. Finally, it is important to get rid of quiz-master questions, in order to foster participation.

<table>
<thead>
<tr>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To have a plan B, if something fails</td>
</tr>
<tr>
<td>• Have a strong/interesting consolidation</td>
</tr>
<tr>
<td>• Put into course context</td>
</tr>
<tr>
<td>• Clear hand-writing</td>
</tr>
<tr>
<td>• Atmosphere</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Build from an initial question</td>
</tr>
<tr>
<td>• Clearer objective and links to pieces back and forward</td>
</tr>
<tr>
<td>• Show connections and explain the reasoning</td>
</tr>
<tr>
<td>• Include headings and how things are related</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Timing/interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Clear about timing and stick to it</td>
</tr>
<tr>
<td>• 1 slide/3 minutes</td>
</tr>
<tr>
<td>• Stress only important things</td>
</tr>
<tr>
<td>• Written questions and clearly stated</td>
</tr>
<tr>
<td>• Pose questions that are eagering</td>
</tr>
<tr>
<td>• Get rid of quiz-master questions</td>
</tr>
</tbody>
</table>

3.3 Day 3

3.3.1 Structure

Fig. 6 presents the interactive sequence of the third day. Specifically, it included the presentation of the exercises from each group. Next, the consolidation of the knowledge is performed on a real flowsheet. Additionally, the students are asked to solve individually an exercise to practice the theoretical concepts. The final block is devoted to introduce the next learning goal related to mathematical methods. As on the first day, students have to answer a CAT related to what they liked most and what they liked least from that day.

Figure 5. Lessons learned from Day 2.

Figure 6. Lecture structure of Day 3.
3.3.2 CAT results

Fig. 7 and 8 show the preferences of the students towards the learning activities of Day 3. On the one hand, Fig. 7 shows that most of students liked the fact that we could solve an exercise all together (50%), the group work (30%), and the presentation of group activities (10%). On the other hand, students were not satisfied with the amount of time that was devoted to theory (29%), the feeling that they had not learned anything new (19%), the group work (17%), and that they did not know what they were supposed to do (14%).

![Figure 7. What students liked most in Day 3.](image1)

![Figure 8. What students liked least in Day 3.](image2)

3.4 Day 4

3.4.1 Structure

Fig. 9 presents the strategy and interactive sequence of the fourth day. That day the strategy was to be stick to the time blocks of 45 minutes of lecture combined with 15 min of break. The interactive sequences combined theory and practice, namely mathematical methods, decomposition strategies and two exercises (individual and in pairs). Additionally, the very first thing was to clarify the course goals and scope, as well as the course approach to tackle the contents. As a result of this continuously evolving process for the teaching experience, the student recognized the effort and acknowledged personally the new interactive sequence.
4 CONCLUSIONS

On the one hand, this experience has shown that a significant amount of work is necessary to prepare consciously the content for engineering courses. It is necessary to apply a wide range of tools and adapt by continuous-improvement to students requirements. In addition, it is remarkable the importance of students being recognized so that they get involved in the course and the learning process. Additionally, it is crucial to provide adequate time/breaks so that the attention can be adequately kept. Finally, including a variety of activities and the listen to what works for students is extremely important to guide the acquisition of the engineering skills. On the other hand, additional issues need to be considered. Specifically, the dilemma about how to consider and integrate all the different opinions from students has to be tackled. It is also extremely difficult to reach a good pace in the presentation of the contents: not too fast/not too slow. Finally, the lecturer needs to reflect on what makes teaching meaningful.