# Experience Gained During the Adaptation of Classical ChE Subjects to the Bologna Plan in Europe: THE CASE OF CHEMICAL REACTORS

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The new European Framework on Higher Education proposed in the Bologna Process (a process with similarities to the Washington Accord on Engineering Education) entails sweeping modifications in the structure of university studies but also in the teaching methodology. The Washington Accord, Sydney Accord, and Dublin Accord are three multilateral agreements between groups of jurisdictional agencies responsible for accreditation or recognition of tertiary-level engineering qualifications within their jurisdictions, which have chosen to work collectively to assist the mobility of engineering practitioners holding suitable qualifications. The Bologna Process proposes to structure higher education in three cycles (Bachelor-Master-Ph.D.), converging the very diverse structures of higher education in Europe and bringing them into line with international standards. This implies a change from a staff-centered approach to a student-oriented approach.[1-3] Accordingly, current teaching methodology has to be converted as also confirmed in the Lisbon Declaration (2007).[4] This involves not only encouraging the use of learning outcomes and being explicit about what graduates are expected to know and be able to do, but also encouraging critical thinking and the active engagement of students.

The Bologna Process as well as the Education & Training 2010 Work Programme[5] establishes that general key competences are to become more prominent, more important, and more explicit in curricula. The European Framework for Key Competences for Lifelong Learning[6,7] identifies and defines eight key competences necessary for personal fulfillment, active citizenship, social inclusion, and employability in a knowledge-based society: 1) communication in the mother language; 2) communication in foreign languages; 3) mathematical competence and basic competences in science and technology; 4) computer competence; 5) learning to learn; 6) social and civic competences; 7) sense of initiative and entrepreneurship; and 8) cultural awareness and expression.

According to the Bologna Process, the European Association for Quality Assurance in Higher Education, by means of the publication of Standards and Guidelines for Quality Assurance in the European Higher Education Area, determines the European standards and guidelines for internal quality assurance within higher-education institutions. In these guidelines, the assessment and involvement of students is highlighted, since it is one of the most important elements in higher education. It is evident that the outcomes of assessment have a profound effect on students' future careers. It is therefore important that assessment is carried out professionally at all times and takes into account the extensive knowledge that exists about testing and examination processes.

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Tuning Project is a university-driven project that aims to offer a concrete approach to implementing the Bologna Process at the level of higher-education institutions and subject areas in all Europe. The Tuning Project makes the distinction between learning outcomes and competences to distinguish the different roles of the most relevant players: academic staff and students. Learning outcomes are statements of what a learner is expected to know, understand, and/or be able to demonstrate after completion of learning. Competences represent a dynamic combination of knowledge, understanding, skills, and abilities. Fostering competences is the object of actual educational programs.[1] Competences can be subdivided into subject-specific and generic. It is important to build up and develop subject-specific knowledge and skills. It should be emphasized, however, that time and attention should also be devoted to the development of generic competences or transferable skills. The Tuning Project distinguishes three types of generic competences: 1) instrumental competences: cognitive, methodological, technological, and linguistic abilities; 2) interpersonal competences: individual abilities, social interaction, and cooperation; 3) systemic competences: abilities and skills concerning whole systems, combining understanding, sensibility, and knowledge.[1]

In the new EHEA, a continuous assessment for learners/students is also proposed. This will imply the remodeling of subject evaluation, leaving the final exam evaluation behind and changing to a continuous assessment of knowledge, understanding, and competences.

To take a specific case, in the classic methodology that has dominated teaching in all fields during past decades, chemical engineering professors lecture much of the time in class.[8-12] Nevertheless, the new European Framework on Higher Education requires a complete reconsideration of teaching methodology. The new Framework argues that learning would improve if professors lectured less and used various active- and inductive-learning methods.[8, 13] These methods include, among others, cooperative group learning, clickers (quick tests), guided design, problem-based learning, quizzes, laboratory improvements, and computer simulations to form part or all of the class periods.

This methodology would be in accordance with the Bologna Process requirements, which would partially substitute the classic lectures/lessons and would reach all the goals proposed by EHEA.

In our university department, the teaching methodology for two classical subjects—Chemical Reactors (chemical engineering) and Chemical Reaction Engineering (technical industrial engineering)—has been modified according to the Bologna Process to provide the students/learners with the knowledge, understanding, and competences necessary as well as with transversal key competences. The results obtained five years after the implementation of the new methodology in both subjects are shown, discussed, and evaluated in this document.

## PEDAGOGIC BACKGROUND

This experience was gained in the Department of Chemical Engineering of Universitat Autònoma de Barcelona (UAB, Spain). Staff in this department provided instruction in diverse subjects such as Chemical Engineering, Technical Industrial Engineering, Environmental Sciences, Biotechnology, and Chemistry, among others.

Engineering is a discipline that is essential to meet the needs of people, for economic development, and for the provision of services to society. Engineering involves the purposeful application of mathematical and natural sciences and a body of applied scientific knowledge, technology, and techniques. It seeks to produce solutions whose effects are predicted to the maximum degree possible in often uncertain contexts. While bringing benefits, engineering activity also has potentially adverse consequences. Engineering, therefore, must be carried out responsibly and ethically, use available resources efficiently, be economic, safeguard health and safety, be environmentally sound and sustainable, and generally manage risks throughout the entire life cycle of a system.[14]

The two subjects in which the new methodology has been introduced and evaluated are Chemical Reactors, instructed in the fourth year of the chemical engineering degree course, and Chemical Reaction Engineering, instructed in the second year of the technical industrial engineering degree course. The main characteristics of both subjects are shown in Table 1. The contents of both subjects are similar, but they differ in the profile of the student participants, in terms of previous education, age, and future professional career.

In addition, the Washington Accord (and the successive Sydney and Dublin Accords)[14] defined the different Graduate Attributes and Professional Competency Profiles differentiating between Professional Engineer (chemical engineer), Engineering Technologist, and Engineering Technician (both comparable to technical industrial engineer status in Spain). This document details the abilities and knowledge expected of engineers in order to satisfy the professional competency profiles. Fundamentally, the main difference in the two qualifications lies in the emphasis of each subject: Professional Engineer (chemical engineer) graduates must be able to comprehend and apply advanced knowledge of the widely applied principles and good practices, while Engineering Technologist (technical industrial engineer) graduates should be able to comprehend and apply widely accepted and applied procedures, processes, systems or methodologies, and standardized practices.

In general, both subjects (Chemical Reaction Engineering and Chemical Reactors), are crucial to the overall degree content since they treat indispensable aspects in engineering education. They are subjects that require a deep knowledge of mathematics, science, and engineering fundamentals. In short, the fundamental content of both subjects is the explanation and development of all the phenomena and processes concerning the design of chemical reactors, essentially based on mass and energy balances. It is also significant that the level of knowledge acquired in these subjects will be also reflected later in other subjects or periods during the degree course. In particular they will be re-evaluated when students carry out the Final Project, where they must design a complete industrial process.

In terms of enrollment, both are medium-level subjects (about 40-50 students per year). Using the classical lecture methodology that normally involves a high subject dropout rate, however, the percentage of class attendance is around 50%. Students have the perception that these subjects are important but difficult to pass. This translates into a high drop-out rate through the year, which is also increased by the fact that many students find jobs before finishing the course.

At present engineering is one of the areas in which fewer subjects have been modified or adapted to new methodologies (especially the core or obligatory subjects), compared to other fields.[15] The traditional methodology applied to the teaching of these subjects used lectures, either those corresponding to theoretical credits, or problem-solving lectures, in which the lecturer solved problems with little or no student-teacher interaction (see Table 1). Subject assessment consisted of a final exam or test in which all knowledge and abilities were evaluated. Students perceived that this methodology is positive for them since they had been taught with similar methodologies in all degree subjects or courses. Moreover, these are considered as crucial and key subjects by the Department of Chemical Engineering staff and had been taught by the best qualified teachers with extensive experience.

## LEARNING PHILOSOPHY

According to the new procedures and methodologies established in the EHEA by way of the Bologna Process, older programs, teaching methodologies, and practices must be modified or in some cases substituted by other new methodologies and techniques that will fit all Bologna requirements. To summarize, the new European Higher Education Framework enforces the application of new methodologies to increase and improve students' understanding and knowledge acquirement and to better assess the complete learning process. At present, all Higher Education Programs are being modified to better fit the requirements of Bologna. Many times modifications are made under teachers' criteria, and they can differ significantly from one university or country to another, although some general guidelines already exist (European Federation of Chemical Engineering, 2005).[16] Thus, the present manuscript could also be used as an evaluated example of a subject program and transformed methodology. During recent years, it has been observed how the number of student drop-outs in the subjects evaluated in this document has increased. Furthermore and even more negative, is how many students who passed the subjects were not able to apply, in later courses or subjects, the knowledge and abilities that they were supposed to possess (this can be clearly confirmed in the Final Project of the degree). This may indicate that some students are able to pass the subjects without learning, or in other words, they miss the chance to learn. This fact was also noticed in other subjects, and even in other degrees, and many times it was attributed to the poor knowledge and intelligence of the new student generations. At this point, the new proposed methodology may also be used for refuting this argument and to improve the learning of the students. The general objective of the experience presented here is to demonstrate that it is possible to modify the teaching methodology in classical chemical engineering subjects while achieving the main goals determined in the EHEA. That would mean switching from an old methodology based on lecture lessons to active and inductive learning methods, making students participate and interact during lectures and activities. In addition, some specific objectives are defined and highlighted in the following points:

- *To demonstrate that continuous student assessment is suitable for these classical engineering subjects.*
- *To compare the implementation of new teaching/learning methodologies in higher engineering studies.*
- *To improve the learning of transversal key competences, such as leadership, teamwork, and oral and written communication skills.*
- *To prove that it is possible to take appropriate action to decrease the level of subject and/or degree abandoning.*

**TABLE 1**
**Main Features of Subjects Studied**

| Subject | Chemical Reaction Engineering | Chemical Reactors |
|---|---|---|
| Degree | Technical Industrial Engineering | Chemical Engineering |
| Length | 3 years | 5 years |
| Year of instruction | 2nd | 4th |
| Courses evaluated | '05-'06, '06-'07, '07-'08, '08-'09, '09-'10 | '05-'06, '06-'07, '07-'08, '08-'09, '09-'10 |
| Type of subject | Obligatory to study (core subject) | Obligatory to study (core subject) |
| Total credits[1] | 6 | 7.5 |
| Theoretical and Problem-Solving credits[1] | 4.5 + 1.5 | 4.5 + 3 |
| Students enrolled per year | 40 | 50 |
| Main contents | Chemical Reactor Design | Chemical Reactor Design |

[1] *At present, in Spain, one credit corresponds to 10 hours of class participation for students.*

## NEW PROGRAMS: GOALS AND COMPETENCES TO BE ACQUIRED

One of the weak points identified in the old Higher Education Systems, in which Engineering disciplines are included, is that the objectives of courses, subjects and grade or degree programs are not defined or, in any case, they are too vague. As established in Standards and Guidelines for Quality Assurance in the European Higher Education Area, programs have to be redefined in order to clearly inform the students about the assessment strategy being used for the course or subject, which examinations or other assessment methods they will be subjected to and what will be expected of them.[17]

In this sense, one of the first tasks was to modify the old subject program that consisted of a brief list of topics, introducing new, extended, and detailed program where all information related to the objectives, evaluation, goals, topics, etc., were included.

The EHEA, as established by The Bologna Process and supported by Tuning Project, intends to make plans of studies comparable, compatible, and transparent in all the European countries by developing reference points at any subject area level. The reference points are expressed in terms of learning outcomes (learning achievement goals) and competences. Learning outcomes are statements of what a learner is expected to know, understand and be able to demonstrate after completion of a learning experience. According to Tuning, learning outcomes are expressed in terms of the level of competence to be obtained by the learner. Competences represent a dynamic combination of cognitive and meta-cognitive skills, knowledge and understanding, interpersonal, intellectual, and practical skills, and ethical values. Considering the guidelines proposed by Standards and Guidelines for Quality Assurance in the EHEA, Tuning Project, The Education & Training 2010 Work Programme and The European Framework for Key Competences for Lifelong Learning, as well as considering the suggestions of the European Federation of Chemical Engineering, new specific learning outcomes and competences to be achieved by the students of both subjects were defined.

The following learning outcomes are defined for each subject:

- *Chemical Reaction Engineering:*
  1. *To comprehend the stoichiometric, thermodynamic, and kinetic basis of the chemical reactions from an engineering point of view.*
  2. *To describe the main characteristics of chemical reactors and their different types.*
  3. *To design chemical reactors.*
  4. *To interpret the flow models of chemical reactors.*
- *Chemical Reactors:*
  1. *To learn how to design real chemical reactors considering ideal reactors as the basis for design, differentiating between isothermal, adiabatic, or neither isothermal nor adiabatic reactors.*
  2. *To describe the main characteristics of chemical reactors and their different types.*
  3. *To design chemical reactors.*
  4. *To interpret the flow models of chemical reactors.*
  5. *To discern between the theoretical concepts associated with chemical reactors and common practices in their design.*

Considering these more concise and specific objectives, students and instructors would be able to evaluate whether they had really achieved the main goals of the subject or not. The new evaluation system is designed for an objective evaluation of these goals and competences.

Some competences are subject-area related (specific to a field of study) while others are generic (common to any degree course). As is mentioned in the Washington Accord and Tuning documents on Educational Structures in Europe and established in the Bologna Process, specific and generic competences have to be defined for each graduate profile.[1, 14] Also, scientific competences would be included in the new subject programs adapted to Bologna Process. In this sense, different competences were defined for Chemical Reactors (Chemical Engineering).

- *Scientific knowledge and fundamental laboratory competences:*
  1. *To be able to apply knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.*
  2. *To know the main reaction systems, separations, fluid dynamics, solid mechanics, and material processing technologies involved in industrial processes related to Chemical Engineering.*
- *Specific competences:*
  1. *Specific theoretical knowledge:*
     a. *To understand the main principles of Chemical Engineering: mass and energy balances and kinetics.*
     b. *To attain a profound knowledge of thermodynamics, phase- and chemical equilibria.*
     c. *To possess extensive knowledge of the kinetics of physical processes such as transference of mass, energy, and movement as well as chemical reaction kinetics.*
  2. *Specific practical competences:*
     a. *Ability to design chemical engineering processes, systems, and facilities.*
     b. *Ability to design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety,*

*cultural, social, and environmental considerations.*

3. *Competences appropriate to a Chemical Engineer professional:*
    a. *Being informed of the contextual knowledge, to assess social, health, safety, legal, and cultural issues and the consequent responsibilities relevant to professional engineering practice.*
    b. *To understand the impact of professional engineering solutions in social and environmental contexts and demonstrate knowledge of and need for sustainable development.*
    c. *To apply ethical principles and be committed to the professional ethics and responsibilities and norms of engineering practice.*
4. *Research competences:*
    a. *To conduct investigations of complex problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.*

- *Generic competences:*
    1. *To work effectively as an individual, be dynamic and organized, and be capable of analyzing and synthesizing.*
    2. *To possess self-esteem and have a spirit of self-improvement.*
    3. *To be able to solve problems and to obtain reasonable results when no clue to the solution is given, with leadership and creativity, and capacity for making decisions and managing information.*
    4. *To communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.*
    5. *To demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.*
    6. *To work effectively as a member or leader in diverse teams and in multidisciplinary projects.*
    7. *To create, select, and apply appropriate techniques, resources, and modern engineering and computer tools, including prediction and modeling, to complex engineering activities, with an understanding of the limitations.*
    8. *To speak English fluently as the lingua franca for worldwide communication and relationships as well as being able to speak correctly in other relevant worldwide languages.*

For Technical Industrial Engineering, almost all competences are similar to Chemical Engineers, but with less emphasis on knowledge, both theoretical and practical.

## NEW TEACHING/LEARNING METHODOLOGY

To switch from the traditional teaching methodology to the new one, wide-ranging modifications were carried out. The main changes, as well as the methods and resources used, are indicated below.

I. *New subject/course program: the curriculum was completely modified and extended in order to also include the specific goals and competences described above, a detailed explanation of how the continuous assessment would be carried out, and a specific and concise description of the assessed tasks, in terms of how task evaluation will be done, the contents and modus operandi of activities or tasks, and their anticipated time requirements.*

II. *Continuous assessment: all activities proposed must be included in the subject evaluation. This is very important because it does not permit the student to discard activities if they are not included in the final evaluation. It is also essential to establish the schedule of activities/tasks according to the program development. An efficient communication system is crucial to provide the final details or instructions for activities as well as for publishing the task marks and corrections. In this sense, the use of the internal University Network (Virtual Campus) was seminal for the success of the new methodology.*

III. *Teamwork activities: Contrary to the previous problem-lesson methodology, in these new activities, students must submit a complete and complex engineering problem, with correct data, correct problem description and considering all necessary points to deal with the problem, Later, each group has to solve another group's problem. In addition, apart from solving, they also have to correct the problem, give a critical opinion and propose improvements and better alternatives. The assessment of these activities should include consideration of the level of complexity, creativity and coherency of the problem proposed, and solving skills, as well as capacity for analyzing, providing argued conclusions, and suggesting improvements.*

IV. *Oral presentations and public discussions: as it is frequently a weak point among ongoing engineers, each student makes at least two presentations during the course in these subjects. Presentations have a stipulated length, normally short enough to encourage students to develop other skills or competences such as the ability to synthesize information and discern ideas or concepts. The first presentation is individual and the second is given by a group. In the group presentation, students have to choose the group's leader who will then be in charge of executing the main points of the presentation. This permits the development of leadership skills.*

V. *Using specialized software and computer solving problems: The use of specialized software is required when simulations or modeling is needed or when the problem* *solving involves extensive numerical calculations. MATLAB is the software chosen for problem simulation and modeling and for mathematical calculation solving, since it is one of the most generally used in the engineering field. The use of computers has been extensive in the engineering sphere in recent years and many references to the topic exist.*[18-20] *One group activity is designed to be carried out by using MATLAB. It consists of proposing and solving exceptionally complex problems in non-steady state and non-isothermal reactors. Computer modeling and simulation are required to determine the behavior of the system and predict the final steady state working conditions. A specific non-steady state system is given for each group and students have to develop all necessary tasks to obtain many final coherent results and the reasoned discussions of them. The use of specialized software and computers for solving engineering problems is also appropriate considering the key competences determined in the European Framework for Key Competences for Lifelong Learning.*[6, 7]

*VI. Quick tests: during the many lessons some quick tests are carried out with some different objectives.*[21] *The first one is included to provide prompt feedback of the depth of students' understanding. Secondly, it permits students to engage actively in learning. Finally, the marks obtained in these tests account for the continuous subject assessment and the final subject qualification.*

*VII. Final subject evaluation by students: Since these are the first years of the new methodology application and most of students have never been taught using this new methodology, a final subject evaluation inquiry is designed to obtain reliable feedback about students' perception of the subject. This inquiry is partially shown in Table 2.*

*VIII. Final meeting students-teachers: At the end of the course, teachers have a meeting with some students to go through the main questions and problems and discuss the main modifications, activities, tasks, etc., in order to hear the students' feelings after completing the course.*

## RESULTS

### General Results

In general, students and teachers are very positive about the new methodology. In the final meeting, it was confirmed that almost all students favored the new methodology and all of them had the feeling that they have learned more than with a conventional teaching methodology.

On the one hand, students assign high positive values to the new activities focused on developing transversal key competences such as teamwork activities and oral presentations and discussions in public. It is surprising that most of students in the fourth course of a chemical engineering degree have never given an oral presentation in public and hence had little or no experience in making presentations using specialized software (for example, PowerPoint).

On the other hand, students are not positive to the fact that the time invested in the subject has been at least doubled. It is seen as negative that quick tests force them to be concentrated and focused on the lecturer's presentation during the entire class time leaving them without a single second of relaxation. It is just these points that the students value negatively, however, that are very highly valued by professors since they are exactly what the new methodology pursues as goal. Consequently these negative points are considered to be "in the nature" of the subject. It is important to note that students realize that they cannot allow themselves to get distracted or to relax during lectures, because in subjects such as these, with a high level of abstraction, distraction is the main obstacle to effective learning.

When the new methodology was launched some students complained because some of them were professionally employed and could not attend class when activities had to be carried out. Two different timetables for all programmed activities were proposed in order to satisfy all students. The first option is the standard one and consists of carrying out the activity during the normal timetable of the subject for the majority of the students. The second one consists of carrying out the same activities but in an alternative timetable in the morning or the afternoon depending on the normal timetable of the subject. The students who were working agreed to this option and, finally, passed the subject without any problems.

The use of the internal University Network is one of the main tools for fluent communication between teachers and students. It was seen to be fundamental to the new methodology, receiving more than 1,000 visits for each course.

The time requirements on teachers that the new methodology demands has been carefully assessed. The result is that teachers must increase the time dedicated to the subject by 50% (class times and double timetable for activities are not counted in this assessment). At present, a normal subject of six credits would mean 60 hours of class and 60 hours of preparation, but with the new methodology, the time dedicated to the preparation or the correction of activities increases to a minimum of 90 hours. It also has to be considered that the time dedicated to classes also increases due to the double timetable for activities. After implementation of the new methodology, most of the extra time is invested in the correction of clickers and activities. The continuous subject assessment implies that clickers and activities must be corrected as soon as possible (one week for activities and two days for clickers). This allows the student to continuously evaluate his/her learning.

Despite the different student profiles found in the two degrees evaluated, the accomplishments of the new methodology are very similar. The trends observed in both subjects are similar: low subject quitting rates, the high assimilation of all new transversal key competences included, and the pass percentages of both subjects.

In any case, it has been demonstrated that both subjects are suitable for the new methodology and, despite different student profiles, both have been remarkably successful.

### Subject Evaluation Inquiries Results

At the end of each course, students are asked to fill out a questionnaire to determine how they value the subjects and what they think about the new methodology. As the answers given by students are similar for both subjects they are combined together in Table 2.

Results show that students are greatly satisfied with the knowledge and understanding acquired as well as with the new transversal key competences developed. The good communication and cooperation with teachers is also well appreciated by students. Oddly, almost all students think that their classmates do not like the new methodology, but at individual level, all of them answer that they are totally satisfied with it.

### Assessment of the Learning Goals and Competences Achieved by the Students

The methodologies used for the continuous assessment of the subjects as well as the final exam evaluation are designed to assess the acquisition of the established learning goals and competences by the students. To deeply assess the benefits of the new methodology proposed, however, the knowledge and new competences acquired should be also

**TABLE 2**
**Questions and General Answers**

| Questions | Answers | Comments |
|---|---|---|
| Compared to classic lecture teaching methodology, do you think that the new methodology is…. | Without exception, all students think that new is better | |
| Do you think that classes have been more interactive? | All agree that classes have been much more interactive | |
| With the new methodology, do you have an up-to-date knowledge of the subject? | All students answered that classes were more up-to-date | |
| Do you think that teamwork activities have been a good experience? | All agree that teamwork activities have been positive | |
| Would you recommend new methodology for next course? | All answer yes | |
| Give a mark to lessons | The average is 8-9 | |
| Do you think that the use of InternalNetwork (Campus Virtual) is positive? | All think that it is a very useful tool | |
| Which activity did you like the most and the least? | The most: teamwork activities; the least: Clickers | |
| What do you think about assessment system? | All think that it is appropriate | Some prefer a final exam instead of continuous assessment |
| How would you define your classmates' feelings about new methodology? | Almost all think that their classmates do not like the new methodology | On the contrary, all of them assign positive values |
| Do you think that you or your classmates would have dropped-out if classic methodology had been applied? | The majority answer no | However, it has been demonstrated that the drop-out rates have significantly decreased |
| If the subject had been taught by using classic methodology, do you think that you would have learned more? | The majority answer no | |
| Time commitment that new methodology demands compared with classic methodology is… | At least twice as much | Some students answer that it is even three times as much |
| Do you think that continuous assessment system allows you to pass the subject easily? | Many answered yes, but a few answered that it is the same as final exam evaluation | |
| Comments: How do you think that subject teaching methodology and assessment could improve? | To coordinate the subject continuous assessment with other subjects, which also use the same system. Not to use the clickers for continuous assessment. To increase the hours dedicated to problem solving. | |

reflected in subsequent subjects, being more representative than the Final Project. In this subject, the level of knowledge and the competences previously acquired are definitely demonstrated. During the last years, Prof. Sanchez has also participated as groups' tutor of the Final Project. Therefore, direct confirmation of the progress in specific abilities such as teamwork and leadership among the students has been possible. In addition, it has been determined that the number of topic-related questions regarding the design of reactors and learning outcomes that are supposed to be acquired in the particular subject of Chemical Reactors has decreased 40% in the last five years. Furthermore, the quality of the work and the deepness in detail knowledge regarding reactor design has been considerably improved. Finally, the use of specialized software has been widely and successfully adapted by the students in simultaneous and subsequent subjects such as Separation Operations, Process and Product Engineering, and Heat Transfer, among others, as well as in the Final Project, where students use MATLAB (or similar specialized software) as the main tool for designing, modeling, and simulating reactors, equipment, and even full plant operations.

## FUTURE PROPOSALS

Given the present framework of changing teaching methodologies in Spain and, in general, in Europe, we consider that it is important to publish the experience gained. It is crucial to change the minds of professors who deny their usefulness. Therefore, in our opinion, the first step is to provide new references of successful application of the methodology in subjects where previously none existed.

In a second step, the communication with students to achieve a continuous improvement of the subject is very important. Our experience has lasted five years, and in each year several modifications have been introduced, typically for the students' learning improvement. Some of them are very simple, such as having two timetables for activities or using specific software, but obviously the teacher must know the problem to correct them.

## CONCLUSIONS

The reflections, discussions, and results presented in this document support the new methodology adopted according to the Bologna Process and to the EHEA. Our experience shows that this methodology is highly beneficial to students since it increases the depth of knowledge and understanding of chemical engineering and also develops substantial transversal key competences.

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