# DESIGN AND EVALUATION OF A CHEMISTRY SUBJECT IN AN ENGINEERING DEGREE

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## ABSTRACT

The beginning of a new Degree at UPC was the opportunity to design a Chemistry subject from the start. It was designed under the criteria of focusing the process on student learning, following the indications of the last meeting of the European Higher Education Area in Rome, November 2020.

The objective of the design was to comply with the regulatory requirements and incorporate the learning outcomes that were already defined in other engineering areas, as well as to facilitate the learning of students who had not studied chemistry in high school (between 20 and 30%).

To this end, videos have been created with embedded questions, tests, summary preparation criteria, various cooperative work methodologies, ... to which part of the subject's grade (10%) has been assigned in order to facilitate student commitment to weekly completion.

Each academic year (3 normal and one in confinement have been developed) an assessment has been made with the students, both of the methodology and the material. In all cases, they reflect that continuous work and immediate or very close feedback is one of the points that has helped them the most in their process. They have also commented (in each academic year) on possibilities for improvement in which they have been directly involved and have helped to bring it to completion.

The material is currently ready to be made public on the University website and accessible to all students.


## 1 INTRODUCTION

### 1.1 Preliminary and regulatory aspects

The design of a subject for a new degree, respecting the indicators set by the ministry, is a challenge for the team of professors and entails a prior extensive search, as well as a consensus on the contents.

The Engeneering and Economics Degree (EnEcD) was born as a fusion of an Engineering Degree (EnD) and an Economics Degree (EcD). The contents of the Official Gazette of the State of Spain (BOE in Spanish) are respected. Nevertheless, the 10.5 ECTS present in Chemistry EnD (divided into two courses) are encompassed by 6 ECTS (one course), respecting the competences.

The regulations only indicate Specific Competence (SC4): ability to understand and apply the principles of basic knowledge of general Chemistry, Organic and Inorganic Chemistry and their applications in Engineering. The Learning Outcomes (LO) are:

1. Able to predict physicochemical properties based on the composition and structure of a compound.
2. Able to correlate the physicochemical properties of pure substances or mixtures with the composition and molecular and electronic structure of the components.
3. Able to solve problems analytically or numerically.
4. Able to know the use of the material and the equipment found in a chemical laboratory.

Other contents:

1. Fundamental concepts of Chemistry. Structure of matter and chemical bond.
2. Basic relationships between the structure of organic and inorganic substances and their physical properties.
3. Reactivity of organic and inorganic substances. Engineering applications.
4. Chemical laboratory, laboratory material and security.
5. Basic chemical laboratory experiments.

In addition, the faculty of the subject incorporates general skills that are specified in aspects of methodology. For this reason, in both theorical and practical lessons as well as in exams take place discussions regarding possible solutions, aspects such as versatility, initiative, adaptation to new situations, creativity, critical reasoning, ability to communicate, understanding of statements, justification of reasoning, autonomous and critical reasoning, consolidation of habits of self-discipline, self-demand and rigor, identification of the key factors of a problem, proactive attitude, continuous improvement, among others.

With all of the above mentioned, the topics, contents and LO are decided. This information is collected in Table 1.

An important point to consider is the initial heterogeneity of the students. Since a percentage of them –between 20 and 40% – do not study Chemistry in high school, they do not understand the basic concepts upon arrival at university.

After discussing "the framework topics" –the learning objectives – the learning methodology and continuous assignments are chosen. The specific learning evidence supporting this choice can be found in the perspective of the "constructive alignment" of Biggs and Tang [1].

### 1.2 Reflections on the methodology of Chemistry

In the last 20 years the concept and planning of Flipped Classroom has gained popularity at all levels of education and in all areas of knowledge, from the humanistic to the technological, including Chemistry. What is important is not the name of the methodology used and following fixed rules, but to build a framework of active learning [3]. The design of a discipline through this methodology has been extensively studied, specifically regarding the benefits it brings to student learning. The effectiveness in improving student performance is no longer discussed, because

it is evident with numerous studies that contrast it. It is worth highlighting an article by Reid, in Milwaukee, in which a global meta-analysis of student satisfaction on the flipped classroom is made, compared to traditional methodologies. They highlighted that flipped classroom had a weak-moderate positive effect on student satisfaction [4]. A recent experience (2019) with positive results in the teaching of Chemistry was carried out at the University of Sydney. They took advantage of the opportunity offered by the renewal of the curriculum to move part of the subject into the “inverted model”. Tutorials, videos and questionnaires were prepared so that students could work outside the classroom in the time not shared with the Lecturer. Moreover, guided work was planned, in pairs, in which the procedures were discussed and both the students and the Lecturer actively participated. The most remarkable aspects of this study are, on the one hand, the students' satisfaction with the learning resources and, on the other, the results, measured as final grades, which were statistically superior to those obtained in "more traditional" learning situations. The number of failures was similar or even lower [5].

Two studies analyzed the situation of an entire branch of Chemistry at country level. The first was held in Poland in 2009: It focused on Analytical Chemistry. However, it does not indicate or advise any type of methodology [6].

*Table 1: Correlation between required legal content, learning outcomes and defined topics*

| BOE content | Designed content | Topic (Chemistry) | Learning Outcomes |
|---|---|---|---|
| CE4 - Ability to understand and apply the principles of basic knowledge of general Chemistry –Organic and Inorganic Chemistry– and their applications in engineering. | | | |
| Fundamental concepts of Chemistry.<br>Structure of matter and chemical bond. | *Le Chatelier* 's principle<br>Bond. Molecular structure<br>Hybridization<br>Chemical kinetics | Topic 2 | Able to predict physicochemical properties based on the composition and structure of a compound.<br>Able to correlate the physicochemical properties of pure substances or mixtures with the composition and molecular and electronic structure of the components.<br>Able to solve problems analytically or numerically. |
| Basic relationships between the structure of organic and inorganic substances and their physical properties. | Hybridization. Link. Molecular structure<br>Functional groups in Organic Chemistry and main reactions | Topic 2<br>Topic 3 | Able to predict physicochemical properties based on the composition and structure of a compound.<br>Able of correlate the physicochemical properties of pure substances or mixtures with the composition and molecular and electronic structure of the components. |
| Reactivity of organic and inorganic substances.<br>Engineering applications. | Acid-base equilibrium<br>Precipitation and complexation equilibria<br>Oxidation-reduction equilibrium.<br>Main reactions in Organic Chemistry | Topic 1<br>Topic 4<br>Topic 5<br>Topic 3 | Able to solve problems analytically or numerically. |
| Chemical laboratory, laboratory material and security. | Specific laboratory sessions and self-study videos | Experimental practices | Able to solve problems analytically or numerically.<br>Able to know the use of the material and the apparatus found in a chemical laboratory. |
| Basic chemical laboratory experiments. | Specific laboratory sessions and self-study videos | Experimental practices | Able to solve problems analytically or numerically.<br>Able use the material and the apparatus found in a chemical laboratory. |

The second, from 2017, was published collecting the difficulties of teaching Organic Chemistry in Russian universities. As a consequence of this meta-study, global recommendations were made to all universities, but more in line with the type of knowledge to be imparted than with methodologies [7] .

Fautch, from York College of Pennsylvania, wonders whether the flipped classroom is effective in small groups for teaching Organic Chemistry. He concludes that the students who worked with the flipped classroom felt "more comfortable" with Organic Chemistry and even became passionate about the subject, which leads him to conclude that the flipped classroom is an effective tool for teaching Organic Chemistry [8] .

In 2016, Eichler and Junelyn Peeples of the University of California-Riverside and of Claremont University Consortium, respectively [9] comment on the large proportion of Lectures in the areas of knowledge of Science, Technology, Engineering and Mathematics that continue to use the so-called master classes or expository classes, focused on what the Lectures does.

One aspect to be highlighted, due to the effort it can save teachers who want to use this methodology, is the use of videos from Khan Academia, which greatly simplifies teacher preparation. In addition, small guides and a support book are provided.

## 2 METHODOLOGY

### 2.1 Chemistry design for engineers

With all the background described, the faculty designs the subject, focusing on student learning and student autonomous work. Hence, there are two key aspects to be considered: (1) integrate the constructive alignment in the contents, methodologies and evaluation; (2) unite the three aspects from which Chemistry can be approached (macro, micro and symbolic) in the development of problems in the classroom and outside it. Figure 1 shows a global scheme of this development.

### 2.2 Contents

In the fifth iteration, which is the one presented here, Chemistry has been distributed in five topics. Three of them are associated with the first semester and two of them with the second semester of the previous grade.

The topics are the following ones:

Theme 1. Acid-base equilibrium (5 sessions + 1 continuous evaluation).

Theme 2. Descriptive Chemistry (4 sessions):

Bond. Molecular structure. Hybridization. Chemical kinetics. Le Chatelier 's principle.

Theme 3. Introduction to Organic Chemistry. Basic organic reactions (4 sessions and mid-term exam).

Theme 4. Precipitation and Complexation Equilibrium. Heterogeneous systems (5 sessions).

Theme 5. Oxidation-reduction equilibrium (5 sessions + 1 continuous assignment).

Presentation by teams: 1 session ; and Lab Practices: 2 sessions

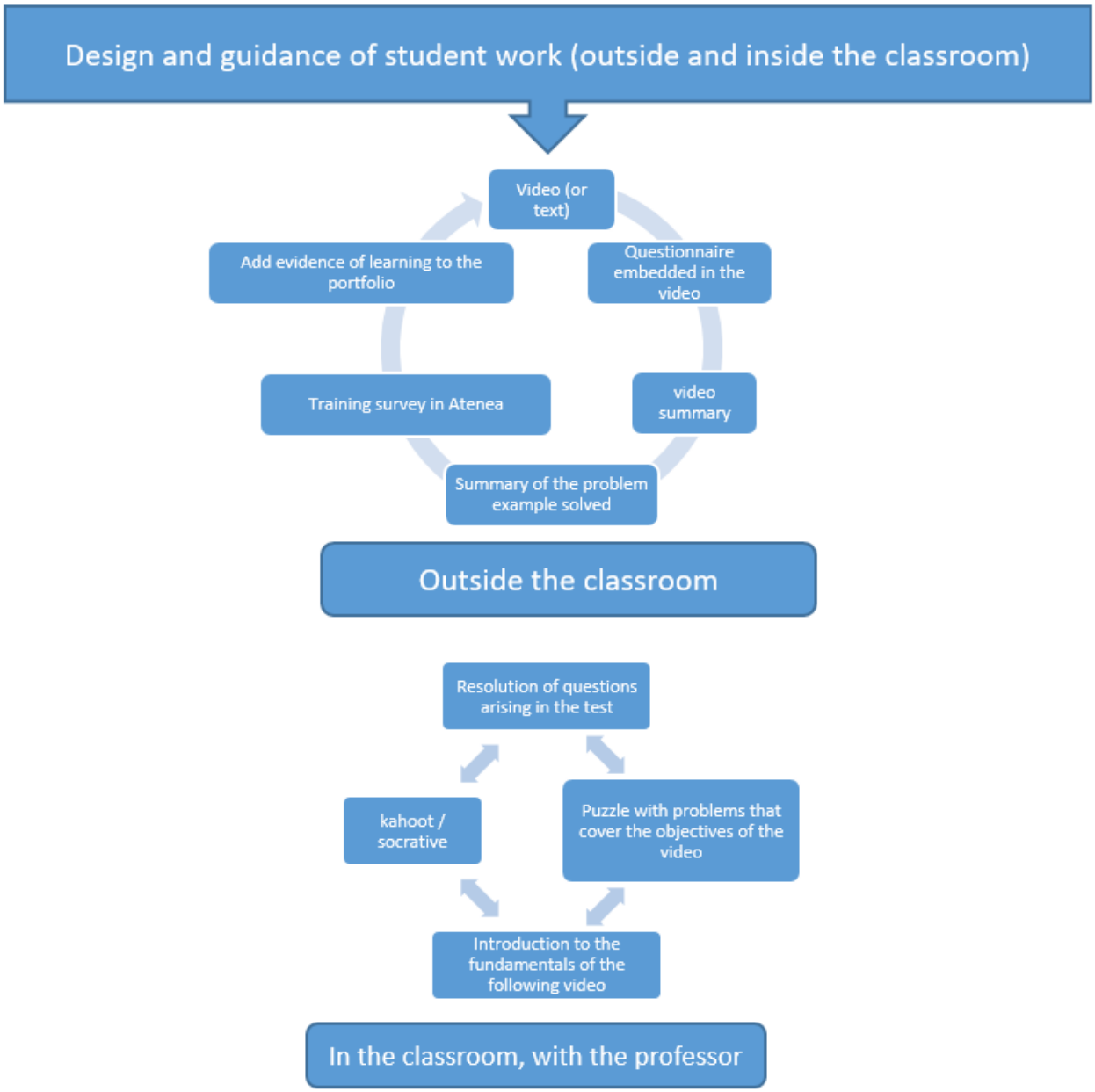


*Fig. 1. Global scheme of planning inside and outside the classroom*

The global evaluation is based on Eq.1:

10%CA1 + 10%CA2 + 25%mid-term exam + 10%(Portfolio+tests+lab practices) + 35%final exam (Eq.1)

being CA: continuous assignment.

The portfolio must be done weekly; the weekly deliveries must be reflected, especially summaries, exercises done in groups, the reasoning, the evidence of learning...

For this reason, it has been decided to evaluate the portfolio as a continuous work of the course, which will be posted on Moodle platform and can be consulted at any time, especially useful for those students who struggle with exams. As the tests are "self-corrected", the professor's time is optimized and so it can be spend teaching.

With the idea of bringing together the three aspects from which Chemistry can be analyzed (macro, micro and symbolic) the statements of some problems have been changed. For example, transforming a typical pH calculation problem in a buffer solution with certain data into a laboratory video in which the same data is explicit in the footage, with a final question mark on the pH meter screen.

## 3 RESULTS

### 3.1 General comments

Figure 2 represents the evolution of grades throughout these 4 academic years. No student failed the subject during the first year, with 1 during the second year and 5 in both the third and the fourth. Nevertheless, the most remarkable feature is the increase in good grades as the methodology of the subject improves due to the enhancement of the aspects collected in the surveys with the students.

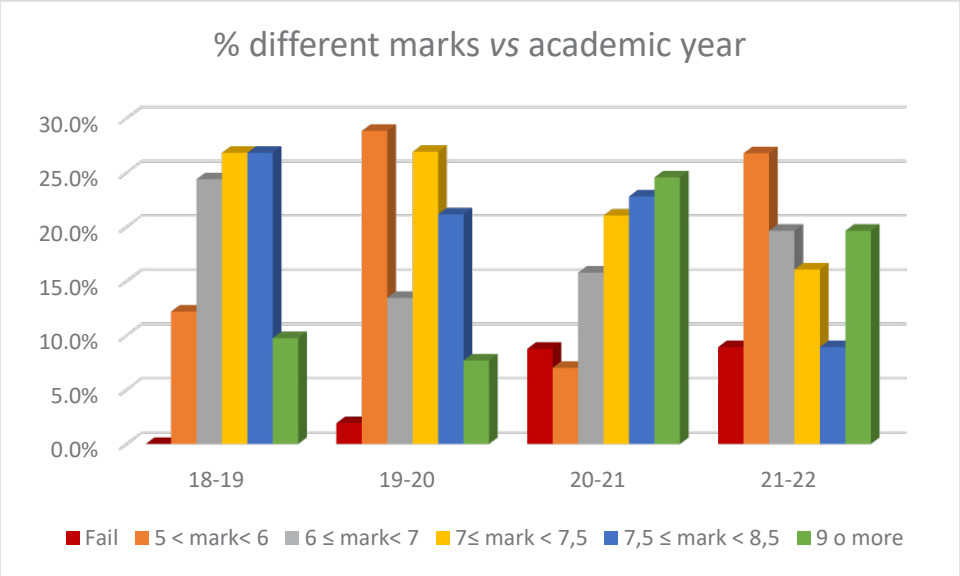


*Fig. 2. Grade distribution (number of students vs intervals) in each academic year*

The EnEcD entry mark requirement was 12.102/14 (18-19), 12.024/14 (19-20), 12.516/14 (20-21), 12.548/14 (21-22). These data indicate that it is a degree highly requested by students, which implies that only the best among those who have applied for it can enter. This allows for a high level of rigorousness that, for the most part, the students can keep up with. The decrease in the entry mark requirement from the first to the second year is due to an increase in the number of places.

In general, the marks obtained by the students are slightly higher (with non-significant differences except for the last academic year) than those obtained in the rest of the subjects. Nevertheless, learning satisfaction (manifested in the different surveys that have been given to the students) and the class attendance is much higher.

### 3.2 Course 18-19

It is perceived that after the half-term exam there is a general discouragement, not focused on Chemistry but on EnEcD. One of the advantages that active

methodologies bring is continuous teacher-student contact, which allows for conversations that facilitate understanding of student behavior from a more anthropological perspective. For this reason, the possibility of personalized teacher-student tutoring is proposed to improve performance. 74% of students make use of academic tutoring.

An anonymous survey was carried out to the students, and the possible improvements for the following course were obtained:

a. Improvement and standardization of the documentation given to students.

b. Homogeneous weekly structuring, without work delivery between classes with only one day in between.

c. Elimination of deliveries of solved problems prior to joint work with the teacher.

d. As a strong point of the first definition of the subject, the students are able to work in group, which they value positively and consider that it helped them to get into the degree itself and to resolve their doubts.

e. Another positive aspect are class presentations made by students, carefully prepared by them and that allow to teach theoretical aspects in a more attractive and dynamic way.

Administrative questions via email student-professors are constant. It is decided to create a document with Frequently Asked Questions (FAQ) that will be explained on the first day and will be posted on Moodle Platform.

### 3.3 Course 19-20

As in the previous course, an anonymous survey was passed through Google Forms in which students had to reflect on the aspects that had helped them in learning and those that they believed could help them if present. One of the most valued aspects was the introduction of laboratory practices, and, again, group work. They value doubt-resolution classes very positively (73%) and they think that it played a role as far as passing the exam is concerned. Nevertheless, they still claim to better plan work outside the classroom (57% of students).

### 3.4 Course 20-21

Laboratory practices are expanded and re-planned so volunteer students (with good performance and previous laboratory experience in high school) act as mentors. This is the year of lockdown, so it had a different structure (which is not the subject of this paper). Most of the classes were online, with the exception of laboratory practices, which were obviously face-to-face. It should be noted that attendance at online classes (mostly problem solving and doubts) was between 70% and 95% (far superior to the rest of the subjects in which the percentage of connected students did not exceed 40%).

The rest of the planned asynchronous activities are maintained: (1) viewing of videos to which embedded questions have been incorporated; (2) weekly tests. The first two exams (first continuous assignment and half-term exam) were carried out online. To

avoid student cheating in the exam, the time frames are adjusted downwards and random problems are generated. The next two exams were done face-to-face.

The average mark is 7.3, almost one point higher than the previous year, even though the data of the entry students were very similar. These results, which are slightly higher from those obtained in previous courses, are attributed to the fact that exams were carried out online and also to the fact that there was an increase in motivation compared to other subjects that entail greater dedication, both due to the interaction in the laboratory practices such as continuous feed back with students.

### 3.5 Course 21-22

The survey of the previous course reflects that the improvements introduced have been successful. For this reason, the improvements introduced focus on the aspects that the team of teachers perceive as improvable, since the students value the methodology and continuous evaluation very positively.

The subjective perception was that, in general, the subject was difficult to keep up with. However, the objective data, the grades, show that they are quite consistent with those obtained in pre-pandemic academic courses.

Class attendance was one of the poorest in this subject, around 70%. Nevertheless, it is a good result compared to the rest of subjects (it does not reach 40%). Often, those who miss classes the most present a higher level of disengagement and with the worst grades, so it is difficult to influence their learning process.

It is important to notice that all the improvements were developed with the students' help.

## 4 SUMMARY AND ACKNOWLEDGMENTS

This paper is not conceived as a final product, but as a step that reflects the planning and monitoring intended to be continued in the subject. The design of a subject must be dynamic and adapted to upcoming situations.
Highlights:
1. The content that students work on when they are not synchronous with the Lecturer must be fully designed. This content incorporates individual and group activities. Specifically, twelve videos have been prepared and many other ones have been selected (many of them from Khan Academia). In addition, documents, self-study tests and templates for weekly summaries have been written.
2. Self -assessment and continuous assessment have been integrated into the design of the subject, increased the number of tests taken in previous years and incorporating videos and new learning material instead of traditional learning.
3. Initial lessons of key concepts of chemistry taught in high school have been planned, to give response to the need of basic knowledge for those students who have never studied chemistry before. This is crucial for students to be able to keep up with the subject optimally.
4. Perhaps, the most important conclusion is that the implementation of a subject by Flipped Classroom requires much more effort and hours of work on the part of the

faculty than the definition of a subject focused on the explanations of the professor, and it is difficult to do in less than four years.
5. A qualification of the subject has been foreseen that counts the continuous effort collected in the electronic portfolio, as well as two continuous assignments (of a conceptual nature and similar to the self-study tests), a half-term exam and a final one that will have to show the mastery of macromolecular and symbolic chemistry and the ability to resolve everyday life situations.
6. The methodology has been used almost equally during the quarantine and results were similar. Nonetheless, the number of exceeding students rose slightly compared to previous years.
This document focuses on the design of a chemistry subject, in which the learning outcomes have been chosen and, based on them, all the necessary material has been designed using the flipped classroom methodology. The entire methodology is applicable to any subject, both newly designed and those that want to be redesigned.

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