DESIGN AND IMPLEMENTATION OF NON-CLASSROOM SUPPORTIVE ACTIVITIES FOR A BASIC LABORATORY COURSE IN THE CHEMISTRY AND ENGINEERING CHEMISTRY DEGREES AT THE UNIVERSITY OF THE BASQUE COUNTRY

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Abstract

In this article, we describe and analyze some curricular experiments using Information and Communications Technology (ICT) such as editing videos, responding to multiple-choice questions in the form of handouts distributed through a computer platform and sharing lab notebooks among students, all of which have been performed at the University of the Basque Country. We focus on Basic Laboratory Operations, which is an essential subject that accounts for 6 ECTS and is taught during the fall semester of the BSc in Chemistry and the BSc in Chemical Engineering in the Faculty of Science and Technology.

Keywords: chemistry laboratory, learning audiovisual support, educational innovation experience, Information and Communications Technology, self-learning material.

1 INTRODUCTION

Information and Communications Technology (ICT) is a widely used tool to improve teaching-learning process in the context of a higher degree in Education [1]. In this article, we describe and analyze some curricular experiments using ICTs at the University of the Basque Country. We focus on Basic Laboratory Operations, which is an essential subject that accounts for 6 ECTS and is taught during the fall semester of the first year in the Chemistry and Chemical Engineering Degrees in the Faculty of Science and Technology. The authors have surveyed around 80 students of both degrees. The methodology of the course is planned as depicted in Fig. 1: seminars (0.2 ECTS), class practice (1.4 ECTS) and laboratory sessions (4.4 ECTS).

![Figure 1. Methodology used in the Basic Laboratory Operations subject.](image-url)
The main objective of the course program is for the students to achieve meaningful learning in the field of basic operations performed in a chemical laboratory, and to develop the specific competences of the subject, as well as the specific and transversal competences typical of the fundamental modules of both Chemistry and Chemical Engineering that appear in Table 1.

**Table 1. Specific competences of the subject (SC) and of the basic module (MC).**

<table>
<thead>
<tr>
<th>SC1</th>
<th>SC2</th>
<th>SC3</th>
<th>SC4</th>
<th>SC5</th>
<th>SC6</th>
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<tbody>
<tr>
<td>Demonstrating knowledge of the instruments, the simplest equipment and the basic usual techniques in any chemical laboratory, as well as being aware of how to use them safely.</td>
<td>Knowing what the basic safety standards in a chemical laboratory are and how to safely handle chemicals and waste generated.</td>
<td>Being able to explain in a comprehensible way the phenomena and processes related to Chemistry and other adjacent areas of knowledge.</td>
<td>Being able to observe, analyze and present one’s results in the field of Chemistry and other experimental sciences.</td>
<td>Knowing how to use various experimental sciences to understand chemical phenomena.</td>
<td>Knowing how to access and use the most common sources of information and documentation in experimental sciences.</td>
</tr>
<tr>
<td>MC01</td>
<td>MC02</td>
<td>MC03</td>
<td>MC04</td>
<td>MC05</td>
<td>MC06</td>
</tr>
<tr>
<td>Understanding and being able to manage the chemical language and the principles of formulation of chemical substances.</td>
<td>Understanding and being able to handle the principles and basic theory of the chemical reaction of different types of substances.</td>
<td>Knowing how to safely use the usual means and techniques of laboratory work.</td>
<td>Being able to observe, analyze and present one’s results in the field of Chemistry and other experimental sciences.</td>
<td>Knowing how to use various experimental sciences to understand chemical phenomena.</td>
<td>Knowing how to use various styles of referring to scientific literature in oral and written communication.</td>
</tr>
<tr>
<td>MC07</td>
<td></td>
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<tr>
<td>Knowing how to access and use the most common sources of information and documentation in experimental sciences.</td>
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</table>

Seminars and class practice are used to explain theoretical aspects, do typical exercises and provide instructions concerning lab experiments. During the laboratory sessions the experimental work aims to provide the skills related to the handling of the basic labware and to the performance of routine procedures requiring strict implementation of laboratory safety regulations.

The classical philosophy of teaching in experimental subjects is based on cooperative learning. Thus, experimental activities are usually carried out in pairs so that the knowledge and skills required for their development not only follow teacher-student dynamics but also student-student dynamics. This gives the teachers the advantage of being able to correct the errors which usually tend to get unnoticed, but which are often put in evidence thanks to the constant presence of a fellow student.

However, the experimental subjects also present a series of disadvantages largely related to non-classroom work and to the temporal limitation of practical sessions. The first disadvantage is due to the limitations of non-classroom work. Students have the written guidelines of the following class practice prior to each session, however, due to their lack of experience the test may be somewhat abstract and difficult to understand. In addition, due to the long duration of such tests, which in certain cases can be extended over several sessions, students forget the details or visual information relevant to the evaluation of the results. The second disadvantage concerns the limitation of the experiments because, despite the long duration of the practical sessions, the number of tests performed is limited. This sometimes means that students do not internalize the experimental procedures since it is evident that it is not possible to replicate tests outside the laboratory or to make modifications in the experiments performed. There is a third drawback that lies not in the experimental nature of the program but rather in the classical teaching methodology. The teaching of inorganic and organic
chemistry through practical tests usually consists of providing written guidelines of class practice where the procedure to be followed is well established. This, however, often fosters in students a passive attitude and the absence of reflection, negatively affecting their learning.

2 METHODOLOGY

2.1 Assessment of educational needs

As mentioned above, the subject of Basic Laboratory Operations has a predominantly experimental character which entails certain disadvantages in the teaching-learning process.

The three disadvantages mentioned suggest a limitation to a greater or lesser extent in the development of all the specific and transversal competences of the subject and the fundamental module of the Chemical and Chemical Engineering degrees.

It is for this reason that substantial modifications have been made in the methodology used in order to overcome the limitations imposed by the experimental nature of the subject, which implies a temporal limitation of practical sessions. Likewise, in comparison with more theoretical subjects where the activities carried out can be repeated autonomously as many times as needed, non-classroom work in this type of experimental subjects is hampered by the limited availability of the teaching laboratories.

2.2 Selection of learning strategies

The main objective of this experience of educational innovation has been to overcome the aforementioned limitations allowing a better development of the specific and transversal competences. After analyzing the causes that prevented a correct learning of the basic operations that are developed in a chemical laboratory, we selected the following learning strategies:

- Implementation of ICTs to promote non-classroom teaching through the instructional videos edited by teachers.
- Implementation of ICTs to promote the development of transversal competences through the videos edited by the students on specific topics of the subject.
- Implementation of ICTs to independently assess the degree of learning achieved by the students through the completion of online questionnaires prepared by the faculty.
- Cooperative learning through the laboratory notebook.

That is to say, there has been an attempt to solve the restrictions imposed by the space-time limitation making use of ICTs and of active and cooperative teaching methodologies that promote an autonomous and significant learning among the students.

The integration of information and communication technologies into training processes is a necessary development in today’s society as a consequence of the change undergone by higher education in recent years [2].

In addition, one of the fundamental tools of all experimental teaching is the laboratory notebook. This subject familiarizes the students with the need to elaborate this notebook conscientiously, meanwhile providing all the necessary data which could be later used both to gather information and to allow the reproduction of certain experiments by third parties. In many cases students lose the sense of usefulness of this notebook and instead seem to focus only on its function as an assessible activity of the subject. This activity is included within cooperative learning processes, since it has been widely studied that peers get to understand the material better than with the same explanation presented by the teacher [3].

2.3 Implementation of learning strategies

In the first phase of the present experiment we have used ICTs to encourage non-classroom teaching in the first practical sessions. Thus, the teachers have developed digital material, recorded and edited educational videos related to the basic operations used in inorganic and organic chemistry, together with some experimental trials, additional processes and tests to carry out. The material prepared has been made available to the students in the eGela computer platform [4] and on YouTube, and can be
accessed before and after the practical sessions, which facilitates the solving of the limitations related to non-classroom work (Figure 2).

**Figure 2. Audiovisual material of the subject of Basic Operations of the Laboratory.**

Another strategy has been the use of the multiple-choice questions handout distributed through the computer platform to check that the students have read and fully understood the theoretical aspects of the experiments prior to the lab session (Figure 3).

**Figure 3. Example of an online multiple choice test that has been used as an educational resource in the UPV/EHU eGela virtual platform.**

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**BASIC OPERATION MOVIES**

1. Weighing chemical substances.
2. Gravity filtration.
3. Vacuum filtration.
4. Making a solution of an exact concentration out of solid substances.
5. Making a solution of an exact concentration out of liquid substances.
7. Bunsen burner.
8. Reflux.
9. Liquid-liquid extraction.
10. Rotary evaporator.
11. Crystallization.
12. Distillation.
13. Thin-layer chromatography.
In the second phase of our experiment we have used ICTs to encourage the development of transversal competences in the last practical sessions. The experience of the first sessions and the associated digital material developed by the teachers has served as a basis for the students to elaborate their own digital material on the last practical sessions. In this phase, students develop competences related to ICTs and learn about the possibilities offered to them as future professionals. For example, the relevance of audiovisual data as data support in an experiment and the possibility of knowledge dissemination and exchange.

Likewise, in order to make the students aware of the real importance of the laboratory notebook and avoid focusing on it solely as an evaluation tool, a small blind activity was designed in which the students had to reproduce a particular experiment from the notes taken by another unidentified student. The students had to write a small report of the deficiencies and strengths of the used extract of the laboratory notebook in order to be able to offer external feedback apart from the teacher’s. In this way, we hope that students not only acquire the capacity to produce a useful and practical laboratory notebook, but above all that this capacity will become a habit.

The implementation of the learning strategies is summarized in Figure 4, which makes evident the great improvement of figures made during the 2016/2017 course, leading to an increase in students’ self-learning.

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![Diagram](image)

*Figure 4. Comparison of the teaching-learning process of the previous courses and the 2016/2017 course.*
3 RESULTS

The produced digital material, educational videos on basic operations used in inorganic and organic chemistry, and the videos related to the experimental trials, additional tests and processes to carry out, have been of great help to the students since they have overcome the limitations that non-classroom work entails. This way, students can consult the experiments to be carried out as many times as they see fit, perceiving initially difficult experimental tests as more comprehensible, feasible and familiar tasks.

In addition, the experience of the first sessions and the associated digital material developed by the teachers have served as a basis for the students to prepare their own digital material on the last practical sessions. The predisposition of the current students towards the use of digital tools has had an impact on their attitude towards these new practices. The teachers have noted the students’ high motivation for designing and preparing experiments in the development of digital material. This way, the students have not only acquired the specific competences of the subject, but also developed those related to ICTs and active and cooperative work.

Furthermore, the use of multiple-choice questions distributed via the computer platform to check that the students have read and fully understood the theoretical aspects of the experiments prior to the lab session has proved to be a positive experience, since there has been a greater involvement on the part of the students in the preliminary preparation before the laboratory session. This, in turn, has resulted in a significant improvement of the corresponding qualifications, especially in the part corresponding to individual work. On the other hand, given that students know and understand the basic aspects of the class practice before its realization, there is a better internalization of all the relevant and new aspects that are emerging throughout the experimental session. There is a more homogeneous rhythm and dynamics in the whole group of students, too.

Moreover, in this subject, it is also very relevant to transcript the experimental procedures and results into a lab notebook that can be checked anytime in the future. Its relevance has been transmitted through the act of sharing lab notebooks among the students in which they are required to perform an experimental task based on the data supplied by a fellow student. This way, the students have been made aware of the importance of recording details in the notebook, as well as of providing efficient annotations since the failure to do so often results in the failure to reproduce the experiments.

The influence of the assessment methods and innovation used in both study degrees has been analyzed in the grading scale below. Figures 5, 6 and 7 show the average grades obtained in the subject in each of the degree programs, as well as the percentage of students in different grade ranges. The analysis has been carried out from the 2011/12 academic year up to the current course.

![Figure 5. (a) Evolution of the average grade (scale 0-10) and (b) the percentage of Chemistry students between the 2011/12 and 2016/17 study courses who failed (<5), got a satisfactory (5-7), very good (7-9) and excellent (9-10) grade.](image-url)
Figure 6. (a) Evolution of the average grade (scale 0-10) and (b) the percentage of Chemical Engineering students between the 2011/12 and 2016/17 study courses who failed (<5), got a satisfactory (5-7), very good (7-9) and excellent (9-10) grade.

Figure 7. (a) Evolution of the average grade (scale 0-10) and (b) the percentage of the total number of Chemistry and Chemical Engineering students between the 2011/12 and 2016/17 study courses who failed (<5), got a satisfactory (5-7), very good (7-9) and excellent (9-10) grade.

We can observe a slight increase in the average grade (6.8 on a scale of 0-10) for both the Chemistry and Chemical Engineering degrees, alongside an increase in the number of grades above 7 - “very good” and “excellent” - and a drop in the number of grades below 5, which means a fail (Figure 7).

In the specific case of the degree in Chemistry, in addition to the slight increase in the average grade (6.9) with respect to the previous course years, it is worth pointing out a considerable increase in the number of “very good” grades (7-9), as well as a decrease in the number of borderline grades and fails, which, on the whole, means a decrease in grades below 7 (Figure 5).

The results obtained from the students’ qualifications in the Chemical Engineering degree are quite similar (Figure 6). There has been an increase in the average grade (6.8) compared to the last 5 years, as well as an increase in the number of “very good” and “excellent” grades (> 7), together with a decrease in the number of fails and grades below 7. This small decrease in the average grade among the students in Chemical Engineering, as opposed to that of the students in Chemistry could be related to two differentiating facts. On the one hand, the average grades in high school (Bachillerato) obtained by the students enrolled in Chemistry are superior to those of the students enrolled in Chemical Engineering (Table 2), which is reflected in the slight increase of the average mark and, above all, in the higher percentage of the “excellent” marks obtained. On the other hand, it is assumed that a subject with a clear experimental content in the chemical laboratory will generate greater affinity and predisposition among the students enrolled in Chemistry than those enrolled in Engineering.

Table 2. Minimum entry grade in the last few years among the students enrolled in both degrees.

<table>
<thead>
<tr>
<th></th>
<th>2014/15</th>
<th>2015/16</th>
<th>2016/17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry</td>
<td>7.8</td>
<td>8.1</td>
<td>8.5</td>
</tr>
<tr>
<td>Chemical</td>
<td>7.3</td>
<td>6.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Engineering</td>
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</table>
After studying the evolution of grades in the last five years, it has been concluded that formative assessment and feedback can be an important tool to enhance the first-year experience and enable the students to develop necessary skills for self-regulated learning.

4 CONCLUSIONS

The work presented in this paper consisted in designing and developing a teaching innovation experience oriented to the integration of ICTs and participative and cooperative methodologies for the students taking Basic Laboratory Operations as a subject in the Chemistry and Chemical Engineering Degrees. The teachers have developed digital material in an attempt to solve the limitations associated with a totally practical subject. The students have also participated in the elaboration of the aforementioned material, which has allowed their integration in the learning process, consequently leading to an increase in their motivation and participation in the subject. On the other hand, cooperative work has been implemented in the preparation of the laboratory notebook in order to demonstrate its importance in the daily work of a future chemist.

The influence of the assessment methods, as well as the innovation used in both degrees, has been analyzed in the grading scale. After studying the evolution of grades in the last five years, it has been concluded that formative assessment and feedback can be an important tool to enhance the first-year experience and enable students to develop necessary skills for self-regulated learning.

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