PROJECT-BASED LEARNING IN CHEMISTRY: THE ROAD FROM HIGHER EDUCATION TO APPLIED RESEARCH

Á. Berenguer-Murcia, R. Ruiz-Rosas, R. Torregrosa-Maciá, A. Bueno-López, D. Lozano-Castelló

Instituto de Materiales, Departamento de Química Inorgánica, Universidad de Alicante (SPAIN)

Abstract

With the Formative Evaluation model founded on project based learning that we propose in this work a student may develop, throughout the duration of practical laboratory teaching which comprises a significant number of hours invested in laboratory demonstrations, a given "project" with concise teaching objectives and solid formative background (as determined by the corresponding teaching staff) that involves the development of diverse skills. By using the term "project" we mean a set of coordinated and intertwined activities of both theoretical and practical character with specific objectives that aim to potentiate the learning of knowledge and skills in the student that may be of great help in his/her development, personal realization, and future professional practice. From a broad perspective, they may be considered small research projects.

Keywords: Formative Evaluation, Laboratory, Interdisciplinary Chemistry, Skills, Project-Based Learning.

1 INTRODUCTION

Adapting the teaching techniques in subjects with a high degree of practical learning to the demands of the European Higher Education Area (EHEA) demands a significant change in focus, especially since students will go from a strong dependence from their teachers to the opposite situation in which students will enjoy an almost complete independence with the teacher’s guidance. From our perspective, this matter can be tackled in a satisfactory manner with a course of action that will allow the student to develop a series of skills which will be very useful for his/her future as a professional or academic researcher.

One of the main hurdles that science higher education students bear is the apparent lack of connection between what they are told in the lecture theatres and what they are shown in the practical laboratories, resulting in a mismatch between what they know and what industry or the labour market wants them to know. The objective of this work is to put forward and explore the possibility of applying a Formative Evaluation [1] process through the application of Project-Based Learning [2] in the Degree of Chemistry within the framework of subjects with a high degree of investment in practical laboratory teaching, with a protocol that may be applicable in different disciplines of Chemistry (be it Organic, Inorganic, Analytical, etc.). This should provide a means for the lecturer to nurture students in subjects which albeit increasingly popular during the past few years, are somewhat disconnected from what is actually taught in the classrooms, and for students to become acquainted with state-of-the-art research which will help them apply the knowledge acquired during the course of the subject from a both practical and applied perspective, thus allowing them to pave their way between academia and research.

2 METHODOLOGY

We start from the basis that a student can develop, by means of the development of a practical lab which invests a significant number of hours in demonstrations, a given "research project" based on current literature with clear learning objectives which should furthermore be committed to a strong teaching drive and which encompass the development of different skills related to the degree which is being taught (in this particular case we will focus on Science, and more specifically on Chemistry). The methodology that we will thus attempt to follow for the development of the so-called "projects" is the one described and exemplified below. The methodology that follows refers to a subject which has a large practical component (i.e. with a significant percentage of laboratory practice ECTS credits) within
the Degree in Chemistry, but this method is perfectly transferable to other disciplines with enough practical workload.

2.1 Project development

1 At the start of the subject, the academic staff will select suitable research articles and distribute them among the students (as many research articles as research projects). The number of projects will initially depend on the number of students, on the capacity of the laboratory facilities, and on the techniques and materials available in the laboratory. It is important to note that depending on the year of the students the literature distributed will be more descriptive (e.g. providing articles from the Journal of Chemical Education for first year students or articles from the Journal of Catalysis to third year students). A suitable estimate would be to establish a project per student in group of less than 10 students and a more challenging project per couple for groups having more than 10 students, but the methodology can be flexible in this respect. Larger student groups may require the laying down of even more far-fetched projects for three or four students at a time (t=0). The first one or two practical sessions will be employed in reading and commenting on the research articles with the lecturer with the aim to comprehend the foundations of each and every project, which are the teaching and skill learning objectives, and how they may be achieved within the allotted timeframe and facilities. To reach this goal, the students will also be also given a list with the materials to be found in the lab, both instrumental equipment and consumables (reagents and glassware), as well a list with the University of Alicante (or any other centre, where applicable) technical services at their disposal. The research facilities in fact will be divided into departmental (those directly depending on the department responsible for teaching the subject, which are prone to have a more flexible and accessible schedule) and general (those depending from the University itself, which a fixed schedule). This/these session(s) will constitute a sort of “kick-off meeting” for the projects, and will be held with the primary main goal of becoming familiarized with all the students and explaining the development of the subject and what is expected during the course of the project.

2 The “researchers” will elaborate a workplan based on the literature given with the help of the academic staff. This task may be carried out in a remote learning way by making use of a platform similar to Moodle (University of Alicante Virtual Campus). At this point it will be key to support and value not only the working capability of each student as an individual, but the lecturer/professor will also encourage students to work on joint projects to foment teamwork. For example, if two students or groups of students are assigned two different projects entitled “Preparation of metallic catalysts on ceramics: Influence of the (in)organic precursor” and “Preparation of metallic catalysts on ceramics: Influence of the treatment temperature”, said students or groups of students should be able to design synthetic shared strategies, as well as characterization studies that will allow to extract overlapping and complementary information which will be useful for both. Once the plan is drafted and upon agreement of the lecturer/professor responsible, the students may now move on to the carrying out of the project per se in the laboratory equipped and readied to such end (t_F1). During this phase, and always under the supervision of the lecturer (on-site learning and hands-on help) the synthetic strategies for the successful preparation of the selected materials will be developed. It is important to put the emphasis on the fact that students must not (or should not) merely copy and follow a synthetic recipe that they have read in a research article, but have to adapt the synthetic strategies found in the research papers to the means available in the teaching laboratories. Obviously, the academic staff will be responsible for selecting the projects/articles more suited for the students to adapt the so-called “recipes” using their previously acquired knowledge and with help from the tutors, as well as the articles that better fit the instrumental apparatus available in the laboratories.

3 Once the syntheses of all the materials associated to the research Project have finished (t_F2), different characterization techniques will be employed in order to establish the physico-chemical, catalytic, textural, and spectroscopic properties of the prepared materials. In order to do this we will make use of the equipment available in the teaching laboratories (in which the student will operate the apparatus under the tutors’ supervision), the research training labs of the teaching staff responsible for the subject (in which the teaching staff will demonstrate the use of the apparatus in the presence of the students), and the university technical&research services (in which the specialist technician responsible for each technique will operate the apparatus while the students oversees the analysis process, granting them a significant power of decision over what and how to do). In this sense, the scope of this phase is to become semi-
on site learning. Proceeding in this manner, our goal is for the student to attain self-confidence in the operation and managing of basic instrumental equipment of general use available in laboratories worldwide, as well as free access to advanced instrumental techniques that may be of great in their future professional and/or research career.

4 Once the characterization phase is finished ($t_{F3}$), the student, with the help from the academic staff by video conference and web 2.0 (Facebook and Twitter) and Moodle tools, will have to prepare a slide presentation of the obtained results (preferred tools will be Powerpoint, Prezi or Slideshare), ordered with the structure we would usually find in a scientific article. The defence of this presentation will constitute the end of the subject ($t_{F4}$). In this respect, it will be important that the student is capable of:
- Assimilate the concepts put forward in the project
- Develop and support a workplan which is coherent with the available means and knowledge of the student(s)
- Correctly interpret the research results and critically compare them with those available in the literature
- Present, discuss, and defend his results in front of a "novel" audience

The chronology of the different stages may be found in the following timeline

![Timeline](image)

*Figure 1: Timeline describing the proposed project-based formative evaluation process. The interphase between Stages 2&3 is marked with a dashed line to represent the coexistence of both stages in the period between $t_{F1}$ and $t_{F2}$. The yellow arrows represent the possible moments and intervals at which the students will interact most with the academic staff in order to seek advice and/or guidance. The faded region under stages 2 and 3 represents the stage during which the students should require less guidance.*

The three stages and student acting modes will be formed in the following way, as illustrated in Figure 2:

- Planning level ($t=0$ to $t_{F1}$): Off-site learning mode (with the possible exception of the first two sessions). It is expected that at this stage the students will require frequent advice from the lecturer in order to fully understand the research articles handed to them. The students may also need a detailed walkthrough of the lab in order to become familiarized with an environment in which they will need to spend a significant amount of time.
- Preparation stage ($t_{F1}$ to $t_{F3}$): On-site learning mode.
- Characterization and results analysis stage ($t_{F2}$ to $t_{F4}$): Semi-on site learning mode.
2.2 Evaluation

Evaluation of the students will be made in the context framework of the European Higher Education Area (EHEA). Thus, it must be performed on the basis of the skills acquired during the course of the subject within the scope of the given subject. In this sense, the EHEA implies, with its new skill dimensionality, a challenge for the academic staff at the time of the evaluation-marking-grading for each student. According to McClelland [3] only the skills of the students should be judged independent from their intelligence. Intelligence, according to the author, is a potential capability while a skill is a capability referred to an observable behaviour that is carried out in the professional practice. In other words, skills are referred to what a person knows and may perform under certain circumstances at a given location. This effectively means that they result from a combination of knowledge, capabilities and personal characteristics (attitudes, traits, values, and beliefs) that enable practical realization in an efficient way.

For this reason we understand that evaluation is only valid if carried out through continuous observation of the student. In this manner of acting evaluation by one single grade or by means of a final exam is completely skipped. The final mark will come from the quantification of the following evaluating elements:

1. At the end of each stage of the project, the student(s) must hand in a report for the academic staff to judge the evolution of the research project. In the report not only the technical characteristics of the research will be contemplated, but also special emphasis will be put on the discussion and explanation in a reasoned way of those aspects which may become a significant drawback in the advancement of the project. In this sense, identification of these hurdles will be a very important item to evaluate. This latter aspect will of course include the socio-economic aspects derived from working in groups. These reports, supported by the final presentation of the project as explained above, will form an evaluating element of great importance. This part will constitute 50% of the final grade.

2. On the other hand, by means of their continuous tutoring, the academic staff will be able to determine the degree of progress of the students with respect to their starting level (at the beginning of the subject) as a function of:
   - degree of fulfillment of the objectives drafted in the project
individual evolution considering the starting capabilities/abilities of each student

personal contribution to the contents of the subject as a whole

The mark of this section will correspond to the remaining 50% of the final grade.

2.3 Expected results

In general terms, the most desirable result from a teaching process at University level is that the student, once his/her formative period comes to an end, is in a position to enter the labour market with a total guarantee of success. If we understand this as a good starting point, then it is logical to reach the conclusion that the teaching process must be directed towards acquiring these skills, which stand out as necessary in the professional world. With this meaning and no other, we present our main train of thought of our project on Laboratories Formative Evaluation based on Project-Based Learning [4]. We must remember, following this reasoning that in the EU Research Framework Programme IV and V preparatory sessions different strategic objectives were defined:

− Employment-oriented education (relevant contents, methodology)
− Continuous learning, lifelong learning
− Research results transfer and productivity

These objectives grant great relevance to employment-oriented education and industrial productivity, apart from potentiating continuous and permanent learning. In this same sense we must highlight the results of different studies on the personal qualities in high demand in the Spanish professional market [5] which offers the following results:

− Skill for working in a group
− Communication ability
− Dynamic attitude
− Ability to interact with other people
− Ability to organize
− Commercial drive
− Leadership
− Compromise with the objectives of the company / organisation
− Flexibility
− Orientation towards service
− Negotiating ability
− Capability and apprenticeship
− Motivation
− Initiative
− Ability to assume responsibilities

This study offers a clear vision about how enterprises in the Spanish national territory, far from establishing employment requisites related to a high level of intelligence of a great knowledge of the matter at hand, the value much more significantly socio-emotional aspects. A national survey passed on to American employers [6] clearly reflects similar results. The six keys skills by order of importance for U.S.A. employers are the following:

− Ability to analyze
− Ability to learn autonomous and permanently / self-development
− Self-control
− Persistence
− Initiative
− Responsibility
This means that 5 out of 6 of the skills selected as the most desires are not of the academic type, but with a marked socio-emotional character.

For this reason we put forward in the present contribution that mostly practical subjects of the new Degree titles may be very useful for the development of general skills which, apart from the specific ones, complete the formative education of the individual.

By means of the Project-Based Learning system we strongly believe that it is possible to establish a collaborative learning by which the student may reach an adequate degree of development of the skills that are summarized below. This list has been compiled on the basis of the three kinds of skills identified by the Tuning project in the EHEA framework.

**Instrumental skills**

1. Cognitive ability to analyze, understand, manage and synthesize ideas related to the carrying out of a research project;
2. Methodological ability to organize one’s own learning and take the right decisions;
3. Technological ability for the use of the technological resources available at the university campus;
4. Linguistic ability for both oral and written communication of scientific texts – this skill is in truth a consequence of the development of two others: oral and written communication in the native language and knowledge of a second language (English);

**Interpersonal skills**

1. Self-criticism ability – it is important that the students make a critical reflection of their work and their performance in the development of the group activity in the reports that they will hand in in each phase of the project;
2. Social ability – interpersonal relationship by the establishing of a workspace with the help of the university campus technical services;
3. Teamwork – even in the case of unipersonal research projects teamwork will be necessary in order to make use of the research facilities available in the research laboratories in the university departments in an optimized way;
4. Social responsibility – this may be acquired through the use of tools and equipment of common use that should be left in perfect working order after use; furthermore the students will be responsible for the maintenance of the equipment during the course of the subject while they are in the research laboratories, even if they will not use the apparatus of which they will be responsible;
5. Ethical compromise – it is important that the student accepts his compromise towards society; to do that special attention will be paid to the adequate use of the means available in the laboratories in the right amounts and the recycling of the waste generated in the laboratories;

**Systemic skills**

1. Ability to integrate all aforementioned skills into abilities such as creativity and directing.

To summarize, we may claim that what is expected from this “Formative Evaluation through Project-Based Learning” is that the student will acquire new technical skills on the subject in question and will, moreover, develop a series of skills of socio-emotional character of great importance for his/her training oriented towards the professional market such as: ability to adapt oneself to new situations, teamwork ability, ability to work autonomously, have interpersonal ability, motivation towards success, entrepreneur spirit, etc.

3 EXEMPLIFICATION

Following on our previous work [7] and elaborating upon it, we present an illustrative example on how we propose to teach the aforementioned skills to Chemistry students basing our method on providing hands-on help whenever necessary while nurturing the students’ independent learning. In the of (e.g.) first and second year undergraduate Chemistry students, we will provide the students with selected bibliography strongly related to our teaching interests. In this particular example we would refer the students to a seminal paper by Mullfinger et al. [8] in which the synthesis of silver nanoparticles (aka.
colloids) is put forward in a clear and simple way. Thanks to the fact that (i) the synthesis is sufficiently simple (yet highly illustrative) and (ii) the study and the characterization of the prepared silver nanoparticles can be carried out at different levels (and thus at degrees requiring different skill levels) there is great teaching potential for Chemistry students. At first the student(s) is(are) asked to read through the paper and extend their basic knowledge on the topic at hand by looking in the available literature (which should be sufficiently large under the selected topic, as is the case of nanoparticles). Once the fundamentals of the reactions/processes that will be performed in the laboratory are understood, the student will be probed on specific aspects of the synthesis concerning for example the purity of the reagents, the experimental methodology, or the possibility of extending the synthetic protocol to other type of metals in order to prepare nanoparticles. The prepared nanoparticles may be then characterized by different techniques depending on their respective skills level. In this respect either UV-Vis spectroscopy (for 1st and 2nd year undergraduates) or Transmission Electron Microscopy (3rd year undergraduates) might be used for characterization. Upon completion of these experiments and through the acquisition of the related skills, the students can tackle more challenging tasks such as postulating modifications of the synthetic process and thus analyze the influence of the synthetic parameters on the outcome of the nanoparticle synthesis.

4   CONCLUSIONS

In this work we have put forward and explored the possibility of applying a model based on Formative Evaluation through Project-Based Learning in subjects taking part in the new university Degrees with a significant experimental workload. This model is based in the development of guided research projects and the continuous evaluation of the student, which should develop both skills specific to the discipline and generic skills oriented towards the insertion in the professional market.

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