Innovation in teaching methodologies for distance classes in practical Chemistry

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1. Description, type of experience, and context in which it was carried out

In the midst of the COVID-19 pandemic and in preparation for the Fall 2020 semester, we decided to design hands-on experiences for a distance Chemistry lab course. The obvious limitation was the lack of apparatuses and materials in the student homes. To circumvent this problem, we designed a set of experiments and enlisted the required supplies. Due to social distancing measures our purchasing department was not fully operational and therefore we decided to purchase all the required items for the 19 registered students out of our own pockets. (This cost roughly one half of the monthly salary of the main author of this communication). This procedure turned out to give us an enormous amount of freedom. We are implementing the same idea for the Spring 2021 semester.

2. Objectives and methodology

The main objective of the designed experience was to enable students to have experimental practice during their home confinement in the elective course entitled "Electrochemical Processes and Corrosion". We were able to proceed thanks to the experience that we had accumulated over the past three decades at the Mexican Center for Green and Microscale Chemistry. This Center was founded in our institution in 1990 with the academic support of the National Microscale Chemistry Center (of Merrimack College, an Augustinian institution in North Andover, Mass, USA). Our Center was recognized by the American Chemical Society as the Mexican Chapter of their Green Chemistry Institute, and received one of the ACS sustainability-related awards in 2011.

The microscale approach involves *the use of micromoles or microliters of at least one reagent, and/or the use of a reactor with at least one micrometric dimension, to perform or study a chemical process* (Ibanez et al, 2007; Ibanez et al., 2008).

By working with small amounts of reagents, we have observed decreases in the following (Ibanez, 2011):

- amounts of wastes dumped into the ecosystem
- toxicity and danger to students and teachers
- reagent and energy costs
- time required to perform an experiment
- breakage of glass material
- amounts of reagents and products wasted in side-reactions

and increases in the:

- simplicity of experimentation and ease of experimental setup
- the variety of experiments that can be done on a lower budget
- the students' attention to what happens in the experiment
- the time available for discussion and reflection activities
- levels of self-confidence and satisfaction when conducting a wide variety of laboratory experiences.

Most of the experiments in the area of Chemistry can be substituted using this technique, without diminishing the educational gain. In addition, this strongly affects the development of skills and the promotion of attitudes and values by requiring greater expertise in the handling of substances and equipment, as well as by generating a culture of saving and caring for our Common Home. In Ignatian terms, we apply the *Magis* concept of *doing more with less*. In this way we have been able to influence students and teachers in 51 countries, including many underprivileged institutions in the 5 continents.

The kit sent to students contained roughly 70+ items including:

- Electrical materials
- General laboratory items and glassware
- Electrode materials
- Volume measurement and transfer equipment
- Solutions and reagents
- Safety equipment

Once we had purchased the necessary supplies, we prepared a set of solutions to be placed in 5-mL plastic droppers. Also, we enclosed solid reagents in small glass bottles (5 mL ea.). Due to the stringent regulations for shipping Chemistry-related materials through regular or courier mail, we hired a private driver to deliver all the kits in the student homes.

3. Results obtained

With the designed kit we were able to complete 25 experiments during the 2020 Fall semester. The main subjects of the experiments were (Rajeshwar and Ibanez, 1997; Ibanez et al., 2005; Ibanez, 2005; Ibanez, 2006):

- Basic electrical circuits and measurements

- Redox reactions
- Energy generation and storage
- Electroless and electrodeposition
- Environmental electrochemistry
- Water electrolysis
- Organic electrochemistry
- Inorganic electrochemistry

The fact of having the kits available all the time permitted to request that student teams designed and tested some experiments on their own, which accounted for 20% of the final grade. Students enjoyed this challenge very much, and some experiments turned out to be quite successful to the point that three of them are being contemplated for external publication in reputable journals. Another 20% of the grade involved the making of a short (3-5 min) video on a selected subject pertaining to the class. Another 20% was assigned to the final, comprehensive test. The remaining 40% of the grade was awarded by the delivery of homework and short quizzes administered during the semester.

4. Lessons learned

We identified diverse learning opportunities that had not been explored previously outside the university habitat, like the development of several abilities and competencies to learn at home. We analyzed the learning outcomes in this course through two instruments: a) the evaluation of teachers by students performed by the institution in the middle of the semester, and a specifically-designed voluntary survey that we applied at the end of the semester (responded by 79% of the students, i.e., 15 out of 19). The main outcomes are now presented.

Students were aware of the fact that it is certainly not the same to be in the laboratory or at home, and they found some differences in the microlab work from home and the laboratory work within the university. In addition, they identified learning opportunities in diverse ways that they had not experienced outside of the university settings, as well as the development of different skills and competencies to learn from home.

Regarding the specific knowledge that was developed during the course, two-thirds of the students commented that with the practice at home they improved their mastery of the topics on environmental, organic, inorganic electrochemistry, energy storage, electrochemical theory and corrosion. Almost half of the students perceived that they learned very well to use basic glassware and laboratory equipment following the proper techniques. All but one of the students said that they learned to design sound scientific procedures to generate new experiments or solve basic experimental problems. All but two of them indicated that they understood and applied green chemistry principles such as decreasing the amounts of substances used and minimizing the generation of waste. All but three affirmed that they discussed with their classmates and with the professor the scientific or mathematical theories and models developed through data analysis to explain some observed phenomena. Lastly, all but two said that using scientific data published in reliable sources helped them better understand or report the results they observed.

Regarding the competencies that were developed during the course, all but two of the students responded that they developed scientific reasoning, particularly in electrochemistry and corrosion. All but three mentioned that they generated oral and written arguments consistent with scientific practice. Almost three fourths considered that they made progress in the ability to prepare laboratory reports and audiovisual resources aligned with good scientific practices. All but three mentioned that they managed their time and space efficiently in their home laboratory and that they improved in developing teamwork skills. All but two said they understood and applied the principles of ethical behavior in academia and in scientific practice, and that they developed learning and autonomous study skills applied to electrochemistry and corrosion.

Regarding the safety skills that they developed during the course, all but two of the students had the perception of knowing and using the safety standards and the proper handling of chemicals in a home laboratory, while all but three participated in chemical practice conscious of safety and the environment.

Essentially all the students appreciated the passion and efforts of the teacher and said that this was a source of motivation, together with his ample knowledge of the subject.

5. Opportunities for improvement

The experiments were performed in a somewhat random sequence. They should be organized according to the regular class syllabus, but time did not allow to do so.
Some students suggested a better balance between theory and practice since the theoretical contents were covered rather quickly. Also, some requested to carry out more group exercises to stimulate teamwork. Lastly, there was a request to solve problems after covering the theory, and that these be offered with feedback and be linked to the assessment instruments.

6. Images (JPG format)

Figure 1. Sample experiment. Homemade magnetically-assisted solar water LED electrolysis.

7. Bibliographic references

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