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SMARTPHONES AS ANALYTICAL TOOLS TO STUDY THE PHOTODEGRADATION OF FOOD DYES IN A LABORATORY SETTING

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Abstract

The use of smartphones as analytical tools represents an innovative approach that expands the possibilities for measurement in the field of chemistry. Thanks to their high-resolution cameras and advanced sensors, these devices can perform functions similar to those of traditional equipment such as UV-Vis spectrophotometers. Furthermore, their portability, low cost, and ease of use make them an attractive alternative, allowing students to interact with emerging technologies and promoting hands-on learning while reducing dependence on expensive equipment. In this study, a method has been developed for students of the course "Advanced Sample Preparation Methods. Sustainability in the Laboratory," of the Master's program in Experimental Techniques in Chemistry at the University of Valencia. The activity has as its main objective to introduce the smartphone as an analytical tool to study and optimize, in a collaborative way, the photodegradation conditions of persistent organic pollutants in a continuous system. To this end, synthetic food dyes are used as models of contaminants and a photodegradation system based on a suspension of titanium dioxide (TiO_2) activated with ultraviolet light has been designed. The methodological approach of the practice allows students to reinforce and apply their knowledge in a real environment, learning to assemble and operate a continuous photodegradation system, analyse the efficiency of the process and compare analytical techniques such as UV-Vis spectrophotometry and colorimetric analysis with smartphones. In addition, the structure of the practice encourages collaborative work and critical evaluation of the results, promoting comprehensive training in sustainable chemical analysis techniques.

Keywords: *Laboratory module, photodegradation, smartphone, UV-Vis spectrophotometer.*

1. Introduction

In recent years, the use of mobile devices in chemistry teaching has gained prominence due to their accessibility, versatility and ability to enhance their learning experience (Wijtmans et al., 2014). In particular, the integration of smartphones as analytical tools in the laboratory represents a methodological innovation that allows students to interact with emerging technologies and develop skills in chemical analysis. Thanks to their advanced sensors and high-resolution cameras, mobile phones can be used to perform colorimetric measurements, offering a fast, simple and low-cost alternative to traditional instruments such as UV-Vis spectrophotometers (Shogah et al., 2023).

At the same time, pollution by persistent organic compounds constitutes a major environmental problem, since these pollutants accumulate in ecosystems and can represent risks to human health. One of the most effective and sustainable strategies for their elimination is photodegradation, a process that uses light as an energy source to degrade these compounds without generating toxic by-products (Chen et al., 2020; Saeed et al., 2022). However, teaching this technique in the academic field requires approaches that not only address the theoretical foundations, but also allow students to apply knowledge in a real experimental context.

Within this framework, the laboratory practice presented in this work has a double purpose: to introduce students to the study of photodegradation as a sustainable technique for the elimination of contaminants and, at the same time, to incorporate the use of the smartphone as an analytical tool in the laboratory. The possibility of comparing the data obtained through UV-Vis spectrophotometry with the results of colorimetric analysis performed with mobile devices reinforces the learning of experimental techniques and allows the precision of this technology to be evaluated.

In addition, the activity is designed to encourage collaborative learning, promoting teamwork in the design of experiments, data analysis and interpretation of results. This methodology promotes critical thinking, evidence-based decision making and the development of essential skills for the professional field (Vaillant & Manso, 2019).

Ultimately, this internship combines technological innovation, sustainability and collaborative work, offering a comprehensive training experience that not only strengthens the understanding of advanced analytical techniques, but also raises students' awareness of the importance of chemistry in solving environmental problems and its role in the scientific challenges of the future.

2. Objectives

The main objective of this practice is to integrate the use of the smartphone as an analytical tool in the collaborative study and optimization of the photodegradation conditions of persistent organic pollutants in a continuous system. Through this strategy, we seek to promote active learning, teamwork and the incorporation of new technologies in the laboratory.

To achieve this purpose, a series of specific objectives have been established, both conceptual and didactic:

Conceptual specific objectives

- Analyze the photodegradation process of persistent organic pollutants using non-toxic synthetic food dyes as a model.
- Design and assemble a continuous system for the photodegradation of organic compounds.
- Identify and select the key parameters that influence the efficiency of the continuous photodegradation process.
- Implement a circular photodegradation system that allows the reuse of the catalyst and minimizes the generation of waste.
- Apply rigorous analysis techniques using UV-Vis spectrophotometry to evaluate the degradation of the compounds studied.
- Introduce the use of smartphones as a fast, simple and low-cost alternative for the colorimetric analysis of samples.
- Interpret the results obtained and formulate consensual conclusions on the optimal conditions for the photodegradation of the compounds analyzed.

Specific educational objectives

- Explore and apply in a practical way a methodology widely used in the industry for the elimination of persistent organic pollutants, addressing a real environmental problem.
- Put into practice theoretical knowledge acquired throughout academic training in relation to the operation of continuous systems.
- Promote collaborative work in the selection and optimization of the parameters that affect the photodegradation process.
- Incorporate new technologies in laboratory practice to enhance student motivation and learning.
- Promote critical discussion and analysis of the results among the different work groups, favoring the collective construction of knowledge and the elaboration of well-founded conclusions.

3. Activity description

3.1. Educational context

This activity is carried out by a total of 25 students, within the framework of the subject "Advanced sample preparation methods. Sustainability in the laboratory", of the Master in Experimental Techniques in Chemistry of the University of Valencia. The subject, of a practical nature, is aimed at teaching advanced methodologies for sample preparation, with a special focus on sustainability within the chemical laboratory. It consists of a teaching load of 2 ECTS credits (equivalent to 20 hours of laboratory practice), of which 4 hours are devoted to this activity. Specifically, the time distribution is established at 3 hours for the assembly, performance of the experiment and data acquisition, and 1 hour for the discussion of results and the completion of the satisfaction survey.

3.2. Activity

The experimental procedure begins with the assembly of a continuous photodegradation system, which students must assemble with the materials provided. This system consists of a Teflon tube wrapped around an ultraviolet (UV) lamp and connected to a peristaltic pump, through which a solution of a non-toxic synthetic food dye circulates together with a suspension of the TiO_2 photocatalyst. During this assembly, participants learn to design a continuous flow system and to work with a circular photodegradation process that allows the reuse of the catalyst and minimizes the generation of waste, thus applying key knowledge about sustainability in the laboratory (Lamiri et al., 1999).

Once the system is assembled, each pair of students performs the experiment under specific conditions of lamp wavelength, light exposure time or photocatalyst concentration. They then repeat the procedure three more times, modifying the light exposure time. This phase of the practice allows them to apply in a practical way the theoretical knowledge acquired on continuous systems and improve their capacity for critical analysis and problem solving, while developing skills to implement methodologies used in the industry in the elimination of contaminants

To evaluate the effectiveness of the photodegradation process, students analyze samples before and after treatment using two methods. First, they use a UV-Vis spectrophotometer, a reference device that allows quantifying the degradation of the dye by comparing spectral signals. In parallel, they take measurements using the camera on their smartphone, photographing the samples along with a color chart to analyze the RGB codes and calculate the concentration of the dye. This part of the practice introduces the smartphone as a fast and accessible alternative for colorimetric analysis, encouraging the use of new technologies in the laboratory and exploring its viability as an analytical tool.

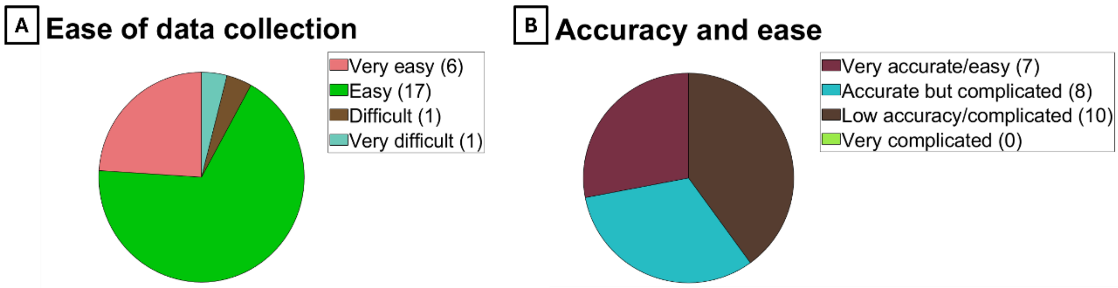
Once the experimental phase is over, all the pairs share their results in a discussion session so that they can collaboratively have an exhaustive study of the photodegradation conditions. Through this exchange, students analyse how the variation of the experimental parameters has influenced the efficiency of photodegradation and reach a consensus on the optimal conditions for the degradation of the dye studied. In addition, they compare the data obtained by spectrophotometry with those obtained through analysis with the smartphone, evaluating their reliability and usefulness as a measurement tool. This sharing promotes collaborative work and the development of critical analysis skills, allowing students to reflect on the precision and limitations of the methods used.

Finally, in order to assess the experience and the impact of the methodology used, students respond to a satisfaction survey. Through this evaluation, their perception of the use of the smartphone as an analysis tool, their understanding of the concepts addressed in the practice and the usefulness of the activity in their academic training are collected. The implementation of this methodology not only allows them to apply knowledge in a practical and realistic environment, but also encourages teamwork, critical thinking and the use of innovative technological tools in the field of analytical chemistry.

3.3. Results

Below are some of the results of the student satisfaction survey, which show that the use of smartphones during the practice was well received in terms of accessibility and ease of use. Most participants found it easy to collect color data using their mobile device (Figure 1A). However, when it came to centering the image and correctly photographing the sample (Figure 1B), some difficulties arose, suggesting that the precision of this method is not optimal. Additionally, although the methodology was considered somewhat intuitive, not all participants found it completely clear, indicating that it could benefit from better guidance or calibration to enhance the user experience

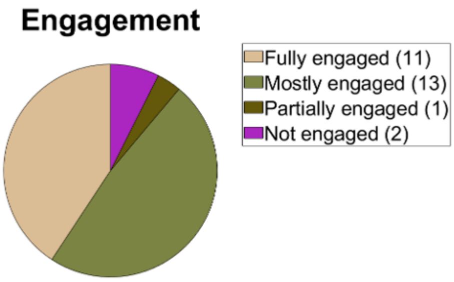
Figure 1. Results on the ease of data collection (A) and accuracy of the method used in the practice (B).



From the perspective of student engagement and interest, the activity was a success. Using smartphones was not only perceived as appealing and moderately innovative but also facilitated learning and helped students better understand theoretical concepts. During the practice, students were fully engaged

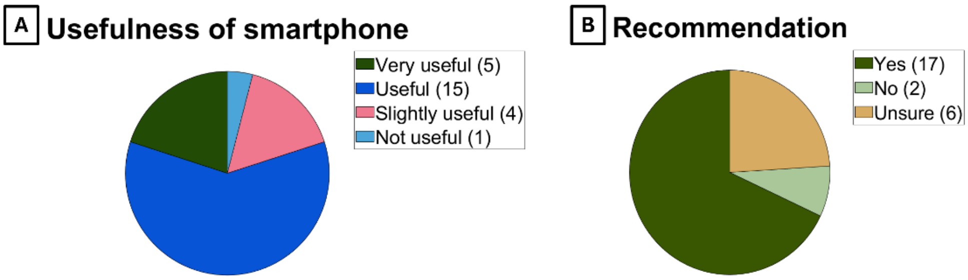
(Figure 2), suggesting that the use of technological tools can be a key factor in increasing motivation and participation in this type of activity.

Figure 2. Levels of student engagement and participation during experimental activity.



Regarding overall satisfaction, the results show that students consider smartphones a useful tool (Figure 3A) though not revolutionary. The comparison with other measurement methods did not reveal significant differences, as most participants rated this practice similarly to previous experiences. Despite this, they would recommend its implementation in future activities (Figure 3B), reinforcing the idea that this methodology is a valid complement to traditional methods.

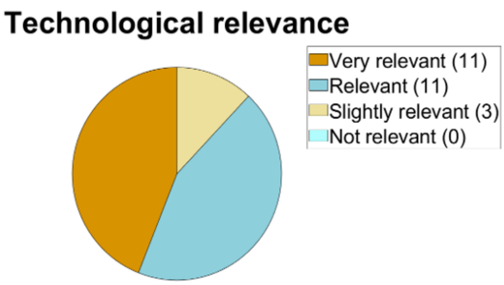
Figure 3. Student opinions on the usefulness of smartphones in practice (A) and their recommendation for future implementations (B).



On the other hand, the organization of time within the practice did not seem to pose a problem. Participants considered that the allocated time was adequate and that the different tasks within the practice were well balanced. Similarly, the level of difficulty was perceived as appropriate for the students' academic level, indicating that the activity was effectively designed without generating an excessive workload.

Finally, a key point to highlight is that most participants considered the use of smartphones to be very relevant to modern Analytical Chemistry (Figure 4). This supports the idea that integrating new technologies into chemistry education is not only feasible but can also provide significant benefits in terms of learning and motivation.

Figure 4. Perceived technological relevance of smartphone use in Analytical Chemistry.



4. Conclusions and future perspectives

The results obtained in this study show the positive impact of using smartphones in the analytical chemistry laboratory, highlighting their accessibility, ease of use and ability to encourage student participation. Furthermore, the comparison between the data obtained with the UV-Vis spectrophotometer and the RGB values captured by smartphones has allowed us to evaluate the reliability of this methodology and its potential in educational environments.

However, the study has also revealed challenges, particularly in relation to the accuracy and clarity of the instructions when capturing and processing images, suggesting that it would be advisable to improve key methodological aspects, such as calibration and standardization of the process, to optimize the accuracy and reproducibility of the results. In this regard, it has been proposed to develop an application that automates image processing and colorimetric analysis, reducing errors associated with manual adjustments.

Despite these challenges, the implementation of this technology has proven to be a valuable teaching resource, promoting active and motivating learning. Its integration into the laboratory not only favors the sustainability and accessibility of experimental practices but also contributes to the training of future professionals better prepared to face the challenges of modern analytical chemistry.

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