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Interdisciplinary Teaching Strategy in the Development of Chemical Courses

Nancy Romero-Ceronio*, Carlos E. Lobato-García, Abraham Gómez-Rivera, Ammy J. Gallegos-García, Domingo J. Velázquez-Oropeza

División Académica de Ciencias Básicas, Universidad Juárez Autónoma de Tabasco, Cunduacán, Tabasco, México

Abstract Today interdisciplinary teaching and research are already strong and important aspects requested for solving questions. In this context, individual disciplines do not consider all the aspects of a complex problem and interdisciplinary courses and programs may help in facilitating or enhancing the transfer of higher-order cognitive skills (HOCS) such as: critical thinking, problem solving, decision-making and laboratory practice. In this paper, we report a systematic integration of three undergraduate chemistry courses: Chemistry of Natural Products (QPN), Laboratory of Organic Chemistry 2 (LQO2), and Laboratory Analytical Chemistry 1 (LQA1). By choosing a common topic, we prepared a series of activities focused in interdisciplinary interaction and the development of students' HOCS.

Keywords Interdisciplinary, Teaching's strategy, Collaborative learning and higher-order cognitive skills (HOCS)

1. Introduction

Traditional teaching of Chemistry is centered mainly on the isolated and fragmented learning of the different tasks and tools of this science, and leaves to one side the development of activities that make it possible to unite skills and knowledge in order to apply them to solving problems. During the last years, the main objective in the teaching of Chemistry has been to develop higher-order cognitive skills (HOCS) in students, including critical thinking, decision making, problem solving (cases) and laboratory practice. [1] Zoller stated that teaching might be improved with teaching strategies that are appropriate and oriented to boosting and strengthening HOCS in students. [2]

Thus, an interdisciplinary approach provides an ideal platform for this objective, as it allows the integration of concepts, theories and methods of different study areas, with a focus on the solution of a common problem or on the study of a specific subject. The development of projects with these characteristics favours significant learning in the students. [3]

2. Background: Interdisciplinary in the Teaching of Chemistry

* Corresponding author:
nancy.romero@ujat.mx (Nancy Romero-Ceronio)
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Several didactic proposals have been made to integrate knowledge of Chemistry in an interdisciplinary education. Results have been promising as students acquire a more holistic awareness and an integral education, placing Chemistry in a real context that relates it to the emerging needs of the present-day world.

Environmental Chemistry, for example, is a fertile field for the application of an interdisciplinary strategy. The design and application of educational strategies that use analytical tools to diagnose environmental problems such as water quality, soil degradation or air quality in a region have been reported. The experience generated in the study was highly positive, as the development of an environmental diagnosis prompted interest in the students, which saw the convenience on considering diverse study areas to obtain a particular result. [4]

Fundamental aspects of Organic Chemistry have been considered in order to associate related areas to develop complex thought and generate research skills. Central topics in this area of Chemistry were selected, with a focus on nutraceutics i. e. food items or parts of food items that, apart from their nutritional value, provide beneficial effects to health as, for example, antioxidants. The study of Organic Chemistry focused on substances that receive general attention because their properties are beneficial to humans puts diverse aspects into context, which would otherwise be abstract, and enhances research. [5]

The interest in developing interdisciplinary strategies is more evident in frontier areas such as nanoscience and nanotechnology, where research is directed to developing new materials and their applications, and necessarily requires dealing with the point of view of different scientific disciplines. [6]

We consider that the integral formation of a Chemist requires the development of skills in the laboratory, Therefore it is prioritary to enhance the importance of practical activities, placing them in laboratories designed for different study areas where aspects of two or more theoretical disciplines can be worked on and the students can obtain a more enriching laboratory experience. [7-8]

In this paper we reported one teaching strategy focused on interdisciplinary development of chemical courses, this project was made as part of innovaCesal network. [9]

The strategy is based on the development of a central topic: acid-base indicators, from the point of view of three courses included in the curriculum of the Undergraduate Program in Chemistry (UC) at Universidad Juárez Autónoma de Tabasco (UJAT): Analytical Chemistry Laboratory 1 (ACL1), Organic Chemistry Laboratory 2 (OCL2) and Chemistry of Natural Products (CNP). The main objective was to develop and enhance higher-order cognitive skills (HOCS) in the students that took part in the project.

3. Methodology

In order to define an ideal core topic, the teachers responsible of the courses analysed and detected the points of convergence between the different areas. A curricular description of the subjects included in the study is presented in table 1, with a reference to the curricular location and the objectives of each course.

Once the central topic: “acid-base indicators” was selected, the activities to be carried out were defined according to each subject, and specific actions were established around the central topic. The strategy was applied throughout the 16-week long school cycle.

The working teams were formed equitably based on the number of students per course included in the process. The activities were supervised both individually and as a whole, in order to observe and record the results obtained for the proposed working strategy.

The evaluation of the student’s performance considered both self and peer assessments and it took place throughout the development of the strategy, using evaluation instruments designed *ex profeso*. [10-12]

In order to explore the students’ perception about this project and to promote their metacognitive process, a questionnaire of three opened questions was applied at the term of the project. The questions were: what happened?, how did I feel about it?, what did I learn? The first two questions were intended to know how they perceived the learning environment of this project, meanwhile the third question was an invitation to think about the knowledge they acquired along this experience. The information provided by this questionnaire was qualitatively analysed by a classical content method. [13]

Additionally, the use of social network and IT was included in order to take advantage of communication channels through which the teams shared information they considered pertinent and were able to discuss and to peer-evaluate the activities of the different teams, in a respectful and propositional way, the construction of different approaches to the central topic. [14-15]

The teachers supervised the participation of the students in this experience. Feedback was favoured by sharing information, comments and timely suggestions, and HOCS were developed through critical thinking and decision making.

Table 1. Curricular description of the subjects included in the study

Subject	Description	Objective
ACL1	Obligatory Professional Substantive Area Four thematic units (8 h/week) Experimental 100% Learning based on experience	To develop skills in the student, in the experimental practice of Analytical Chemistry, in the preparation, valuation and standardisation of solutions, and chemical balances in homogeneous systems, and gravimetric analyses.
OCL2	Obligatory Professional Substantive Area Five thematic units (8 h/week) Experimental 100% Learning based on experience	To develop skills in the student, in the experimental practice of Organic Chemistry, through the exploration of chemical aspects of the following functional groups: ketones, aldehydes, organometallic compounds, carboxylic acids and derivatives, carbanions, amines and sulfur compounds.
CNP	Optional Professional Integral Education Area Eight thematic units (6 h/week: 3 h theory, 3 h practice)	To introduce the student to the study of natural products and the knowledge of methods for the extraction, separation and identification of secondary metabolites.

4. Result and Discussion

Three working teams were formed, each of which had one CNP student, one ACL1 student and four OCL2 students. The CNP students (mentors) were responsible for their groups, as they were the most advanced students. Once the teams were formed, activities were proposed in a way that, depending on the subject taken at the time, specific activities were carried out around the acid-base indicator topic. Follow-up integrating activities and analyses of the work were also carried out. A model of the activities followed by each team is synthesized in table 2.

The activities started with a plenary session in which the students of the four groups and the teachers in charge took part. The working teams were made up in this session.

The students were allowed to choose their fellows with whom they were comfortable to work. This favoured an increase in their cognitive, communication and socio-emotional capacity, which in turn contributed to the objective of the project.

The specific objectives of each group and the sequence of the experiments to be carried out by each group were established. Table 3 presents the general characteristics and the specific activities of each team.

In order to optimize the reagents, the activities related to the synthesis of indicators were distributed as follows: one of the groups was in charge of synthesizing and characterizing phenolphthalein by condensing phthalic anhydride with phenol. [16] The other two groups isolated the anthocyanin from beans (*Phaseolus vulgaris*) [17] and extracted logwood hematoxylin (*Haemathoxylum campechanum*). [18-19] Afterwards, every team applied the three acid-base indicators of the project (one synthetic and two natural) to evaluate the acid content in regional fruits. Cocoa seeds (*Theobroma cacao*) juice, fresh pineapple (*Ananas comosus*) juice and fresh orange (*Citrus aurantium*) juice were selected for this part of the process. The acidity of each juice was evaluated by a classical acid-base titration, using a standardised solution of sodium hydroxide.

The three teams had to tackle the problem of evaluating the acidity of regional fruit juice. To solve the problem, they had to use their experimental and theoretical knowledge and skills in order to transfer the traditional acid-base titration model to a different matrix –the fruit juice. Aspects like the extraction and handling of the sample, up to the analysis of the results, provided an excellent opportunity to potentiate HOCS in the students.

Throughout the experimental work, the teachers observed that the three teams worked in harmony on their experimental problems, integrating the isolation, synthesis, structural characterisation and analyses around a central topic in Chemistry.

Table 2. Model of working teams activities throughout the project

Activity	Working teams		
	CNP	**OCL2**	**ACL1 and OCL2**
Specific activity to be carried out	General direction of the work. Isolation of a natural product with acid-base indicator properties.	Synthesis of an acid-base indicator. Spectroscopic characterization of both the natural product and the synthetic indicator.	Applying both natural and synthetic indicators in the acidic determination in regional fruit.
Integrative activities	Discussion group in a social network to promote the interaction among the teams. Periodical meetings to analyze progress. Final seminar to discuss results.		

Table 3. Distribution of activities to be carried out by the students throughout the project

Team	Students	Activities to be carried out
1	Responsible teacher: A Formed by: 1 CNP student (responsible) 1 ACL1 student 4 OCL2 students	Isolation and characterisation of bean anthocyanins. Application of the three acid-base indicators to evaluate the acidity of cocoa seed juice.
2	Responsible teacher: B Formed by: 1 CNP student (responsible) 1 ACL1 student 4 OCL2 students	Synthesis and characterisation of phenolphthalein. Application of the three acid-base indicators to evaluate the acidity of pineapple juice.
3	Responsible teacher: C Formed by: 1 CNP student (responsible) 1 ACL1 student 4 OCL2 students	Extraction and characterisation of logwood ethanolic extract. Application of the three acid-base indicators to evaluate the acidity of orange juice.

In addition, social networks were used as spaces that allowed student interaction, the integration of information and the generation of feedback among peers. A high level of student participation was recorded, and it was possible to go further compared with the traditional elements of experimental teaching in which laboratory work, log books and reports are used as evidence of learning.

Integrating activities took place at the end of the project, when the work made of each team was presented and the results were analysed interdisciplinary in a seminar. As we mentioned before, we have the aim to know the students' perception about this project, consequently, we applied the questionnaire to them at the end of the seminar.

The classical content analysis of the students' answers of the questionnaire provided two categories: one for the dynamic of the activities and another related to cognitive development. In the first category, it was possible to identify three subcategories: the first one oriented to socio-emotional capabilities, another related to communication skills and the third one concerned to adaptability. The cognitive development category was divided in four subcategories: learning of analytical procedures, contextualization, solving problem skills and attitudes towards making decisions.

According to these results, it was found that the students showed great interest and willingness to work in groups. This indicated that the work dynamics of the mixed groups was enriching as it united the outlook of different areas of knowledge.

Table 4. Classical content analysis of the students' answers

Category	Subcategory	Examples of students' statements
Dynamic of the activities	**Socio-emotional capabilities (enthusiasm)**	"Un poco de nervios por trabajar con personas que no conocía.." I was a little bit nervous because I was working with people I did not know before.
		"Había un ambiente de cordialidad, tolerancia y respeto…" There was a nice, tolerant and respectful environment
		"Me sentí interesado por el proyecto desde el inicio…" Since the beginning, I was very interested in this project.
		"Me gustaría que siguieran haciendo este tipo de actividades" I would love if you keep on doing this kind of activities.
	Communicative skills	*"Aprendí que trabajar en equipo se recolectan ideas que uno a veces no tiene".* I learned that by a team work, it is possible to share new ideas.
		"Me sentí muy a gusto con todos y nos la pasamos muy bien compartiendo muchas cosas y poniendo nuestros puntos de vista". It was nice to work with everyone, I had a great time sharing many things and points of view.
	Adaptability	*"Me sentí muy bien al trabajar con personas de diferentes grupos…"* It was nice to work with people of other groups.
		"…mientras nos íbamos adaptando en el equipo, ya que no habíamos trabajado…" We needed some time to adapt each other, since we had not worked together before.
Cognitive development	**Learning of analitycal procedures**	*"Aprendí una nueva técnica de extracción…"* I learned a new extraction technique...
		"desarrolle más mi habilidad para hacer cromatografía en capa fina" I improved my ability on working with thin layer chromatography.
	Contextualization	*"(Fue importante)…el conocer la acidez de frutas que se dan aquí en la región…"* (It was important)… to know the acid value of regional fruits
	Solving problems skills	*"la practica parecía fácil, pero presentó ciertas dificultades …"* At first glance the experiment seemed easy, but it presented several difficulties
		"Al final después de un intento fallido logramos obtener un resultado". Finally, after a failed attempt, we obtained a result.
	Attitudes towards taking decisions	*"llevar a cabo la síntesis de la fenolftaleína con cambios previos a la técnica…".* We proceed with the phenolphtalein synthesis by changing the procedure. *"Las reacciones no son una receta de cocina que en el momento a veces se tienen que cambiar los medios de reacción".* Reactions are not cooking recipes and sometimes it is necessary to change the reaction's conditions.

A representation of this analysis is shown in Table 4, which also includes examples of statements extracted from the students' answers.

It was possible to observe that when students of different semesters interacted, those more advanced had to explain more clearly the concepts learned, and at the same time the fresher students handled basic concepts more clearly (as they had reviewed them recently) and helped their more advanced fellow students in the discussion of the results. In other words, this strategy potentiated collaborative learning, critical thinking and problem solving, in short, HOCS in the students that took part.

The data recorded in the work log books, presented as progress of results at the final seminar, showed that team work allowed the students to make knowledge theirs in an integral way (not a fragmented way), obtaining significant knowledge and a holistic view of Chemistry, by working on an integrated central topic.

5. Conclusions

The application of this multidisciplinary work strategy, dealing with a central topic in Chemistry from the perspective of different areas, strengthened collaboration among teachers and made it possible for the students to learn in a significant way, to favour collaborative learning and to generate an holistic view of tasks in Chemistry.

The feedback obtained from both the working teams and the teachers who took part in the project proved the accomplishment of HOCS such as critical thinking, problem solving and laboratory practice, as well as the students' collaborative learning. The experience of sharing in a social network what was learned in the laboratory generated the possibility of carrying out groupal discussion and analyses of specific topics of each of the interdisciplinary projects developed by the students.

The results obtained in this study are encouraging and favour proposing a greater number of inter- and multi-disciplinary work strategies for the teaching of Chemistry.

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