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Teaching Chemical Equilibria: A Contextualized Scientific Method and Forensic Chemistry Class

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Abstract This paper presents an experimental class involving forensic chemistry topics and principles of the scientific method in the investigation of a fictitious death case, where the students can understand the chemical reactions and respective equilibria involved in the case. Therefore, the aim of this experimental class is to provoke students to examine the interrelationships between the concepts of chemical equilibria, by observing the occurrence of reversible chemical reactions and the equilibria involved, in each experimental step. The practical activity was executed based on the "discovery methodology". Experimental classes generally arouse the interest of undergraduates in chemistry, and this particular class increased the students' interest in forensic chemistry, and contextualized the chemical reactions and equilibria for crime-solving, which is a common theme in popular media such as books, films, and plays. From the reports of the students, it was affirmed that this experimental class, which was based on a rediscovery technique, promoted interest and learning of chemical equilibria to a satisfactory level.

Keywords Experimental class, Chemistry teaching, Discovery methodology

1. Introduction

Chemical equilibrium is an important concept in the understanding of various chemical interactions, but it is complex and considered one of the most difficult themes in chemistry teaching, both in high school and university, [1, 2] given the large number of studies investigating the conceptual difficulties of students regarding chemical equilibria. Most studies identify the students' main misunderstandings: misunderstanding the differences between a complete and incomplete chemical reaction; [3-6] believing that the reverse reaction begins only when the direct reaction ends; [3-6] and difficulty in understanding the dynamic nature of equilibrium. [7, 8]

The contextualization of chemistry teaching has emerged as a proposal in national curricula for improving secondary education, aimed at channeling the scientific information in a social context. Thus, chemistry should provide young learners with a broad vision of life, allowing them to reflect on current problems that exist in the world. Importantly, they should be capable of making a connection between chemistry and the subjects directly related to this science, and the issues that are routinely encountered in daily life. [9]

Considering the importance of understanding the concepts of chemical equilibria and its ubiquity, this paper reports the application of an experimental class involving forensic chemistry, where principles of the scientific method were used to investigate a fictitious case. The goal is that the students understand chemical reactions and respective equilibrium involved in the different steps of the investigation.

Forensic science is a multidisciplinary subject that involves biology, physics, mathematics, medicine, and chemistry, to assist in investigations related to legal issues. This field uses chemical techniques and concepts to investigate facts related to certain crimes. Forensic chemistry deals with field forensic investigations involving specialized chemistry to meet judicial requirements. This field also incorporates the disciplines of criminology and forensic medicine. [10]

Table 1. Examples of chemical analysis procedures of forensic interest [11]

Procedures
Qualitative and quantitative detection of narcotics (marijuana, cocaine, LSD, etc.)
Fingerprint identification
Analysis of gunpowder residue
Identification of blood traces collected from crime scenes
Identification of metallographic adulterations in vehicles and weapons

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Table 1 lists examples of chemical analyses commonly used in forensic chemistry.

The use of colorimetric tests is possibly the most widespread qualitative analytical procedure for detecting the presence of a particular substance. This is related to the low cost of the reagents and easy operation because through a simple chemical reaction, the results are revealed and interpreted using only the naked eye. Thus, colorimetric methods commonly used in routine analyses in analytical chemistry laboratories and in the field. Even those without chemical training can perform colorimetric tests without major difficulties. Examples include public safety professionals in routine work searching for illicit substances without the need for expensive laboratory equipment.

In colorimetric tests, the appearance of a color may indicate the presence of a drug or a particular class of drugs. However, as more than one molecule can produce the same result, colorimetric tests are generally considered non-specific and cannot conclusively identify the compound. Therefore, colorimetric tests serve as a preliminary method to rapidly identify the presence of a possible chemical target. The unknown compound can be subsequently evaluated by a more selective and sensitive analytical technique to determine its concentration and composition.

The routine tasks of a forensic expert are not restricted to those in laboratories and police investigations. Forensic experts can also assist with environmental expertise, evaluating possible damages caused by people or companies, disturbing the balance and preservation of the environment; industrial expertise, assessing physical spaces, equipment and working conditions or the manufactured products if risks to workers and consumers exist. [11]

Therefore, the aim of this experimental class based on forensic chemistry is to provoke students to consider the concepts of chemical equilibria by observing different types of reversible chemical reactions and their respective chemical equilibria involved.

2. Experimental

2.1. Materials

In this experiment, the following materials were used by each group of students: test tubes, droppers (1.0 mL capacity), spatulas, test tube holders, cotton swabs, acetylsalicylic acid (ASA) tablets, NaCl crystals, and solutions 0.10 mol.L^{-1} of $Pb(NO_3)_2$, HCl, K_2CrO_4, KSCN, and $FeCl_3$. In addition, 1.0 mL of 1.0 mol.L^{-1} HCl was added to prevent hydrolysis of Fe^{3+}. All reagents were purchased from Sigma-Aldrich®.

2.2. Sample Preparation for the Experimental Class

A total of 10 samples were prepared, which simulated three different situations, i.e., samples whose analysis results could lead to the correct conclusion of the "causa mortis":

- Sample A (simulated urine): pineapple juice was filed in distilled water to 100.0 mL (1:100 (v/v) dilution), as it has the same color and appearance as urine. For the test result to be positive, 1.0 mL of 0.10 mol.L^{-1} $Pb(NO_2)_3$ was added to 1.0 mL of the simulated urine sample. In contrast, to provide a negative test result, 0.50 g of NaCl was added to 1.0 mL of sample A.
- Sample B (white powder): for the positive sample, a small amount of pre-crushed aspirin tablets was added to a test tube. For the negative sample, 0.50 g of NaCl was added to the test tube.
- Sample C (crumpled paper): the tip of a cotton swab, slightly moistened in KSCN solution, was used to write words on the surface of irregularly cut filter paper pieces, like "FUI! (goodbye in Portuguese) and "GOODBYE!" (indicating suicide) or "SOS" and "HELP ME!" (calls for help). For samples indicative of death by natural causes, no words were written on the paper.

Note: To reveal the alleged message contained on paper, each group of students was instructed to gently rub the tip of another cotton swab, moistened with $FeCl_3$ solution, on the paper.

2.3. Methodology

Understanding the basic principles of the scientific method is not the learning goal of this study, but it is necessary for the preliminary approach to the experimental class (pre-laboratory). The basic concepts of the scientific method were presented to allow the students to execute and understand the practical activity proposal involving chemical equilibria.

The pre-lab started with the following question for the students: "What is the scientific method?". Subsequently, the method was explained by saying, doing, and teaching emphasizing certain principles and methodology to reach an end. The scientific method can be said to be the path taken by the scientist when he seeks scientific "truths". [12]

The scientific method is widely used in the physical and life sciences and consists of studying a phenomenon in the most rational way possible to avoid mistakes, always seeking evidence and proof for the hypotheses, conclusions, and affirmations. It is therefore a "set of approaches, techniques, and processes to formulate and solve problems in the objective acquisition of knowledge".

During the pre-lab, steps involved in the scientific method were presented to the students:

a) Observation: a phenomenon is observed, and curiosity often develops based on the observation.
b) Experimentation: the same phenomenon is triggered several times while monitoring all possible variations and values. At this stage, careful measurements are taken.
c) Establishment of scientific laws: after analyzing the experimentation data, a scientific law can be formulated, which is a generalization that relates to the studied phenomenon. It is important to note that the

scientific law is not an explanation of why, but only a description (preferably mathematical) of the phenomenon.

d) Elaboration of hypotheses: at this stage, explanations are generated for the phenomenon and its related laws. The explanation (why?) often leads to the creation of a "model". The simplest hypothesis or model should be chosen as the most probable explanation for the phenomenon studied. A model is a formal description of a phenomenon, which can make predictions. In this context, a hypothesis is an assumption that is made in an attempt to explain the problem.
e) Establishment of a thesis: if the hypothesis is proved by experimental testing, it becomes a thesis. *A thesis is a proven hypothesis*. From the theses, models are created.
f) Elaboration of a theory: a theory is a set of theses that explain the same phenomenon or some related phenomena and that has been tested and proven by a large number of experiments.

The importance of establishing suitable methodology for experimental classes was highlighted by Hodson, [13] indicating that if there are no research situations proposed in experimental classes, there will be no difference in the type of classes planned by the teacher for expository, demonstrative, or practical experiments. Therefore, difficulty in understanding the chemistry course content, such as chemical equilibria, may be more directly related to the methodology used in chemistry teaching, than to the type of lecture, whether experimental or theoretical.

The methodology used for the execution of practical classes was based on the "discovery methodology", since it favors scientific knowledge construction through directed activities that stimulate doing and thinking. In other words, they involve the students in the manipulation of materials, stimulating them to reflect, make decisions, and draw conclusions. [14] The experimental teaching of chemistry using discovery methodology leads the students to develop their skills and scientific attitudes. The discovery methodology, using the scientific method formally or informally, allows the students to constantly developed their observation, measurement, comparison, hypothesis formulation, graphing, data analysis, and interpretation skills to draw conclusions.

Rediscovery is a technique that commonly appears in this methodology. It is a didactic tool by which the teacher proposes practical activities and, through experiments, leads students to observe and interpret results, enabling them to draw their own conclusions. [15] In this technique, students work without knowledge of the final objectives, and only discover the objectives when a certain stage is reached, or when the experiment is finished.

In this experimental class, the teacher provided the materials, assisted the students in assembling the experimental setup, and encouraged them to make observations and draw their own conclusions, but the actual experiments were performed by the students. Experiments based on aspects of forensic chemistry were performed in a group of thirty undergraduate students in the experimental analytical chemistry discipline at the State University of Valley of Acaraú, in Sobral-CE, Brazil.

The class was divided into 10 groups of 3 students and the groups were divided into three sections: initially they were given a script whose introductory text covered the principles of the scientific method and forensic chemistry, followed by the materials and methods. An expository class (pre-laboratory) was given so that the class could perform all steps of experiments with minimal errors, because according to Mayer, [14] sometimes the development of the activity requires prior knowledge, as some students may lack the contextual information.

The steps of the class align with the rediscovery technique, that is, it is up to the teacher to identify an objective subject that justifies the realization of the experimental class; verify its feasibility and adequacy, and provide the materials and bibliography to be used in class proposal. [14]

In this proposal, each student should act as a forensic chemist to elucidate the "causa mortis" of a person. In this fictitious scenario, the forensic chemist collaborated with the local police department, which made a summary report of the death that was being investigated:

(i) a male approximately 50 years old was found dead in his apartment;
(ii) a declaration from a friend of the deceased stated that for more than three days, the victim had not returned telephone calls, and so he decided to go to the apartment. He found the door locked, sensed a strong smell coming from inside the apartment, and immediately called the police. The informant also stated that the dead friend, complying with medical advice, always had aspirin® (ASA) tablets on hand to relieve heart pain (angina);
(iii) according to the police, who arrived after 30 min, they had to break into the apartment and found the man lying on the ground;
(iv) forensic experts were called in and attested that the man had been dead for at least 72 h.

As determined by the forensic experts, the possible causes of death were either: (i) poisoning by the ingestion of some heavy metal salt (arsenic, lead, or mercury); (ii) suicide caused by ingestion of a large excess of drugs (e.g., anticonvulsants, antidepressants, or antihypertensive drugs); or (iii) death due to natural causes (myocardial infarction, stroke, etc.).

To accept or disprove these hypotheses, the teacher (representing the forensic expert), handed out, for each group of students (forensic chemists), samples (evidence) found close to the victim, to be analyzed in the laboratory.

Regarding the hypothesis of poisoning by unconscious ingestion of some heavy metal salt, the presiding doctor collected a sample of urine (sample A) from the bladder of the deceased and sent it to the forensic chemists.

The forensic chemists should be made aware that two pieces of evidence (clues) were found next to the victim and may be of fundamental importance in the elucidation of the cause of death: a) a glass of water next to a plastic bottle containing powder (sample B) on the table in the apartment, and b) a piece of blank crumpled paper (sample C) in the dead man's hand.

Thus, students acting as forensic chemists performed the following procedures:

- Physical description of sample A (color, turbidity, etc.). In a test tube, 1.0 mL (approximately 20 drops) of sample A and 1.0 mL of HCl were added and the mixture was observed. If this test provided a positive result, color change, precipitate formation, or gas release, students mixed sample A with 1.0 mL K_2CrO_4. On the other hand, if the initial test performed with HCl was negative, students continued to the direct powder analysis (sample B);
- Physical description of sample B (color, solubility, etc.). In another test tube, a small amount of sample B and 1.0 mL of distilled water were added, stirred, and mixed together. The resulting mixture was observed and described. Subsequently, 5 drops of $FeCl_3$ were added to the mixture, with a lilac color indicating the presence of acetylsalicylic acid (ASA). If the solution remained colorless or was colored differently, this would indicate the absence of ASA;

Table 2. Guidelines for the identification of “causa mortis”

Reagent	Results Obtained for Samples			Conclusion
	A	B	C	
HCl	Colorless solution			Death by natural causes
K_2CrO_4	No precipitate			
$FeCl_3$		Colorless solution	No message	
HCl	Colorless solution			Death by suicide
K_2CrO_4	No precipitate			
$FeCl_3$		Lilac solution	Written message (Goodbye or Fui)	
HCl	White solid			Death by poisoning (murder)
K_2CrO_4	Yellow solid			
$FeCl_3$		Colorless solution	Written message (SOS or Help me!)	

- For sample C, the students, in addition to describing its physical characteristics, were prompted by the teacher to question whether there was any meaning of the piece of paper, since a more experienced forensic expert would immediately suspect that the victim would have written a message. Therefore, this suspicion should be considered by the forensic chemists, who proceeded as follows: the tips of cotton swabs were dampened with $FeCl_3$, passed gently over the paper, and the occurrence of any reaction was observed and noted.

Table 2 contains the guidelines provided to the students, with the steps of each test of the samples and possible results.

Therefore, the responsibility of each student, acting as a forensic chemist, was to examine the evidence and write a technical expert report to the investigating officer, including a detailed description of observations made at the scene, results of the physical-chemical analyses, and possible conclusions regarding the death.

3. Results and Discussion

At the end of the experimental class, possible phenomena related to the observations were explained to the students. For the groups of students who tested sample A and observed changes in the initial stage (positive test), the explanation given by the teachers was that the appearance of a white solid (precipitate) when mixing sample A with HCl was due to precipitation of $PbCl_2$. After the addition of K_2CrO_4, formation of a yellow precipitate ($PbCrO_4$), occurred, and can be used to identify the presence of Pb^{2+} in the systematic analysis of cation groups. Ionic reactions presented to the students were as follow:

$$Pb^{2+}_{(aq.)} + 2Cl^{-}_{(aq.)} \rightleftharpoons \underset{\text{white precipitate}}{PbCl_{2(s)}}$$

$$\underset{\text{white precipitate}}{PbCl_{2(s)}} + CrO_4^{2-}{}_{(aq.)} \rightleftharpoons \underset{\text{yellow precipitate}}{PbCrO_{4(s)}} + 2Cl^{-}_{(aq.)}$$

The solubility product, K_{sp}, of $PbCl_2$ and $PbCrO_4$ are 1.7 x 10^{-5} and 3.0 x 10^{-13}, respectively, [16] and the students were shown that the K_{sp} values can be used as a reference to predict precipitate formation in a mixture of solutions. In this test, the final concentrations of chloride and chromate ions were high, so both precipitates were formed, since *product of the ion concentrations exceeds the K_{sp}* of each compound. This resulted in a supersaturated solution and precipitation occurred to reestablish equilibrium conditions.

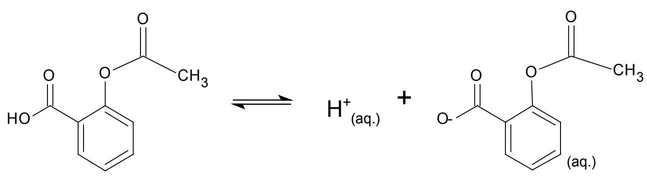
Thus, it was possible to demonstrate to the students a practical example of precipitation equilibria of Pb^{2+} as a function of K_{sp} values of $PbCl_2$ and $PbCrO_4$. Students were able to understand that the rate at which the insoluble compounds are formed is related to the concentrations of the ionic species and their K_{sp} values.

The dynamics of the experimental class favors the reinforcement of previous concepts related to reversible chemical reactions studied by the students in the general chemistry course. In addition, some discrepancies encountered in laboratory activities, such as those discussed by DeMeo, [17] may contribute to understanding these concepts. In this case, the qualitative investigation of two precipitation reactions — (i) the formation of lead chloride ($PbCl_2$) from lead nitrate and hydrochloric acid solutions, and (ii) the formation of lead chromate ($PbCrO_4$) from the $PbCl_2$ precipitate and potassium chromate solution — were used to introduce the concept of chemical equilibrium.

These reactions were selected because they are easy to implement, fit well with the students' prior knowledge and favor educational improvements. Procedural and motivational questions inherent in the experimental class are likely to attract students interested in an environment conducive to the process of constructing ideas. [18]

Although the definitions of reversible and irreversible reactions and equilibrium constants were previously addressed, the concept of a "dynamic model" was used to explain these subjects in a more attractive manner, by presenting the principal macroscopic characteristics of chemical reactions at equilibrium.

For the groups students who tested sample B (reaction with 0.10 mol.L^{-1} $FeCl_3$) and observed a lilac-colored solution, it was explained that the coloration confirmed the presence of ASA, according to the ionization of ASA in aqueous medium and subsequent reaction with Fe^{3+} ions (Schemes 1 and 2) explained during class.



Acetylsalicylic acid (ASA) Acetylsalicylate (ASA^-)

Scheme 1. Ionization equilibrium of ASA. [16]

The acidity constant (K_a) for ASA is described by Eq. (1): [16]

$$K_a = \frac{[ASA^-] . [H^+]}{[ASA]} = 3,3 \times 10^{-4} \text{ mol.L}^{-1} \quad (1)$$

The complexation reaction of Fe^{3+} can be described by the following scheme:

$$Fe^{3+}_{(aq.)} + ASA^{2-}_{(aq.)} \rightleftharpoons \underset{\text{Lilac complex}}{(FeASA)^+_{(aq.)}}$$

Scheme 2. Formation of the iron (III) acetylsalicylate complex

Iron salicylates and catecholates are important in the study of non-heme iron enzymes. [19] In these biological systems, the oxidation state of iron is easily altered, and is catalytically relevant. In the pharmaceutical field, salicylic acid has been used as a Fe^{3+} complexing (chelating) agent. [20] Another important application of salicylate is in analytical chemistry, since $(FeASA)^+$ is a colored complex that can be used in the quantitative determination of iron and to establish the stability constants of $(FeASA)^+$ complexes by spectrophotometry. [21-23]

Complex stability constants provide values to asses relative stabilities, since larger values indicate more stable complexes. The stability constant (K_{st}) for the complex can be calculated using Eq. (2): [24]

$$K_{st} = \frac{[(FeASA)^+]}{[Fe^{3+}] . [ASA^{2-}]} = 2,5 \times 10^{16} \text{ mol.L}^{-1} \quad (2)$$

The test performed on samples A and B were classified as investigative and those for sample C as conclusive tests. The students analyzed the results obtained for samples A and B and the written message on paper, could attest that the person had been victim of murder or suicide; and in the absence of a message, death from natural causes was confirmed.

The message revealed on some pieces of paper (sample C) was explained in terms of complexation reactions, because when rubbing the cotton swab moistened with $FeCl_3$ on the paper, red coloration was observed, which was attributed to the reaction of Fe^{3+} ions with thiocyanate (SCN^-) ions impregnated in the paper from the ink.

Formation of complexes of thiocyanate (SCN^-) with iron (III) is widely used for the photometric determination of iron (III), since Fe^{3+} ions are strongly complexed by SCN^-. Depending on the concentration of SCN^- present in solution, complexes of various compositions may be formed as the ratio of SCN^- linker and Fe^{3+} may range from 1 (at low SCN^- concentrations) to 6 (maximum with excess SCN^-) and all complexes are similar in color. [25] At low concentrations, formation of $FeSCN^{2+}$ predominates, with an intense red color. In this study, the ratio $[SCN^-]/[Fe^{3+}]$ was 1:1 for the formation of $Fe(SCN)^{2+}$ complex, according to Scheme 3:

$$Fe^{3+}_{(aq.)} + SCN^-_{(aq.)} \rightleftharpoons \underset{\text{red complex}}{Fe(SCN)^{2+}_{(aq.)}}$$

Scheme 3. Formation of the iron (III) thiocyanate complex

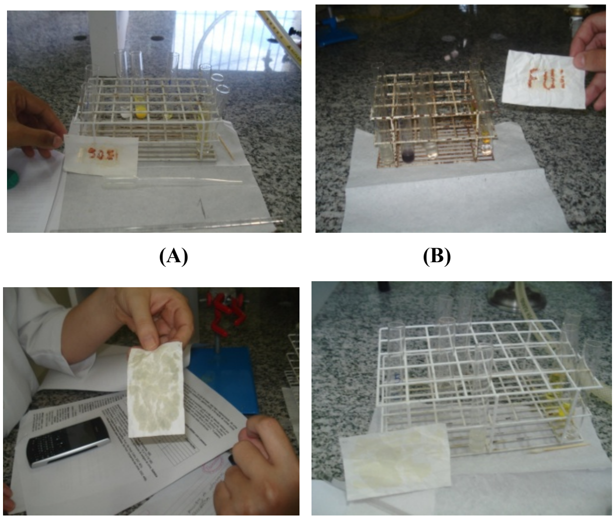
Frank and Oswalt [26] were the first to use a series of solutions with low concentrations of Fe^{3+} and SCN^- to calculate the equilibrium constant for the reaction presented in Scheme 3. When the Fe^{3+} concentration is much higher than that of SCN^-, the lower concentration is used as that of the complex and a plot of absorbance as a function of concentration of complex is constructed to determine the molar absorptivity and equilibrium constant. [27]

The thermodynamic constant, K_f, for the formation of $Fe(SCN)^{2+}$ can be calculated using Eq. (3) and its value is: [28]

$$K_f = \frac{[(FeSCN)^{2+}]}{[Fe^{3+}] . [SCN^-]} = 7,1 \times 10^2 \quad (3)$$

In this test, students were given the opportunity to experience another practical situation involving equilibria. In addition, the similarity of this test to that used for the identification of Fe^{3+} in the systematic cation analysis in the experimental analytical chemistry discipline is highlighted.

Results obtained for the revealed message written on the piece of paper (sample C) are shown in Figure 1.



(A) **(B)** **(C)** **(D)**

Figure 1. Photos of the paper containing messages revealed with $FeCl_3$: "SOS" (A), "FUI" (goodbye, B), without messages (C) and (D)

A total of 10 groups of students were able to successfully complete all steps of the experimental class, and most correctly obtained the data for each of the samples provided.

This aligns well with the concept of rediscovery, since an investigative situation was presented. The students started with experimental facts and finished with conclusions and generalizations. Unlike typical "experimental classes" proposed by some textbooks, which aim to confirm the "truth" proclaimed in these books, the technique of rediscovery aims to obtain experimental facts which can subsequently be generalized, in line with the scientific method. [14]

All student feedback was positive, because according to them, they were able to contextualize the steps of the scientific method with the tests performed to identify the victim's "causa mortis."

From this experimental class it was observed that the majority of students became more interested in the theoretical aspects underlying the classes on chemical equilibria. It is necessary to confirm that the success in the correct execution of experiments was mainly due to the commitment of the students in their attempts to explain phenomena in light of concepts already discussed in the qualitative analysis principles lectures.

At the end of the class, two questionnaires were given to the students to evaluate the skills/abilities related to the subjects taught in the class and to determine the motivation of the students to study forensic chemistry (Tables 3 and 4).

Analysis of questionnaire presented in Table 3 revealed that: (a) students stated that they used/developed skills related to forensic chemistry/scientific method experimentation: observation (96%), group work (57%), and motivation (36%); (b) that the majority (75%) of the class said that they improved their ability to observe and record information, of which 64% said they feel more prepared to analyze data and propose hypotheses, and 36% declared that they are more motivated and interested in chemistry.

Table 3. Questionnaire with closed answers regarding the theoretical/behavioral aspects of the students after the experimental class on chemical equilibria

What abilities did you use/develop in experiment class?
( ) Observation. ( ) Creativity. ( ) Motivation
( ) Work in groups. ( ) Others. Which are?
About the experiment relating topics of forensic chemistry and scientific method, you can say that:
( ) improved their ability to observe and record information;
( ) is better prepared to analyze data and propose hypotheses for the observed phenomena;
( ) increased their ability to verify facts and topics previously studied;
( ) others. Which are?
What contributions did you obtain in this activity for your training as a future professional of Chemistry?
( ) Learning new scientific concepts.
( ) Understanding the nature of science and role of scientist in an investigation.
( ) Improvement of the abilities manipulation of lab materials.
( ) Application of the knowledges previously acquired. Leave a reply.

When questioned about the execution of the experimental activity involving forensic chemistry principles as part of their education as future chemistry professionals, a majority of the students interviewed opted for more than one item on question 3. Therefore, the related results are presented in percentages where 68% of students answered that they had a better understanding of the nature of science and of the role of a scientist in a criminal investigation, 64% said they learned new concepts, 29% admitted to having improved their abilities in the manipulation of lab materials, and 39% were able to apply previously acquired knowledge.

In relation to this topic, some students wrote comments that read: *"learning new knowledge that may one day practicing them", "valuing chemistry by experiments using simple substances, knowledge of more possibilities of my future career", "discovering how chemistry can help in an investigation",* and *"practical application of the scientific method"*.

The questionnaire presented in Table 4 prompted the students to think about the theoretical/practical aspects of the experimental class.

Table 4. Questionnaire with open answers regarding the theoretical/practical aspects of the experimental class

1. What steps of the scientific method have you been able to visualize in investigating the motivation of the person's death?
2. Did you find any difficulty in performing the experimental class? Leave a reply.
3. Did you find it difficult to interpret experimental results? Leave a reply.
4. Were you able to conclude anything about the investigation? Leave a reply.
5. Do you know what is hypothesis?

When asked to identify the steps of the scientific method used in the experiment, it was observed that only 53% of students were able to correctly identify the steps, 29% forgot one or more steps, and 18% could not identify any steps. These results were lackluster, but the scientific method topic was approached for first time, as this group had not yet taken the scientific work methodology course. This provides evidence of the importance of this course in the first semesters of undergraduate chemistry courses.

When asked about the difficulties encountered in execution of the experimental class, all students stated that no difficulties were encountered and all managed to reach the correct conclusion regarding the sample provided by teacher. With regard to this question, some students wrote: "*In principle I was anxious ... but later it was easy to discover the cause of death*", "*practical class was easy to perform, as there was the help of an experiments guide in which we had easy understanding of how to execute and get results*" and *"the materials, reagents, were organized on the bench of experiments"*.

When asked if they encountered any difficulty in interpreting the experimental results, a majority (93%) said that they did not experience difficulty. Answers given by students were as follows: *"I had no difficulty because I had read the experiments guide and attended to the pre-lab"* and *"tests were confirmed by the color changes of the reaction products"*.

Only 7% of the class said that they encountered difficulties *"because they were experiments to elucidate death crimes"*. However, despite the different opinions concerning the difficulties of interpreting results, all the students, when observing and analyzing the provided samples, correctly identified the "causa mortis" of the person found on the apartment floor.

The lack of knowledge regarding the philosophy of science was clear from the majority of undergraduate chemistry students at this university, as only 29% were able to correctly answer the question: "what is a hypothesis?", which corroborates other studies conducted by the authors (unpublished data).

4. Conclusions

Experimental classes generally arouse interest of undergraduate chemistry students, but this class especially increased students' interest and curiosity regarding forensic chemistry and was able to contextualize different kinds of chemical equilibria with current themes that unfortunately are not pleasant (unresolved crimes). These themes are part of daily life and are often the subject of books, films, and theatrical performances.

This experimental class included more intense participation and discussions compared to those of previous practical classes. This was also observed during the pre-lab class, and success was achieved in the orderly execution of experiments. This, is a crucial factor to achieve the correct conclusion to unravel the mysterious death in the fictitious scenario. All students accepted the teacher's instructions to observe the steps of the scientific method, seek explanations, and confirmation hypotheses.

With regard to the theoretical approach of the scientific method, a lack of maturity was observed because of the novelty of this concept. However, rediscovery improved the learning outcomes with regard to chemical equilibria to a satisfactory level, since the students were initially provoked to execute and observe assays involving chemical equilibria and to draw conclusions regarding importance of chemical equilibria in the assays performed by forensic experts.

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