Case Report

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Forensic chemistry in a pedagogical workshop: mobilizing teaching and learning for high school students

Summary

This case report argues that forensic chemistry in conjunction with inquiry teaching can contribute to the teaching and learning process in an effective way for students in the third grade of high school at a public school. This process took place in a pedagogical workshop entitled Cases and Traces: detective workshop, proposed in the curricular component Research and Educational Processes III and IV, at the Instituto Federal Catarinense - Campus Araquari - Brazil. The methodology was based on the Three Pedagogical Moments, which prioritized teaching by investigation, interdisciplinarity and the degree of freedom of the students. The results showed that the approach promoted discussion, reflection and explanation of the criminal case, placing the student in a central position and favoring the participants' engagement in solving the case. After application, it was found that forensic chemistry in an inquiry teaching approach can promote an effective teaching and learning process for students.

Keywords: forensic chemistry, inquiry teaching, pedagogical workshop, learning, interdisciplinarity

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Abbreviations: TV, television; DNA, deoxyribonucleic acid; pH, hydrogen potential; IPM, post-mortem interval; IFC, Instituto Federal Catarinense

Introduction

Forensic science comprises a body of scientific knowledge and techniques needed to elucidate not only crimes, but a variety of legal issues, whether civil, criminal or administrative. Because of its wide-ranging nature and its investigative nature, it has the potential to arouse curiosity and interest among teenagers in cases reported on social media or TV series.[1] From this perspective, the choice of this theme in the planning and development of a pedagogical workshop is justified, specifically in relation to the teaching of forensic chemistry in an investigative case, with the intention of providing learning methods and techniques for analyzing evidence with a view to elucidating cases involving crimes. Some concepts related to forensic science involve chemical knowledge, i.e. they act in the "use/application of knowledge of chemical science to problems of a forensic nature".[2] However, when forensic chemistry goes into the school context, it is necessary to consider aspects that surround the teaching and learning process, which enhance this knowledge in didactic strategies favorable to research and scientific practices.

The idea of solving a crime is based on the premise of mobilizing students in an experience that is out of the ordinary, making chemistry more interesting and meaningful, promoting active participation and involvement in the learning process. The introduction of innovative approaches, such as investigative teaching, aims to break with passivity and stimulate students' curiosity, creativity and critical thinking, providing a richer and more meaningful educational experience. Furthermore, "forensic science can provide the opportunity to develop interdisciplinary activities in the teaching-learning process".[1] In view of the above, this article is an experience report that describes the development of a pedagogical workshop, entitled: Cases and traces: detective workshop, designed and planned in the curricular component: Research and Educational Processes, in the Chemistry Degree Course, of the Federal Catarinense Institute - Araquari Campus - Brazil, on the theme of forensic chemistry through teaching by investigation, for students of the third grade of high school, in the evening, of a state public school, held on November 6, 2023. Initially, considerations will be presented on Forensic Chemistry as an enabler of the inquiry-based teaching approach. The pedagogical workshop will then be described, highlighting the methodological procedures used and the data generated from its development. The data collected in the pedagogical workshop that highlights aspects of the learning process through the investigation and resolution of a criminal case. Finally, we discuss possible considerations based on the experience of the pedagogical workshop, which specifically aims to provide future teachers with tools through successful experiences in planning and developing teaching materials for learning chemistry.

Investigative teaching as a didactic approach to teaching forensic chemistry

Forensic science as an area of knowledge has become interdisciplinary, as it encompasses knowledge from genetics, ballistics, anthropology, toxicology and entomology, among others; which in some way correlate with chemistry, specifically forensic chemistry[2] defines forensic chemistry as [...] "the branch of chemistry that deals with forensic investigation in the field of specialized chemistry, in order to meet aspects of judicial interest"[3] consider forensic chemistry to be "[...] a branch of forensic science, which uses chemical techniques and concepts to investigate the contribution of certain factors in the realization of crimes in order to provide significant collaboration to forensic science"[1] add that "the knowledge of chemistry and related areas to solve problems of a criminal nature, using analytical, organic and physical-chemical methods, mediating between chemical knowledge and social reality".

In forensic analysis, the areas of chemistry that help elucidate the presence or absence of chemical compounds at crime scenes are analytical and organic chemistry. For example, when fluids of biological origin are used as evidence, knowledge of organic

chemistry and biochemistry is required, which highlights the cross-cutting nature of forensic chemistry in relation to the diversity of concepts linked to solving crimes.[1,2] In the field of forensic genetics, investigations are carried out using DNA (deoxyribonucleic acid), which is responsible for genetic characteristics. DNA is a double helix of nucleotides comprising the nitrogenous bases: adenine, cytosine, guanine and thymine, which are structurally organic compounds made up of carbon, hydrogen, oxygen and nitrogen. The relationship between genetics and forensic chemistry occurs in the identification of criminals through the investigation of biological materials found at crime scenes: blood, hair, nails and semen.[2] According to[2] "firearms, their ammunition and the effects of the shots produced by them, whenever they have a direct or indirect relationship with criminal offenses, aim to clarify and prove an occurrence". This knowledge is linked to forensic chemistry through the analysis of metallic and non-metallic particles and even gases expelled when a projectile is fired. The process of analyzing this residue is called residuography.

One of the applications of forensic anthropology is the "study of hominid fossils and skeletonized human remains that have been buried for a long time".[4] It can also help in the identification process in cases where the evidence has lost other forms of analysis, such as fingerprints or physiognomy. The main relationship between forensic chemistry and anthropology is radiocarbon dating, which looks at the amount of carbon 14 (a radioactive isotope of carbon) present in the body. This is a determining factor in knowing when a person or animal died, because the lower the levels of carbon 14, the longer the body has been dead, so it is possible to date the death.[5] Farias R[2] states that forensic toxicology "is a specialized area of study of pharmacology, and can be defined as the study of toxins and their antidotes." This knowledge is undoubtedly related to forensic chemistry, as it includes the study of various substances that have toxicological action, identified as drugs, marijuana, cocaine, morphine, heroin, these being organic compounds with psychoactive principles, and that their excessive use causes overdose.

Forensic entomology, "is the study of insects and other arthropods associated with various criminal issues",[6] relates to the post-mortem interval (PIM) and the life cycle of insects, the main relationship with forensic chemistry is the "development of insects according to temperature and the recognition of the succession of arthropods involved in the decomposition of organic matter",[6] where the decomposition process is nothing more than successive chemical reactions,[6] where the process of decomposition is nothing more than successive chemical reactions, and biochemistry can also be related to the life cycle of insects. Based on these theoretical assumptions, it is possible to see the potential of using forensic chemistry techniques in the classroom, with the intention of enabling student engagement, interest and active participation, in order to promote the understanding of concepts and their practical applications, enabling the construction of scientific knowledge.[7]

In traditional methodologies, students are often placed in a passive position, receiving information unilaterally and having to memorize concepts without a deep understanding,[3,8] points out that the traditional approach does not encourage students to develop critical thinking, creativity and autonomy. In favor of this perspective, research in science education has been dedicated to developing teaching approaches that seek to arouse students' interest and motivation, encouraging active participation and effective engagement in the learning process. Among these, the inquiry teaching approach allows for the collective construction of scientific knowledge through investigation, experimentation and dialog.[9–11] The inquiry approach to science teaching encourages curiosity by putting students in the role of investigators and encouraging the search for answers and solutions. Instead of being mere recipients of information, students are encouraged to ask questions, raise hypotheses, collect data, which can be by carrying out experiments, analyzing and communicating the results, which promotes a deeper understanding of the concepts in articulation with reality in a meaningful way.[7,11,12]

This active and participatory approach has proven to be effective in the learning process, as it develops essential skills such as critical thinking, problem solving, effective communication and group work. According to,[13] the investigative approach provides an environment in which students can recognize and reflect on their own ideas, negotiating different points of view with other students and evaluating their usefulness in relation to the theories presented by the teacher. From this perspective, the teacher acts as a mediator, guiding the students through the proposed actions, enabling discussions, provoking conversations in which they can present their explanations and arguments, contributing to the construction of knowledge,[11,14] highlights two essential actions for approaching scientific themes/content from an investigative perspective: the degree of intellectual freedom given to the student and the elaboration of the problem, because "[...] it is the proposed problem that will trigger the students' reasoning and without intellectual freedom they will not have the courage to expose their thoughts, their reasoning and their arguments".[14]

In the meantime, it is important to consider the construction of arguments that support their positions and discussions, which for[15] occur in three ways: pragmatic, argumentative and epistemic, where the latter is marked by the deepening of understandings. By considering the teacher an epistemic authority, their role in promoting interactions is indispensable for the construction of new knowledge and for effective engagement among students.[16] When it comes to investigative teaching, the use of activities related to forensic science has proven to be effective, as it enables the application of scientific knowledge in the classroom to solve crimes.[1] It is believed that incorporating techniques related to forensic chemistry into chemistry teaching enables students to engage with and investigate cases that require an active stance, considering the collection of data and analysis of evidence that promotes the development of procedural skills for learning science, problem solving, group work and the development of critical thinking.[3,17] Furthermore, the benefits provided by the use of active methodologies in the teaching and learning process are significant, as they act on students' motivation, autonomy and authorship.[18]

It is argued that the case study together with investigative experimentation has the potential to mobilize students in learning in an interactive way, developing cognition, cooperativism, perception and independence in the process of solving a case, from the perspective of[19] "[...] the student's action should not be limited only to the work of manipulation or observation, [...] they should reflect, discuss, explain, report, which will give their work the characteristics of a scientific investigation". In addition, the aim is to prioritize interdisciplinarity, integrating chemistry with other areas of knowledge, contributing to learning.

Methodological procedures

This experience report takes a qualitative, analytical-descriptive and interpretative approach, aiming to discuss the potential of the pedagogical workshop - Cases and Traces: detective workshop, developed with high school students, in relation to engagement in solving the criminal case with a view to learning techniques/methods

used in forensic chemistry. Methodologically, the pedagogical workshop was based on the Three Pedagogical Moments:[20] initial problematization, when everyday situations that are involved with the proposed topic are discussed, encouraging students to present their previous knowledge about the situation being addressed. In the organization of knowledge, the teacher develops practices and addresses important concepts for understanding the situation being studied. And in the application of knowledge, students take ownership of the concepts covered in relation to their context.

The activities developed in the pedagogical workshop took place in the school's biology laboratory, with 30 students from the third grade of secondary school, in the evening, who interacted in a playful setting, built for this moment. In the initial problematization - sticky notes were handed out, the teachers/mediators (the Chemistry degree students teaching the pedagogical workshop) began with some questions, asking the students to write down their answers to the questions on the sticky notes:

I. What is Forensic Science?

II. What is forensics?

III. Do you know of any cases in which forensics is involved?

IV. Have you ever watched a series or movie that deals with this subject?

Based on the students' notes, the answers were shared and the planned actions continued. In the organization of knowledge, knowledge related to forensic chemistry was covered in an expository and dialogical way. After the conceptual systematization stage, the workshop's practical proposal was introduced: solving a crime through the students' interpretation of the suspects' statements, the characteristics of the crime and the results of five experiments. Each group received a handout with investigative activities using forensic techniques: DNA identification; substance identification using pH (hydrogen potential); papilloscopy; ballistics and deciphering messages in invisible letters - Chart 1.

Chart 1 Forensic techniques used in the investigation of criminal cases

DNA identification - Each group received four samples of artificial strawberry juice, each representing the blood of the suspects in the crime, and one sample of natural strawberry juice representing the blood that was collected at the crime scene. Part of the experiment had already been carried out prior to the workshop. The students analyzed a blood sample (this sample contained the strawberry DNA that had already been extracted) found at the crime scene, and based on this, they had to identify the presence of genetic material, which consisted of putting a few milliliters of alcohol on each sample and identifying which one indicated the presence of DNA.
Identifying pH through the red cabbage solution test - Each group received four samples (sugar, lemon, bleach and sodium bicarbonate solutions), representing hallucinogenic drugs, nut extracts, painkillers and poison respectively. The lemon juice represented the sample taken at the autopsy. To identify the substances, glassware, pipettes and red cabbage extract were used as a pH indicator. The murder victim was allergic to painkillers and using a sample of a solution containing an unknown substance found at the autopsy of the body, the students had to identify the possible substances present in the victim's body using the acid/base indicator, comparing the resulting coloration in the presence of red cabbage.
Papilloscopy - the materials used were charcoal powder, a switch, brushes, adhesive tape, sulphite sheet and a Petri dish. The switch was the item taken from the crime scene, as it contained the suspect's fingerprints when he turned off the security cameras. Using paintbrushes, the students put powdered charcoal on the switch to reveal the fingerprints, removed them with adhesive tape and fixed them to the paper for a better view, after which they had to compare them with a database of the suspects' fingerprints.
Ballistics - A mock-up of the crime scene (Figure 1) was used for ballistics, where the students observed and analyzed the clues that incriminate some suspects, correlating them with other experiments. In the model there was a blood sample on the window, left by the perpetrator of the crime; this blood sample was analyzed in the DNA extraction experiment. In addition, the students had to see inconsistencies in the victim's statements and cause of death, such as the location and angle of the gunshot.
Invisible letters - Some papers were found at the scene of the crime, with indications that they could contain messages written in lemon juice. The message is revealed by heating the area where the lemon juice is present. The main idea of this experiment was to offer clues to the suspects through statements that a character made to the victim of the crime. The students then had to reveal three cards and write down what they were seeing.

Source: Authors' collection.

Figure 1 Crime scene model.

Source: Authors' collection.

The teachers/mediators presented the contents of the handout (descriptive material about the proposal) and the board. The board consisted of a visual representation containing all the experiments, statements and characteristics of the suspects, so that the students could visualize the experiments of the other groups Figure 2. The handout contained the same information as the board to make it easier to handle and avoid crowds around the table containing the board, but each group received the handout only for the experiment they were to carry out Figure 3.

The main objective of the investigative activity was to identify the culprits of the crime. The experiments were not explained verbally to the students; they were encouraged to read and start the practices based on their interpretation and logic. The teachers/mediators intervened only when doubts arose during the process, thus promoting greater autonomy and freedom for the students. In the application of knowledge, after carrying out all the experiments and analyzing the results, each group reached a consensus on the perpetrators of the

crime. Each group presented their hypotheses about the possible suspects in the crime to the class. After all the groups had presented their results, a discussion took place in the large group, with the aim of everyone reaching a consensus on the outcome of the crime, including clarifying any doubts. At the end of the workshop, the students were asked to answer two questions: What did you learn from this workshop? What worked and didn't work in this workshop?

Figure 2 Board with information about the experiments.

Source: Authors' collection.

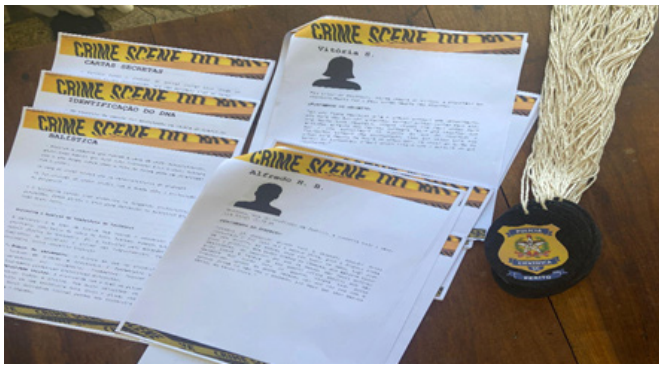

Figure 3 Handout with information on the criminal case and instructions for carrying out the experiments.

Source: Authors' collection.

It's important to note that scientific knowledge of chemistry, biology and physics was covered in the experimental activities proposed in order to unravel the investigation of the crime through analysis techniques. In papilloscopy, adsorption occurs through interactions between molecules, which highlights the concepts of intermolecular interactions. In DNA extraction, the concepts of density and solutions, as well as integration with biology. As for ballistics, physics concepts were used by analyzing the range and trajectory of projectiles expelled by weapons. In the invisible cards, chemical reactions were shown by the change in color, as the citric acid in the lemon turns dark when exposed to heat, as well as the identification of substances using the acid/base indicator. In all the experiments, the students have to handle glassware, equipment and solutions containing the reagents.

It should be noted that all the experiments took place at the same time and with the attention of the teachers/mediators, always urging the students to develop coherent answers to solve the case and exemplifying the importance of the experiments for solving it, as well as the scientific knowledge on which this experimentation was based. The evaluation process used in the workshop was based on how close the students came to the real story of the crime, from how it happened, the suspects involved and how each experiment would be related to this story, it should be noted that the story of the crime was not told to the students.

Results and discussion

The results discussed refer to the students' previous knowledge collected in the initial problematization, the students' interactions during the investigation of the criminal case and the learning identified after the pedagogical workshop was completed through the two questions. The students didn't feel comfortable at first, probably because it was the first time the teachers/mediators had spent time with them. However, when they were asked about TV series and films involving crime investigations, they showed interest and participated effectively, pointing out some criminal cases with national repercussions. When asked about the concept of forensic science and criminal investigation, the students were unable to answer. This proves the importance of knowing what the students know about the topics covered in the classroom, enabling teachers/mediators to act assertively in conceptual approaches after this point, ensuring meaningful learning, which according to[21] "is when ideas expressed symbolically interact in a substantive and non-arbitrary way with what the learner already knows". In this case, the students have no prior knowledge of forensic science, structured in scientific language, only what they watch in episodes of TV series, which could influence the resolution of the criminal case proposed in the educational workshop.

In order to discuss the students' interactions during the resolution of the criminal case with the learning after the pedagogical workshop, it is possible to see that the students had more autonomy to investigate the crime scene, developing hypotheses and testing those using forensic techniques. This made them feel more comfortable, considering them to be in a central, more important role than in the conventional way (an expository class where the student has a passive attitude). This corroborates what[10] says about the didactic approach of inquiry teaching, which is "promising for the appropriation of epistemic practices, since it presupposes the creation of a learning environment in which the student participates actively in the investigation, also valuing epistemic and social aspects of the scientific enterprise". From the observation that the students had more autonomy in conducting and carrying out the activities that involved solving the criminal case, it was possible to observe the characteristics that identify teaching by investigation, which in the pedagogical workshop was intended for the students to construct explanations for the data collected and establish how to communicate the conclusions.[10]

The attitudes identified in each group were positive and assertive, since some of them were reading the guidelines on the criminal case individually, while in others, one student was reading to the rest of the group, this was observed as a division of tasks and engagement. The students realize the importance of reading carefully, observing the details, the hypotheses of all the participants in the group and analyzing the conclusions in the light of the data collected in the experiments; these findings are related to the students' autonomy in solving the criminal case. This represents an opportunity to engage in epistemic practices,[10] as evidenced by the responses of three students: *"Paying attention to the small details". "To identify a crime scene you have to work as a group". "We have to pay a lot of attention to details, testimonies and listening, analyzing opinions and other experiments".*

All the groups did the experiments excellently. There were times when mediation was needed, but in none of them did the teachers/mediators tell the answer or any part of the story, they just guided the development of the investigation. For example, the students doing the invisible letters experiment were having difficulty carrying out

the experiment, and during the mediation they were shown how the color of a lemon changes in the presence of heat. In ballistics, students needed help to understand physics concepts related to the range and trajectory of projectiles expelled by weapons. In papilloscopy, the differences in fingerprint morphology meant that concepts relating to intermolecular interactions had to be addressed. In this case, the intervention of teachers/mediators was important, as they represent the epistemic authority in the classroom at that moment, relevant for helping students and mediating discussions.[22] Finally, the conceptual approaches proposed showed the contextualization evidenced in the case investigated through forensic chemistry and/or forensic sciences. In this respect, it is effective for learning that students engage in discussions, which show perceptions of what is present in their reality, enabling them to seek to solve a problem proposed by the teacher, providing the exercise of practices and reasoning of comparison, analysis and evaluation commonly used in scientific practice.[12]

At the end of the workshop, we could see that, through experimentation and investigation, the students had come up with a resolution to the case that was practically identical to the story envisioned by the teachers/mediators, with few disagreements between the students. With regard to some of the perpetrators of the crime, they came up with very valid arguments for classifying this character as the perpetrator. Blank sheets of paper were provided for the students to write down their hypotheses about the criminal case while they searched for new evidence of the culprits. Two groups recorded their ideas about solving the crime, described in the following paragraph.

At dinner with the victim, the suspect Clara contaminated the victim (with painkillers), after he was unconscious in his room when the effects took effect on the victim, the suspect Luciano, Clara's husband, climbed in through the window and murdered the victim. Some notes that were scribbled are shown below: The butler may be an accomplice, the cameras may have been deactivated for no apparent reason, the only one with internal access would be this suspect. The brother could be the mastermind (the only one who would profit from the victim's death). (Group 1)

We found out that it was Luciano because he had a fight with the victim related to his wife's (the victim's son) past with the victim and his blood was compatible with the sample found on the window. (Group 2)

These records show how the students structured their arguments to indicate who was guilty of the crime. Argumentation is a basic activity of thought from the point of view of understanding the processes of constructing understanding, whether orally or in records, which makes it possible to highlight students' ideas, concepts and positions in explaining phenomena.[12] Throughout the process of solving the criminal case, the students had discursive interactions in order to solve the proposed problem. From this perspective, discursive interactions promoted the argumentative process, contributing "directly to the development of thought and, consequently, to intellectual development".[12] The answers to the questions at the end of the pedagogical workshop relate the students' learning and perceptions, taking into account all the activities developed during the pedagogical workshop. It is possible to see progress in learning about the work of a criminal expert, as indicated in the students' answers: *"How the role of a criminal expert works, evidence analysis, substance analysis, crime interpretation". "I learned about how experts follow various steps and fundamentals." "I learned that it takes a complexity of departments to solve a case for scientific experts [...]".*

In this way, it is possible to see what the students have learned, considering that at the beginning of the workshop they were unable to answer the question about the definition of forensic science and the work of a criminal expert.

When asked about what worked and what didn't in the workshop, the majority responded positively in relation to the activities provided to solve the criminal case, as evidenced by one of the answers: *"The whole plot worked well, the lesson went well and with great class participation to achieve the proposed goals".* The effective participation of the students throughout the pedagogical workshop showed that the use of investigative teaching through the resolution of a criminal case was relevant to student engagement, mobilizing learning and investigative attitudes favorable to science education.

Conclusion

The main aim of the educational workshop - Cases and Traces: detective workshop - was to find out what potential there was in terms of student engagement in solving criminal cases with a view to learning the techniques/methods used in forensic chemistry. The observations and findings made during the application of investigative activities from the perspective of forensic chemistry were favorable and effective in terms of student participation, data collection and experimentation, the development of hypotheses and the construction of arguments for solving the criminal case. At every stage, the students showed commitment and complicity with the proposal, demanding their attention, reading, group discussions, reasoning in the face of the evidence found in the experiments involving techniques used in forensic chemistry, creating an environment conducive to learning and exercising autonomy in making decisions about solving the criminal case.

The students were able to take ownership of the experiments, developing procedural skills for learning science, encouraging them to reflect, discuss, explain and report, making a significant contribution to the learning process. All the findings found in this experience corroborate the research of[7,9–11] that the inquiry teaching approach allows for the collective construction of scientific knowledge through investigation, experimentation and dialogue, where students are encouraged to formulate questions, raise hypotheses, collect data, which can be by carrying out experiments, analyzing and communicating the results, which promotes a deeper understanding of the concepts in articulation with reality in a meaningful way.

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Conflicts of interest

No conflict of interest.

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