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Laboratory Experiment

Sustainability in Practice: Using Residual Biomass As a Theoretical-Practical Strategy to Bring Students Closer to Valuating the Activity: Perceptions of Students and the Concepts of Chemistry and Environmental Issues

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ABSTRACT: With the goal of bringing scientific research closer to students and stimulating their professional skills and competencies, this work is aimed at analyzing the benefits that High School students can obtain from performing scientific theoretical–practical activities, using residual biomass, that are generally conducted at the Higher Education level. The theoretical-practical activities performed were focused on the following themes: sustainability, organic solid waste, adsorbents, pollution, and water treatment. The practical activities were carried out using inexpensive household materials/resources; that is, without the need for expensive materials or laboratory equipment. To aid them in the conduct of the theoretical activities, the students were provided professional guidance and orientation on how to prepare scientific reports, perform searches on Google Scholar, and access search systems to obtain scientific materials and publications through databases, repositories, portals and specialized Web sites. The conduct of the proposed scientific theoretical-practical activities helped stimulate the High School students' autonomy to perform experiments, understand the importance of scientific writing and how to write a scientific essay. Students who participated in the meetings said that the activities played an important role in helping them understand and associate chemistry concepts with issues related to the environment and sustainability.

KEYWORDS: *High school, adsorbents, chemistry, sustainability*

■ INTRODUCTION

For one to pursue a scientific career path, the individual is required not only to have knowledge of specific scientific topics, but also professional skills, including being good at writing, decision making, problem solving, planning and organizing. Although one can find competencies in the school curriculum that stimulate students' professional skills, Giordano et al. have shown that there are significant deficiencies and differences between the demands of the job market and the job candidates'/applicants' proficiencies/competencies, including the ability to develop and put critical thinking into practice and being well versed in problem solving.[1] When High School students actively engage in laboratory activities/practices that are generally conducted at the Higher Education (college) level, they acquire individual and group research experiences which can help stimulate and enhance their professional skills and competencies - as the skills and competencies from Basic Education (BE) are merged with Higher Education (HE) activities/practices, while contributing toward fulfilling the requirements and demands of the increasingly competitive job market. Apart from helping fulfill the requirements of the job market, the challenges posed by climate change and natural resources depletion point to the need for developing scientific theoretical-methodological practices and activities in schools that bring the issue of sustainability in the students' reality, so that it becomes an integral part of their daily lives.[2,3] Through the presentation and analysis of the theoretical-practical activities conducted by High School students, among the main objectives of the present study include bringing scientific research closer to BE students, with the valorization of prior knowledge, encouraging the reading of scientific texts, cooperative work, planning and conduct of experiments, and stimulating and developing students' skills and competencies in problem solving, scientific writing, and group discussion.[4]

Addressing scientific concepts and sustainability beyond theory is still a major challenge for the vast majority of science teachers. According to some researchers, daily routine practices that point to the importance of preserving the environment,

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such as the simple act of separating, treating and reusing organic waste, are still seen as a major problem by a significant portion of the population.[5] Due to the absence of a reutilization culture, the food chain generates a large amount of organic waste. In places where there are no waste collection systems, waste is discarded haphazardly into the environment, often on abandoned land or in rivers, causing soil contamination, direct pollution of water bodies and the proliferation of vectors that cause diseases.[6] Within this context, the following issues have emerged as prominent curricular initiatives in schools worldwide and beyond the academic level: sustainability, climate change and access to potable water. The United Nations (UN) and several countries are taking active measures that are intended to galvanize support and promote collaborative efforts, with a view to addressing these issues globally. By virtue of that, the Sustainable Development Goals (SDGs) were established for the 2030 Agenda as a form of awareness campaign for community development programs in several countries around the world.[7] As part of our contribution and responsibility toward addressing the issue of sustainability, it is essentially important for us to work on such topics in Basic Education subjects,[8] with a view to engaging the students in performing theoretical-practical activities that are intended to raise awareness of the sustainability problem.[9,10] In their work on sustainable practices, where they conducted experiments aimed at undergraduate students, Sammet and Valiyaveettil (2018) successfully demonstrated how fruit peels can be effectively used as adsorbents; however, the authors employed relatively expensive equipment to perform these experiments, and this may not be feasible to perform in many other schools due to the harsh realities of these schools, especially in poor regions.[11] In a study related to the combat of water pollution through the use of theoretical-practical activities with students at the BE level, Jian Shen et al. showed that most of the students had difficulty in understanding and writing scientific texts and performing laboratory activities; the authors recognized the need to conduct studies that address and show the importance of working on environmental issues at the school level.[12,13] Taking the above considerations into account, the present study reports the development of theoretical-practical activities, based on chemistry concepts and under the principles of sustainability, which are intended to help address environmental problems; the activities, which are aimed at BE students, involved the use of organic waste (food peels) as adsorbents and are targeted at stimulating the students' professional skills and competencies. With the conduct of these activities based on sustainable practices, the present study seeks to highlight the use of inexpensive household materials in scientific practices aimed at addressing environmental problems in our societies without the need for high-cost materials or laboratory equipment.

■ THEORETICAL–PRACTICAL ACTIVITIES

The research presented in this article was carried out with BE students, under the coordination and guidance of university professors and undergraduate students from the University of São Paulo (USP). All the activities reported here are an integral part of the project titled "Transforming waste into a product beneficial to the environment and human health" of the Institutional Scientific Initiation Scholarship Program for High School students (PIBIC – EM), funded by the National Council for Scientific and Technological Development (CNPq), a research funding agency in Brazil that offers scholarships for Basic Education students to develop research projects.

To aid readers' comprehension, the activities will be presented in 5 phases:

- Theoretical Activities:
  - Phase 1: Bibliographic Review
  - Phase 2: Safety Standards and Laboratory Procedures
- Practical Activities:
  - Phase 3: Adsorbent Production
  - Phase 4: Adsorption Test
- Final Theoretical Activity:
  - Phase 5: Scientific-Academic Writing

Theoretical Activity

All the theoretical activities were carried out in a classroom at the School of Arts, Sciences and Humanities of the University of São Paulo (EACH/USP). The steps and procedures executed in this phase are illustrated in Figure 1.

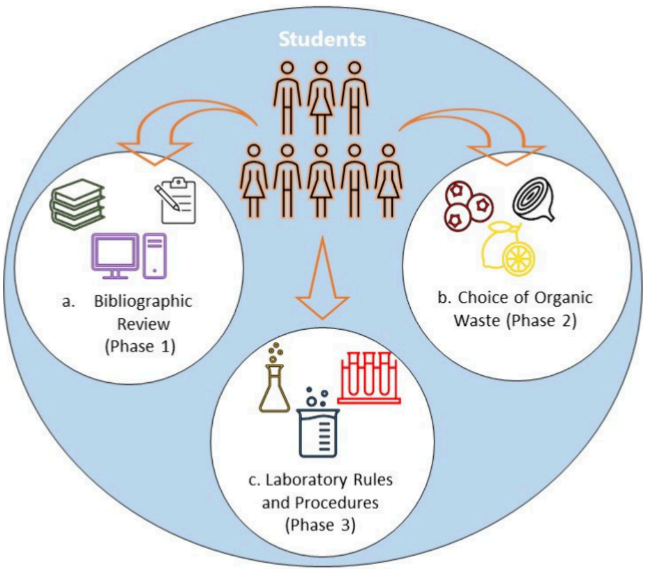

Figure 1. Step 1: Guidelines followed by High School scholarship-holding students for the development of the theoretical-practical activity: (a) bibliographic review on organic waste, sustainability and adsorption, (b) safety in the laboratory, and (c) selection and separation of organic waste.

Phase 1: Bibliographic Review. This theoretical activity involved 5 days of face-to-face meetings (4 h per day), where students were given lectures and presentation on the following: definition, typology and reliability of information sources; introduction to the Google Scholar search engine; and online library systems/platforms used for obtaining scientific materials and publications, with access to databases, repositories, portals and specialized Web sites.

Through this activity, students learned about the tool: "homework activity", which helped them in their search for scientific texts, using relevant keywords from the following topics: sustainability, organic solid waste, adsorbents, pollution and water treatment.

Students were instructed to access the UN Web site and analyze the SDGs related to the topics mentioned above; they were required to specifically analyze the following:

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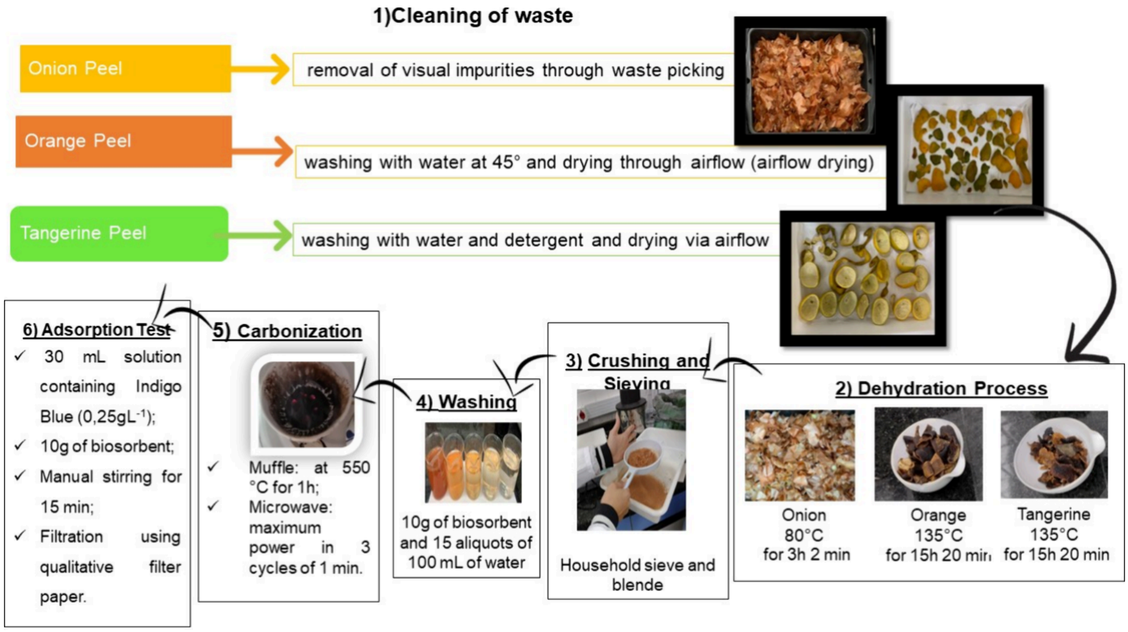

Figure 2. Practical activity—processing of organic waste (onion, orange, and tangerine peels): (1) cleaning of waste, (2) dehydration process, (3) crushing and sieving, (4) washing, (5) carbonization, (6) adsorption test. Waste picking and separation by the students for the production of adsorbent.

- SDG 4: This is aimed at ensuring quality education and for students to acquire the knowledge and skills necessary to promote sustainable development.
- SDG 6: This is aimed at improving water quality, reducing pollution.
- SDG 11: This goal deals with the promotion of sustainable cities and communities.
- SDG 12: This goal proposes the use of environmentally sound management practices for managing chemical products and part of municipal waste.
- SDG 15: This goal deals with the sustainable use of terrestrial ecosystems, through minimizing the use of land to install new landfills for the disposal of waste.

After gaining access to and reading the scientific bibliographic materials, five additional days of face-to-face meetings were organized (4 h per day) in order to allow the exchange of knowledge on each of the topics (sustainability; organic solid waste; adsorbent; pollution and water treatment) and provide clarifications for any doubts that the students may have had about the topics.

Regarding the topic "adsorbent", in addition to researching and studying the theoretical concepts of the material, the students deepened their searches for bibliographic references that dealt with the use of waste to manufacture adsorbents. Through their reading of scientific articles and national academic works, the students identified organic waste commonly discarded in everyday life by the population, and which had adsorbent properties. Thus, working under full autonomy, the students identified and defined three different types of waste, with adsorption potential, for the practical activity, which included the following: onion peel, orange peel, and tangerine peel.

Phase 2: Safety Standards and Laboratory Procedures. The second phase of the theoretical stage involved the preparation of the BE students to carry out laboratory activities. Two manuals were created by the university professors and undergraduate students at EACH/USP; these manuals were made available to students in digital and printed forms. One of the manuals described the Laboratory Safety Standards and the other one dealt with Basic Laboratory Principles: glassware, accessories and operation.

After reading the two manuals, 2 days of face-to-face meetings (2 h per day) were held for expository presentations of the glassware/accessories and procedures (weighing, drying, sieving) to be used/executed in the laboratory. These meetings were also used to clarify students' doubts about laboratory safety standards and the materials/procedures presented.

Practical Activity

The practical activities were divided into two phases (phase 3 and phase 4) and were carried out in the research laboratory of the Phytochemical Studies, Pollutant Analysis, and Waste Use Group at EACH/USP, in meetings that took place once a week, for 6 weeks, lasting 4 h a day. For each procedure, participants were given the autonomy to get their hands dirty during the practices while they received guidance from university students and professors.

Phase 3: Adsorbent Production. To produce the adsorbents, the students collected selected organic waste. These materials were obtained from waste generated in the homes of students, family, neighbors, friends, and businesses (supermarkets and grocery stores).

After collecting the necessary amount of waste, the experimental procedures were initiated: 1) cleaning of waste; 2) dehydration process; 3) crushing and sieving; 4) washing, 5) carbonization; and 6) adsorption tests. Each week, a different procedure was carried out using the waste, as shown in Figure 2.

Hazards. Although indigo blue dye does not present potential toxicity to human health and microwave equipment does not present a high risk in its case, we recommend that both should be handled with caution. To ensure safety, students should wear protective equipment throughout the experiment, including a lab coat, safety gloves, goggles, and a

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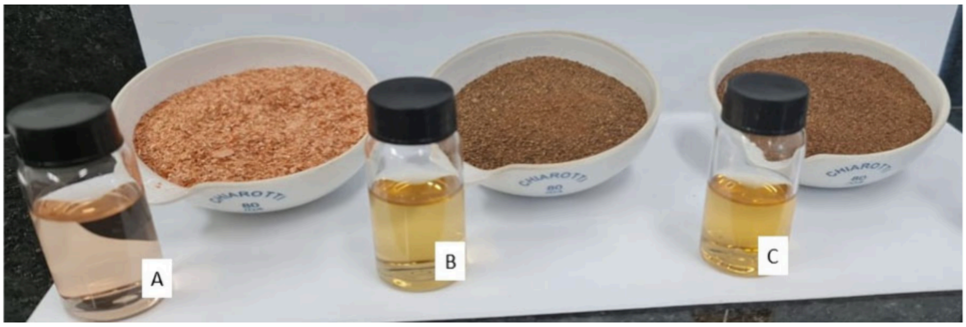

Figure 3. Biosorbent in powder form and solution obtained after washing with water: (A) onion peel, (B) orange peel, and (C) tangerine peel.

mask. In the event of contaminated exposure to chemicals, it is essential to wash with plenty of water. At least one instructor or graduate professor should be in the laboratory while the student is experimenting.

The waste cleaning stage was mainly intended for the removal of impurities such as fungi and earth from onion peel and the remaining pomace (pulpy matter) and/or other particles that have stuck in the orange and tangerine peels. The dehydration process was aimed at the removal of the water present in the waste in order to produce suitable biosorbents. With the aim of sharpening the students' logical reasoning, during this procedure, the concepts and calculations of moisture and yield were worked on, by weighing the residues before and after drying. The crushing and sieving of the dry shells were carried out in order to obtain homogeneous particles of a size characteristic of adsorbent materials (approximately 1 mm).

As they were derived from biomass, the adsorbents produced presented natural coloring substances which are soluble in water (Figure 3) and that could harm the students' visual assessment during the execution of the next stage (adsorption test). In order to eliminate these substances, the biosorbents were subjected to washing. The colors and the shade intensities of the washing water were used to explain the concept of content, concentration and type of organic substances present in each waste.

The steps taken in Phase 3 allowed the production of adsorbents using simple procedures that can be reproduced in schools, without the need for acquiring expensive materials, reagents, high-cost equipment or specific laboratory infrastructure. This procedure was complemented with the carbonization step, which led to the production of adsorbent materials in the form of charcoal. As it involves high temperature, during carbonization in a muffle furnace, the students followed the process without manipulating the samples and/or equipment. However, for an alternative carbonization process, one can use a domestic microwave, which is safer for High School students to handle and is quite viable to be employed in schools.

Phase 4: Adsorption Test. By testing the efficiency of the adsorbents they have developed for the treatment of dye-contaminated water, the students were critically assessed on their knowledge of the possibilities and routes of using solid waste, as well as their application of the adsorbent materials and the contextualization of the study carried out in relation to the SDGs and the Brazilian legislation on water. The efficiency of the adsorbents developed by the students was tested using the polluting substance indigo blue; this substance was used because it is one of the most commonly employed dyes in the textile sector, with its polluting activity widely reported in the world.[14−16] The use of dye in this analysis also allowed the students to see the removal of the dye with the naked eye, without the need for analytical equipment.

As an efficiency parameter, we employed the color limit value (called true color) defined in the Brazilian legislation. Based on a visual comparison of the color of the treated effluent with the standardized APHA-Hazen scale, which varies from intense yellow (250 mg Pt L^{-1}) to colorless (0 mg Pt L^{-1}), the apparent and/or true color is estimated. CONAMA resolution 357/2005 stipulates that effluents must be treated until they reach the true color of, at most, 75 mg Pt L^{-1}.[17] Under the GM/MS ordinance no. 888, the apparent color values must be, at most, 15 mg Pt L^{-1}.[18]

As can be noted in Figure 4, the materials developed (biosorbents and charcoal) were able to remove the blue dye

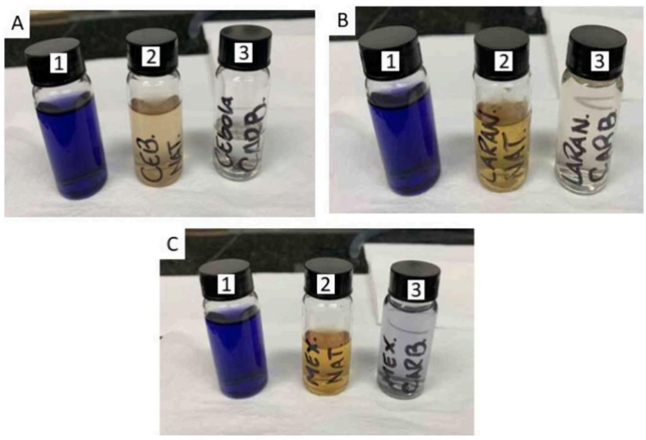

Figure 4. Glasses A.1, B.1, and C.1 contain water with diluted dye; glasses A.2, B.2, and C.2 contain filtered dye with in natura onion, orange and tangerine powder, respectively; glasses A.3, B.3, and C.3 contain filtered dye with charcoal made from onion, orange and tangerine peels, respectively.

from the contaminated water. In the case of in natura biosorbents, despite the washing process, substances were still released into the solution, leaving it yellowish. The charcoal removed the indigo blue pollutant, leaving the solution clear. For the charcoal produced from onion peel, the true color obtained was found to meet the true color range stipulated in the GM/MS no. 888 (maximum of 15 mg Pt L^{-1}). For the charcoal derived from orange peel, the true color approached the range of 40 mg Pt L-1, which is in line with the CONAMA resolution 357/2005 (maximum of 75 mg Pt L^{-1}).[17]

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The differences in performance and efficiency of the adsorbents in natural and carbonized forms allowed the students to clearly perceive the differences in the remediation capacity of the processes employed and the two types of materials produced (biosorbent and charcoal).

Final Theoretical Activity

Phase 5: Scientific–Academic Writing. After the practical activities, the students took part in five face-to-face weekly meetings (one per week), with each meeting lasting approximately 2 h. In this stage, the participants were provided guidance and orientations on the basic rules for preparing, writing and formatting scientific texts. The guidelines to scientific text writing provided to the High School students were conceptualized based on a report model developed by the students and researchers of EACH-USP. In addition, discussions were also held in the classroom on how to effectively prepare scientific texts; these discussions were used to teach the students how to contextualize scientific language information and structure technical-scientific-academic work, detect plagiarism, provide citations, prepare bibliographic references, and to acquaint students with the Brazilian standard writing rules - ABNT NBR 10719. After the experimental activities, the lessons were put into practice by the students when writing technical reports based on the mandatory standards of the Institutional Scholarship Program for Scientific Initiation for High School Students (PIBIC-EM). The reports were prepared in the form of a "homework activity", which contained the following sections: abstract, introduction, experimental part, results and discussion, conclusion and bibliographic references.

EVALUATING THE ACTIVITY: PERCEPTIONS OF STUDENTS AND COLLEAGUES

The preinitiation scientific extension activities in partnership with public schools took place over three consecutive years. Each scholarship lasted one year, and therefore, three to five scholarship recipients were selected for each year, depending on the number of scholarships the university made available to preinitiation scientific students. For this research, the activities of 12 high school scholarship students, each 15 years old, from a public school in São Paulo were analyzed and monitored. The participants had no previous experience in reading and writing scientific texts, nor in conducting theoretical-experimental activities within a university. Overall, this scientific project helped to raise students' awareness about the harmful socio-environmental effects associated with the current production and disposal of organic waste and how science works to mitigate them; this can be observed in some excerpts reported by the participants who we identified as Student 1, Student 2, Student 3, Student 4, and Student 5:

> *At the end of the project, we were able to understand that biosorbents are a good alternative material for water treatment [...] It was also possible to learn about how to search for bibliographic materials with reliable content and write reports in scientific format.*
>
> Student 1

By virtue of the activities developed in the project, the students had the opportunity to live in an environment where they were able to experience day-to-day life at a university in a research laboratory and acquaint themselves with scientific methodological practices that allowed them the freedom and autonomy to conduct research and critical analyses of the topics under consideration. Based on the theoretical knowledge acquired through this experience, the students were able to make informed decisions that contributed to the development of basic research on sustainability. The excerpts transcribed below were taken from the scientific report written by the students.

> *This theoretical activity, along with report writing, gave us more knowledge about research and how to improve the writing of theoretical works.*
>
> Student 2

> *The search and reading of bibliographic reference materials helped in the choosing of the residue to be used in this research and in understanding the experiments carried out. Report writing has helped improve the way we write our work at school and understand the structure of a scientific report.*
>
> Student 3

> *One can also conclude that for reliable research it is necessary to identify safe data sources and always search for bibliographic material within these databases. With the concepts and results of the practical part of the research, it was possible to learn how to write a scientific document.*
>
> Student 4

> *In conclusion, it is necessary to understand what databases are, how to identify a scientific database and how to search for bibliographic material within these databases. The PIBIC-EM reports helped us understand how to write a scientific document.*
>
> Student 5

As can be noted in the excerpts above, all the students emphasized the importance of theoretical-practical activities in scientific learning, especially when it comes to learning to write scientific reports.

FINAL CONSIDERATIONS

This article reported the development of theoretical-practical activities, with the main objective of promoting teaching-learning strategies in chemistry. The activities performed helped bring Basic Education students closer to scientific research carried out within universities. Against the backdrop of increasingly evident climate change, learning strategies that involved the use of sustainable practices to tackle environmental problems were implemented, since this issue was close to the students' reality. During the theoretical activities, the students took part in group discussions, where they were given important guidelines and orientation on scientific text writing. Through the experimental activities, the students were able to perform and experience laboratory practices at the Higher Education level in a science laboratory at EACH-USP.

All the students noted that the activities conducted in this project helped them to understand and associate chemistry concepts with issues related to sustainability and the environment. The students also pointed out that this way of learning and interaction allowed them to break down barriers regarding scientific research while learning and having fun.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.4c00928.

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Student handout, objective, procedure, prelaboratory evaluation, prelaboratory evaluation (PDF, DOC)
Instructor guide (PDF, DOCX)

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Notes

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