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Education

# Applying Problem-Based Learning to Raise Awareness on Mollusc Contamination by Harmful Algae

Priscilla Salles de Almeida de Araujo[1], Marcielle Branco dos Santos[1], Luiz Eduardo Garces[1], Claudia Cristina Machado de F. de Oliveira[2], Mathias Alberto Schramm[3], Rachel Ann Hauser-Davis[4], Renato Matos Lopes[5], Manildo Marcião de Oliveira[1]*

[1] Laboratório de Ecotoxicologia e Microbiologia Ambiental, Instituto Federal Fluminense, Campus Cabo Frio, RJ, Brazil
[2] Universidade Veiga de Almeida, Cabo Frio, RJ, Brazil
[3] Instituto Federal de Santa Catarina, Itajaí, Brazil
[4] Laboratório de Avaliação e Promoção da Saúde Ambiental, Instituto Oswaldo Cruz, Fundação Oswaldo Cruz, Rio de Janeiro, RJ, Brazil
[5] Laboratório de Comunicação Celular, Instituto Oswaldo Cruz, Fundação Oswaldo Cruz, Rio de Janeiro, RJ, Brazil

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## Abstract

Harmful algal blooms (HABs), formerly known as red tides, have increased in frequency and severity due to climate change, significantly impacting mariculture. Phycotoxins produced by certain microalgae are known to accumulate in bivalve mollusks, posing health risks to humans. Education is vital for raising awareness and fostering communication networks to assist managers in addressing this issue. In this sense, Problem-Based Learning (PBL) is an active methodology that enhances understanding among students and the public, training future researchers and environmental managers to tackle challenges like HABs. This study engaged two public education classes in the Lakes Region of Rio de Janeiro, Brazil, in a PBL course focused on harmful algae. Results indicate that PBL promotes meaningful learning on this topic. When paired with concept maps, PBL yielded specific insights and reflections on tutorials and related activities. Thus, PBL can effectively develop scientific foundations, create reflective learning environments, and empower citizen action among involved social actors.

**Keywords:** Environmental education, Harmful algal blooms, Phycotoxins, Science education, Teaching ecotoxicology.

## INTRODUCTION

Problem-based learning (PBL) was formalized at McMaster University's medical school in 1969 (Wijnia & Servant-Miklos, 2019). The curriculum planners were deeply concerned about the rapid growth of biomedical knowledge, and their goal was to educate graduates with the skills to manage this information explosion through self-directed learning, information search and retrieval, critical appraisal, and self-assessment (Neville & Norman, 2007). Currently, PBL is utilized in various ways across different subjects, disciplines, and educational levels worldwide (Chen *et al*., 2022; Gomes *et al*., 2024; Kumas, 2023; Liu *et al*., 2019; Maksum *et al*., 2024).

In PBL, students are presented with a meticulously crafted, well-structured problem. This problem serves as a catalyst for teaching and learning, fostering an investigative learning environment in which learners define their learning objectives (Hung, 2016; Hung, 2009). PBL can be considered a teaching method for small groups that integrates the acquisition of knowledge with the development of skills linked to the school curriculum (van der Vleuten & Schuwirth, 2019; Wood, 2003). It encourages the valuation of students' prior knowledge, based on the theory of meaningful learning proposed by David Ausubel (Bryce & Blown, 2024). In this context, the teacher's role is to facilitate and guide the learning process (Pinho *et al*., 2021).

*Corresponding author: manildodpicf@gmail.com

The use of PBL in curricular structuring is more common in higher education institutions (Zhang *et al*., 2022). This method could be an effective approach to promoting careers in science, technology, engineering, and mathematics (STEM) fields (LaForce, Noble, & Blackwell, 2017; Odell *et al*., 2019). It also prepares future scientists and professionals with the skills to face the challenges of Industry 4.0 and Society 5.0 (Joko *et al*., 2023; Lopes *et al*., 2020).

In this study, a PBL approach was applied to a critical issue in coastal regions that cultivate bivalve mollusks on marine farms (Cheng et al., 2020; Machado & Lourenço, 2008) that face harmful algal blooms (HABs) (Villalobos *et al*., 2023). Bivalve mollusks, such as oysters, scallops, and mussels, feed by filtering seawater, retaining the phytoplankton and zooplankton that form their diet (Guimarães Filho *et al*., 2022). Due to this food capture mechanism, these mollusks can accumulate several pollutants (Souza *et al*., 2016), bacterial pathogens (Jaksic *et al*., 2002), and harmful microalgae toxins or phycotoxins (Farabegoli *et al*., 2018). Thus, human consumption of mollusks raises significant public health concerns due to the potential risk of contamination associated with the consumption of contaminated mollusks (Braga *et al*., 2023).

Algal blooms in marine ecosystems are natural events resulting from altered water parameters and excess nutrients. HABs can cause significant damage to marine biota, including cultivated bivalve mollusks (Berdalet *et al.*, 2016). Certain microalgae species produce phycotoxins that, when ingested by humans, lead to foodborne illnesses. For instance, amnesic shellfish poisoning (ASP) is caused by domoic acid produced by the microalgae *Pseudo-nitzschia* spp., with clinical symptoms including nausea, vomiting, hallucinations, and memory loss. Diarrheal shellfish poisoning (DSP), in turn, is caused by okadaic acid, produced by the microalgae *Dinophysis* spp. and *Prorocentrum* spp., and is characterized by nausea, vomiting, diarrhea, and abdominal pain. Finally, paralytic shellfish poisoning (PSP) is caused by saxitoxin and its congeners, produced by the microalgae *Gymnodinium* spp. and *Alexandrium* spp., with clinical symptoms including numbness in the lips, headaches, muscle paralysis, and death due to asphyxiation (Farabegoli et al., 2018).

Bivalve mollusk mariculture areas frequently face challenges due to HABs, which can significantly impact both the environment and human health. To mitigate these risks, many producing countries, including Spain, France, the United States, Japan, New Zealand, Chile, and China, among others, have implemented monitoring programs to manage and restrict the marketing of these products during harmful algae events (Neves *et al*., 2021; Trottet *et al*., 2022).

In Brazil, the consumption of shellfish contaminated with phycotoxins is also a concern. National legislation, established through Interministerial Normative Instruction 07/2012 by the Ministry of Agriculture, Livestock and Food Supply aims to address this issue (Brasil, 2012) through the implementation of the National Safe Bivalve Mollusk Program (MoluBis), which was established under Ordinance No. 884. The program aims to enforce hygienic and sanitary controls for bivalve mollusks intended for human and animal consumption. It sets forth minimum safety and quality requirements and ensures compliance through rigorous monitoring and inspection processes (Brasil, 2023). However, enforcement and promotion efforts at the state level are still insufficient. Santa Catarina, the largest national producer of bivalve mollusks, stands out as the most proactive state. The Agricultural Research and Rural Extension Corporation of Santa Catarina has implemented comprehensive legislation and measures to promote shellfish farming (Suplicy *et al*., 2017), demonstrating the importance of localized efforts and dedicated agencies in effectively managing and promoting the shellfish industry.

To safeguard the population from these issues and support cultivation owners, continuous monitoring and educational programs are essential. These initiatives aim to mitigate impacts and improve the reporting of events to environmental agencies (Hardy *et al*., 2016). Implementing PBL in formal education and environmental education activities can, thus, make significant contributions. Combining field trips, laboratory activities, individual and group studies, PBL fosters critical thinking, autonomy, and a sense of citizenship, enabling preventive or mitigating actions that reduce the risk of contamination by phycotoxins. Therefore, this study aims to apply the PBL methodology in professional education and education for young people and adults to address the topic of harmful algae toxicology, verifying its effectiveness in learning the main concepts and in raising awareness among these students regarding a topic relevant to environmental education.

## MATERIALS AND METHODS

This study involved the following teachers (tutors): one student from the Postgraduate Program in Science Teaching and four students from the Biology Course (Degree in Biology) and from the Laboratory of Ecotoxicology and Environmental Microbiology of the Fluminense Federal Institute of Education, Science and Technology, Cabo Frio Campus. The project was carried out as part of a 20-hour extension course entitled "Introduction to the Analysis of Environmental Problems". The course was delivered at two locations: the Federal Institute for technical high school students, with eight participants, and the Municipal School of São Pedro da Aldeia, RJ, involving 18 students from the 8th Youth and Adult Education (EJA) year.

The PBL methodology was presented to the students to raise awareness about the use of tutorial meetings, practical classes, individualized studies, and information about conceptual maps. The latter was presented during the course. The diverse group of participants provided a broad perspective on the environmental issues discussed and facilitated a comprehensive learning experience.

During the course, students engaged in various stimulating activities, including problem analysis (Reading and Brainstorming), field sample collection (with phytoplankton net), laboratory practices (observations of mussel anatomy and phytoplankton under the microscope), and tutorial group discussions. These activities facilitated both self-directed and collective knowledge construction. The PBL methodology was implemented through tutorial groups, each consisting of 8 to 12 students and a tutor (Pinho *et al*., 2021; Wood, 2003). Students were required to maintain a logbook, which served as a protocol documenting all discussions and research conducted by the group during the PBL practice. Each week, a coordinator was elected to encourage research among group members, and a secretary was appointed to record all the information in the logbook.

During tutorials, the problem-solving process was reviewed and discussed. The tutor played a crucial role in mediating the self-directed learning process, guiding the group to think logically, and suggesting the democratic election of a coordinating student and a secretary for each case under study. The tutorial group dynamics followed a specific technique known as the "7 steps" (Table 1) or the PBL cycle (Hmelo-Silver, 2004).

**Table 1**. The seven steps of the PBL.

| | |
|---|---|
| Step 1: | Clarify the terms and concepts not understood when reading the problem |
| Step 2: | Define the problem |
| Step 3: | Analyze the problem |
| Step 4: | Draw an inventory of the explanations inferred from step 3 |
| Step 5: | :Formulate learning objectives |
| Step 6: | Collect additional information outside the group |
| Step 7: | Synthesize and test newly acquired information |

Assessments on each of the moments sought to meet the principles of formative process. Actions that enabled the student to learn at all moments of the course were considered, whether through practical activities, tutorial meetings, group research meetings, individualized study, and presentation of conceptual maps. These actions were implemented, always aiming to meet the learning objectives of the two groups which presented at different levels of education. In vocational high school, the aim was to enable interdisciplinarity between the concepts of biology and chemistry treated in environmental themes, while in the EJA segment, the objective was focused on other skills such as interpersonal relationships, motor skills, empathy, and cognitive aspects.

**Scheduled contents**

The course contents were meticulously organized to provide meaningful knowledge on the topic, tailored to the educational level of each student group. For the Technical High School course, the curriculum included:

*Microbiological Aspects:* This section covered the study of microalgae and bacteria, providing students with a foundational understanding of these microorganisms.

*Toxicological Aspects:* Focused on intoxication syndromes caused by phycotoxins, with a particular emphasis on diarrheal shellfish poisoning (DSP). This component aimed to educate students on the health risks associated with harmful algae.

*Ecological Aspects:* Highlighted the importance of abiotic factors such as pH, temperature, and dissolved oxygen in the establishment of harmful algae blooms. This section aims to provide students with an understanding of the environmental conditions that contribute to these phenomena.

*Environmental Management:* Investigated the role of monitoring and educational programs in supporting environmental managers and the directly affected population. This component emphasized the importance of proactive measures in mitigating the impacts of harmful algae.

Concerning the EJA course, the curriculum was adjusted to exclude the ecological aspects related to abiotic factors, as the students already possessed the necessary understanding of these basic chemistry principles (Figure 1).

**The generator problem**

The PBL problem is central to the learning process, leading to exploration and study of the presented topic. The 3C3R model can be considered central to problem construction in PBL (Hung, 2006, Hung, 2009).

This model encompasses:

**3C**: Content, Contextualization, and Connection

– support content and conceptual learning.

**3R**: Research, Reasoning, and Reflection – concern students' cognitive processes and problem-solving skills.

In this course, the problem was centered around the theme of harmful algae, specifically: "Intoxication of people who eat oysters and mussels and impacts on the local mariculture production chain." By engaging with this problem, students were guided to define cognitive learning objectives, fostering a deeper understanding of the subject matter.

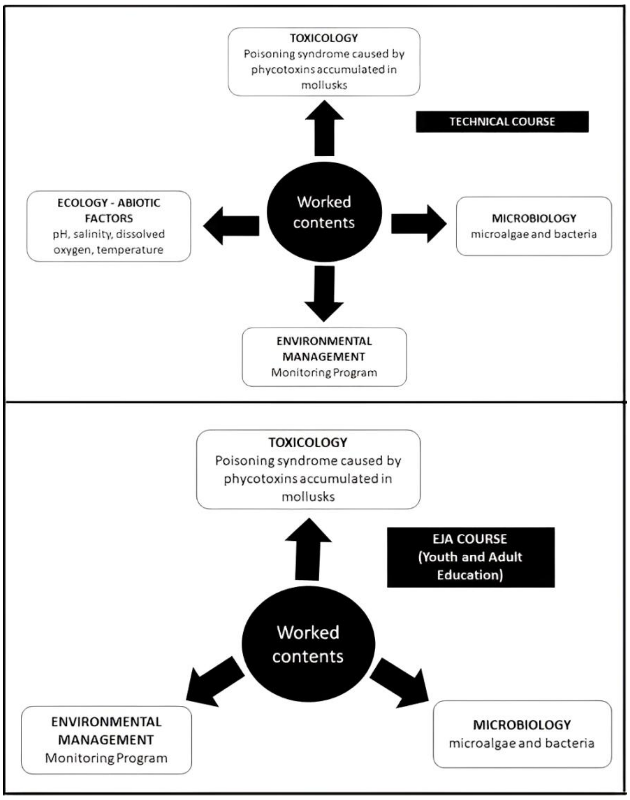


**Figure 1.** Planned contents for the Technical High School and Youth and Adult Education courses.

## The problem

"On the last weekend of his well-deserved vacation, Alfredo leaves the capital with his family to visit the Lakes Region. As a mandatory stop, he and his family spend an entire morning enjoying the Armação dos Búzios beaches (Geribá, Azeda, Azedinha, João Fernandes). At lunchtime, they choose to eat seafood at a renowned restaurant in the city, whose menu features squid, fish, oysters, mussels, and shrimp. A few hours later, Alfredo suffered from very severe abdominal pain, being admitted to the city hospital and diagnosed with a gastrointestinal tract infection requiring hospitalization for intravenous rehydration for several hours. After a difficult night, Alfredo promised the family not to return to the city, given the embarrassment and feeling of helplessness in view of the failure to clarify possible causes for what had happened."

Questions:

1. What happened to Alfredo in this case? What is the cause?
2. What attitudes should be implemented to avoid a repetition of this problem?

## RESULTS AND DISCUSSION

Table 2 provides a comprehensive summary of the five meetings conducted to develop the ABP tutorial cycle, specifically tailored for Vocational Education and Youth and Adult Education classes.

Tutorial groups are fundamental to the PBL (de Pinho *et al*., 2021; Hmelo-Silver, 2004; van der Vleuten & Schuwirth, 2019). In our studies involving basic education (technical high school and elementary school Youth and Adult Education modalities), we observed that tutorial groups facilitated a unique approach for students. The PBL tutor occupies a central and unique role in students´ learning (Chan, 2008), dialogical relationship between students and tutors enhanced students' engagement, fostering their autonomy, creativity, and empathy, as evidenced in their concept maps. The construction of explanations and answers was tailored to the level of each class (Figures 2 and 3). However, the topic of environmental management was seldom addressed in the concept maps produced, possibly due to a lack of emphasis on its relevance during the tutorials. This indicates that formal education still has a considerable way to go in aligning with the transversal approach advocated by environmental education. This approach is crucial for fostering new perceptions of environmental issues, such as HAB. Smith and colleagues (2014) underscore the importance of environmental education in acquiring scientific knowledge about harmful algae (Smith *et al.*, 2014). Their project in fishing communities significantly improved the reporting of HAB events, enabling environmental managers to make more timely decisions.

Although the topic of environmental management was not extensively addressed, several significant issues are noteworthy. For instance, despite the problem being repeated across classes at different levels, it was resolved within the knowledge level of each group. This demonstrates the methodology's effectiveness in reflecting realistic learning aspects. This approach appears to be an efficient strategy for teaching introductory toxicology related to the accumulation of phycotoxins in bivalve mollusks, as well as other related topics (Lewinsohn *et al.*, 2015; Lopes *et al.*, 2020; Lopes *et al.*, 2011).

**Table 2.** Activities conducted during each meeting.

| Meeting | Activities | Level of education |
|---|---|---|
| First day | Icebreaker: "I am the other" dynamic | 1 |
| | Problem Presentation and Analysis | 1 and 2 |
| | Brainstorming and Verification of Prior Knowledge | 1 and 2 |
| | Group Formation; Development of Work Plan for Problem Solving; Establishment of Hypotheses | 1 and 2 |
| Second day | Tutorial Groups and Individual Study Goals | 1 and 2 |
| Third day | Fieldwork - Collection of Microalgae Samples Using a Phytoplankton Net | 1 and 2 |
| | Fieldwork: In Situ Analysis of Physicochemical Water Parameters Using a Multiparameter Probe | 1 |
| | Laboratory class: Observation of Mussel Anatomy and Microalgae Under a Microscope | 1 and 2 |
| Fourth day | Tutorial Groups. Re-equating the problems | 1 and 2 |
| | Class on Constructing a Concept Map | 1 and 2 |
| Fifth day | Presentation of Problem-Solving Using Concept Maps | 1 and 2 |
| | Student Course Evaluation | 1 |

***Note:*** 1 - Technical High School; 2 - Youth and Adult Education

The marine environment is a frequently marginalized topic that needs to be included in environmental education in schools (Gough, 2017). Furthermore, conserving and sustainably using the oceans, seas, and marine resources for sustainable development is one of the 17 Sustainable Development Goals (SDGs) adopted by all United Nations Member States in 2015 (Bhore, 2016). The issue of HABs is particularly noteworthy, as these events are likely to become more frequent and severe due to climate change (Wells *et al.*, 2015). In this context, environmental education and scientific communication are essential to ensure human safety, enabling the creation of a network for reporting new HAB events and developing public health strategies (Hardy *et al.*, 2016). PBL can make significant contributions through its interdisciplinary approach, offering opportunities to propose citizenship actions aligned with the sustainable thinking that should guide education in this century and to introduce learners to pedagogies for a political ecology of education (Kirsop-Taylor *et al.*, 2020).

These methodologies immerse students in real-world problems that align with their scientific research and outreach activities. The PBL approach not only enhances students' collaborative skills in the laboratory but also deepens their understanding of fundamental ecotoxicology and ecology concepts. In the present study, students with no prior exposure to the subject of HABs made significant advances in their understanding. This was evidenced by comparing the concepts presented during initial brainstorming sessions with the results of conceptual maps created after the PBL intervention, which demonstrated substantial acquisition of new, scientifically justified concepts that bolstered students' arguments on the topic investigated (Table 3).

Concept maps (CMs) are a graphical tool for organizing and representing knowledge (Novak, 1990), and have long been valued in curriculum development, instructional strategies, and evaluation, linking learning theory with teaching practices (Maylath, 1989; Stewart, Vankirk, & Rowell, 1979). When integrated with PBL, CMs facilitate the assimilation of new knowledge, promote critical thinking, and help identify knowledge gaps (*Alt et al.,* 2023; Hung & Lin, 2015; Veronese *et al*., 2013).

The concept maps created by the technical high school class were highly detailed and conceptual. Group 1 successfully identified the microalgae genera, *Dinophysis* and *Prorocentrum*, as well as the phycotoxin okadaic acid, implicated in the presented poisoning scenario (Figure 2). Both maps followed a sequential structure, highlighting their effectiveness in organizing and representing complex biological information.

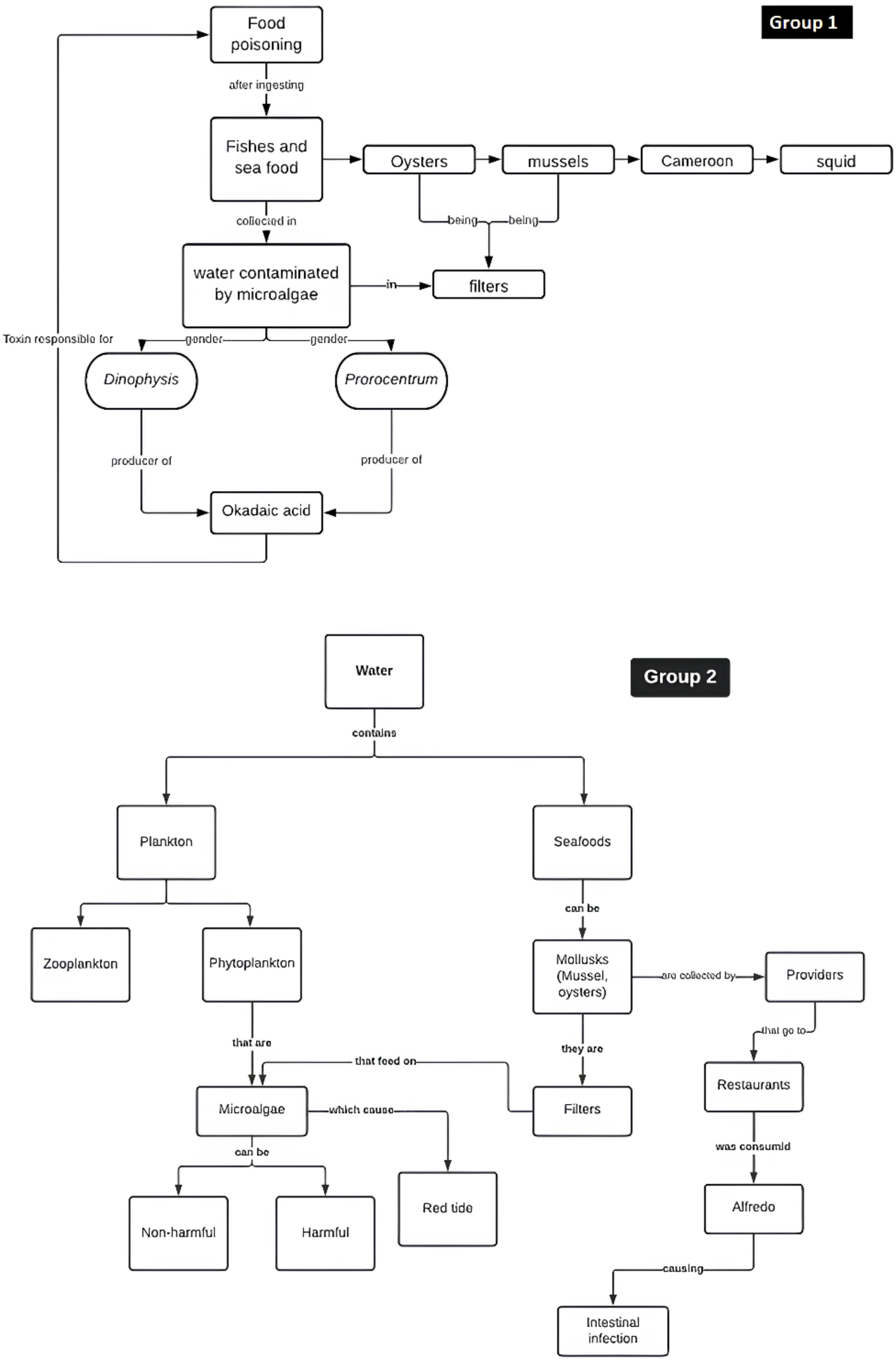


**Figure 2**. Conceptual maps created by the technical high school student group at the Federal Fluminense Institute - Cabo Frio Campus, Lakes Region, Rio de Janeiro, Brazil.

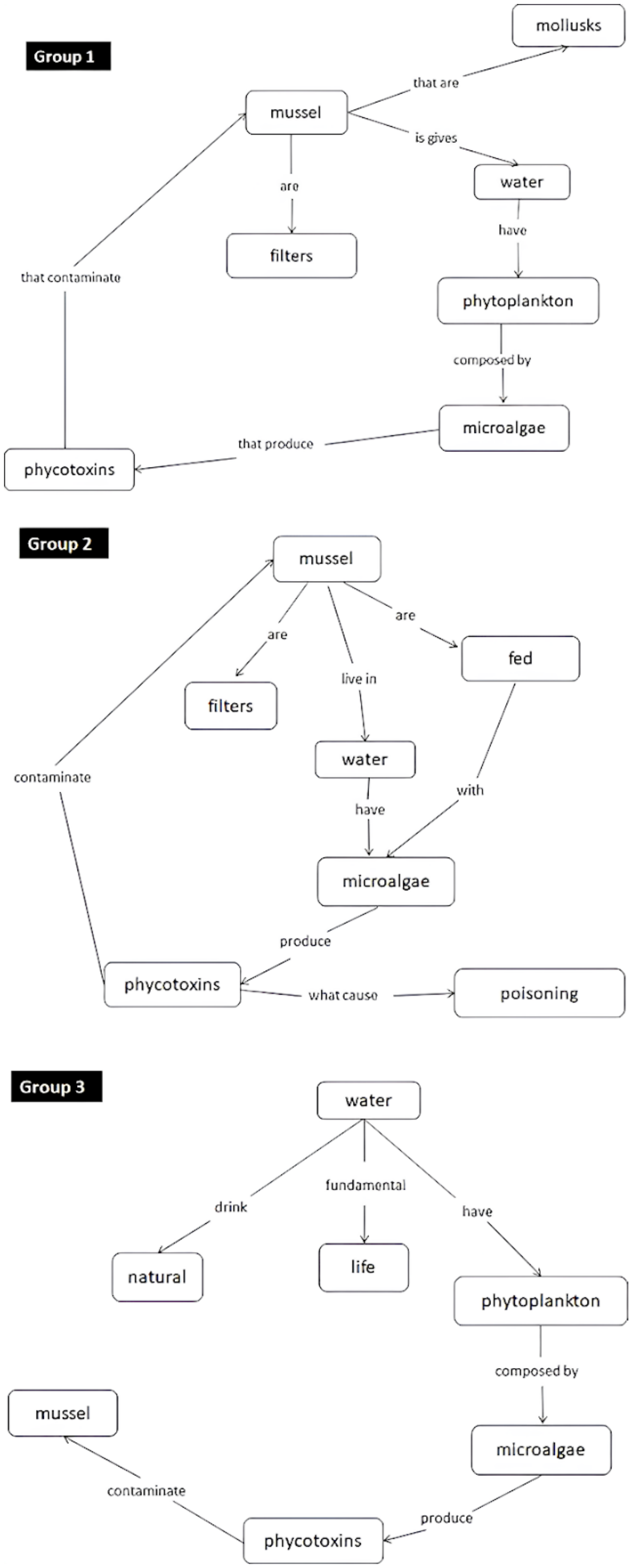


**Figure 3.** Conceptual maps of the Youth and Adult Education group at the Vinhateiro Municipal School, São Pedro da Aldeia, Lakes Region, Rio de Janeiro, Brazil

**Table 3**. Hypotheses Proposed During Brainstorming to Explain Alfredo's Intoxication

| Youth and Adult Education | Technical High School |
|---|---|
| • Food poisoning | • Seafood |
| • Mixing foods | • Food poisoning |
| • Spoiled food | • Allergy |
| • Lack of usual with seafood | • Lack of habit of eating seafood, |
| • Travel bullshit | • Lack of hygiene |
| • Hours without eating | • Something in the sea |
| • Sick | • Sand in food |
| • Beach water | • Contamination of part of the food, fecal coliforms |
| • Allergy | • Attempted murder by Alfredo's wife |
| • Dirty hand | • Heat stroke |
| • Germs | • Consumption of spoiled snacks |
| • Sewer | • Bacteria that cause allergies |
| • Waste | |
| • Bacteria | |
| • Seasoning | |
| • Badly washed food | |

These results may reflect differences in educational background and institutional focus. At the Federal Institute Fluminense, students were enrolled in a high school program with a curriculum that provides more extensive coverage of the natural sciences—chemistry, biology, and physics—taught as separate subjects. This broader exposure could help explain the variation in performance observed between the groups. Added to this is the fact that the Federal Institutes (IFs) are federal technical education organizations that aim to "break down the barriers between technical and scientific education, articulating work, science, and culture from the perspective of human emancipation" (Pacheco, 2010). According to Nascimento *et al.* (2020), students at IFs obtain results similar to those at private schools in high school exams, despite belonging to lower socioeconomic levels, largely due to an adequate structure of laboratory duties, libraries, retention and success programs, and qualified teaching and administrative staff. While EJA students were in elementary school, they were at a level of education where natural sciences are taught together, providing initial knowledge about these sciences. And in a municipal educational institution that, although it is fulfilling its duties regarding access to elementary education for students, does not have the same structure and resources as IFs. Thus, it seems necessary for educational institutions to encourage municipal governments to invest in school structure, in addition to training and continuing education for their teachers, combined with career plans that encourage teachers to engage in more interesting activities for teaching science. In a study carried out in an elementary school in another municipality in the State of Rio de Janeiro, Viana and Cruz (2021) found difficulties in implementing more stimulating science classes and propose the need for education departments and school managers to provide access to teacher training with the aim of bringing science learning closer to the student's reality, thus making science teaching more attractive to students and complying with the National Common Curricular Base (BNCC). PBL can therefore be an important ally in achieving this objective and aligning with the national curriculum parameters (PCN) established nationally.

The CMs generated by the EJA class were notably less detailed, encompassing only seven concepts, in contrast to the technical high school groups, which included 11 and 15 concepts, respectively. While both groups produced sequential maps, there was an observable inclination towards developing a network structure. This tendency suggests an initial understanding of more complex interconnections, although both classes underexplored the interrelationships between concepts. This under-exploration indicates a potential area for further instructional focus, aiming to enhance students' ability to identify and articulate the nuanced connections within the subject matter.

PBL and other active methodologies are valuable approaches for training ecotoxicologists and ecologists (Kostova, 2021; Lopes *et al*., 2020). Our findings suggest that both PBL and CMs are effective methodologies for teaching ecotoxicology. These strategies are also applicable to other disciplines, including cell biology, chemistry education, and nursing (Chan, 2017; DiCarlo, 2006; Sen, 2023). By engaging students in hands-on scientific experiences, these integrative approaches address educational challenges and provide a valuable alternative to traditional curricula. PBL and CMs foster a more holistic and effective learning environment, better preparing students for real-world challenges in their respective professional fields. These methodologies not only enhance subject-specific knowledge but also develop critical thinking, problem-solving skills, and the ability to apply theoretical concepts in practical scenarios. This comprehensive educational approach ensures that students are well-equipped to meet the demands of their future careers.

Thus, PBL and CMs can also be effective in promoting environmental education due to their characteristics, including reflection and review, in-depth investigation, questioning, and cooperative learning (Hong, 2022). As advocated by the Tbilisi Conference on Environmental Education ("Declaration of Tbilisi Inter-Governmental Conference on Environmental-Education", 1978), pedagogical actions should prioritize the resolution of local environmental problems to promote sustainability. By focusing on real-world issues, these methodologies increase environmental awareness and empower learners to apply their knowledge in practical ways for sustainable development.

## FINAL CONSIDERATIONS

In the context of an educational process that fosters meaningful learning and the development of planetary citizenship awareness, active methodologies serve as effective pedagogical strategies. The application of Problem-Based Learning (PBL) to the topic of Harmful Algal Blooms (HABs) in basic education has achieved satisfactory levels of student understanding. This teaching experience can inspire other educators to adopt this methodology, thereby promoting environmental education and scientific dissemination across various educational settings. Additionally, it enhances efforts towards effective environmental management of natural resources and encourages collective critical analyses on issues of environmental preservation and recovery.

The limitations of this study are attributed to the lack of refinement in the planning and execution of tutorial meetings in their evidentiary which could otherwise support decision-making related to individual learning. However, this point involves a real paradigm shift in the teacher/tutor's praxis within a more transformative context.

## AUTHOR CONTRIBUTIONS

**RML**, **MMO** – Conceptualization. **PSAA**, **MBS**, **LEG** - Formal analysis, Investigation, Methodology. **CCMO**, **MMO** - Project administration, Resources, Supervision. **MAS**, **RAHD**, **RML**, **MMO** – Visualization, Writing – original draft, Writing – review & editing.

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