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Education for Sustainability Through Field Activities and Game-Based Tasks

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Abstract

There is a consensus that the content of education for sustainability should be integrated into the curriculum, engaging students in activities that promote awareness and practice of sustainability. To achieve this goal, it is essential to adopt a student-centered approach that involves creative, stimulating, and challenging activities. This research reports a case study in which 8th grade students had the opportunity to develop these types of activities. Field activities were conducted on a local river combined with a game-based task focused on the role of benthic macroinvertebrates in ecosystems. These activities enabled collaborative learning and the social construction of knowledge, which are pivotal for more sustainable education. It should be noted that students learned how to collect, observe, describe, organize, and classify species to make inferences about water quality. The main issue we intended to address was how to improve and integrate scientific activities into the students' curriculum to foster a more sustainable education. The specific research questions were put forward: a) Do the implemented activities instigate collaboration for a more sustainable education? b)

Do the implemented activities increase scientific curiosity and develop critical thinking and attitudes? c) Do the implemented activities increase students' knowledge concerning aquatic resources, such as benthic invertebrates? The results confirmed the important role of student-centred activities, in this particular case fieldwork and game-based tasks, in the development of knowledge and scientific thinking skills, which could be scaffolded through feedback, rewards and flow states. This study provides a more holistic perception of local river ecosystems, their role in improving environmental attitudes, and promoting a more sustainable science education.

Keywords: Active learning, education for sustainability, fieldwork, game-based task.

Introduction

Education for sustainable development is therefore defined as a "holistic and transformational education that addresses learning content and outcomes, pedagogy and the learning environment" (Rieckmann, 2017). Expanding the horizons of both educators and learners is essential to guarantee sustainable development within educational establishments (Briede & Drelinga, 2020).

Teaching transcends merely guiding students through activities or lessons within the confines of a closed classroom door. Instead, it should be regarded as collaborative work taking place across the entire school environment, involving cooperation among educators (UNESCO, 2021), mainly for the implementation of environmental educational programs targeting young students to contribute to a future generation of scientifically literate and environmentally conscious citizens. The development and implementation of environmental education activities in schools are also crucial for intellectual growth. Furthermore, environmental education enhances awareness of environmental problems and promotes students' behavioral change.

In the current era, it is challenging to find pristine habitats due to increased anthropogenic pressure on the environment (Steg & Vlek, 2009). The global growth of the human population, intensive agriculture, and increased industrialization have resulted in negative impact on the quality of the environment, particularly on aquatic resources (M. M. Azevedo, 2008; Merian & Clarkson, 1991). That is why it is of fundamental importance to invest in environmental education regarding the defense of aquatic resources. Believing that knowledge is a prerequisite for action, before individuals can intentionally act on a particular environmental issue, they must be conscious of the existence of that problem (Hines et al., 1987).

Since river pollution is a great problem, we designed and implemented an activity for 8th grade students to determine water quality of a local river, using benthic macroinvertebrates. In collaboration with a scientist, we designed a field activity followed by a game-based task. The combination of the two activities allows students to learn how to collect, organize, and classify the species to make inferences about water quality, which are central practices to ensure the sustainability of their learning.

This study aims to engage students in real-life environmental problems and put them in contact with scientists and scientific methodology mainly related to fieldwork and taxonomy. Benthic macroinvertebrates have been used as bioindicators of water quality since the 1980s (Coimbra et al., 1996). These organisms possess characteristics that allow them to react to environmental changes simultaneously and over long term (Rosenberg, 1992). Benthic macroinvertebrates have several advantages as bioindicators. They are abundant, relatively easy and inexpensive to collect. They constitute heterogeneous communities present in the majority of aquatic habitats, displaying different sensitivities to pollutants and reacting quickly. Additionally, they have long life cycles that allow for observation of temporal changes caused by external disturbances and predominantly sedentary, reflecting the effect of pollutants in a restricted area (Metcalfe-Smith, 1994; Platts et al., 1982). These organisms are taxonomically well-defined and relatively easy to identify using simple and appropriate identification keys. Taxonomic determination at the family level is a reliable indicator of environmental conditions (Graça & Ferreira, 1995).

The activities followed active learning methodologies that included fieldwork, game-based tasks, collaboration, peer review, discussion, problem-solving using real data, and practical work. Bonwell and Eison (1991) define active learning as "instructional activities involving students in doing things and thinking about what they are doing". According to several other studies, active learning strategies increase students' performance and retention (Freeman et al., 2014; Marques et al., 2021). Several works emphasized the pertinence of active learning strategies (H. Azevedo et al., 2022; M. M. Azevedo et al., 2012; Marques et al., 2021; Sé et al., 2008) mainly problem-based learning (Khoo, 2005; Marques et al., 2021; Parikh et al., 2001; Prince et al., 2005). Some other works (H. Azevedo et al., 2022; Costa & Rangachari, 2009) highlight the importance of students' collaboration, discussions, and sharing opinions to build knowledge. In this line of thought, Tripp and co-authors (2020) also revealed the importance of collaborative work between students as they exchange expertise.

Fieldwork is considered an important tool to improve student attitudes and clearly has a positive influence on students' knowledge (Yıldırım & Şen, 2019). These authors hypothesized that fieldwork activities within the school context could be an important additional resource for academic success and, more importantly, an effective instrument for raising awareness of environmental topics. Additionally, fieldwork is important for the development of students' epistemic practices as they could be engaged in significant actions within the context of scientific production and develop scientific thinking skills (Kelly & Licona, 2018). Scientific thinking skills must be scaffolded via educational and cultural tools, such as feedback, rewards, and flow states that could be fostered by challenges and games (Morris et al., 2013). According to these authors, "scientific thinking encompasses the set of reasoning and problem-solving skills involved in generating, testing, and revising hypotheses or theories" (Morris et al., 2013, p.2).

Studies (e.g., Furtak & Kunter, 2012) highlight that fieldwork induces intrinsic motivation linked to students' active and engaged behaviors. Furthermore, hands-on, and out-of-class education improve students' interests, scientific inquiry skills, autonomy, and understanding of scientific concepts (M. M. Azevedo et al., 2013; M. M. Azevedo et al., 2012; M. M. Azevedo et al., 2020; Khoo, 2005). Finally, providing students with autonomy is an additional factor contributing to an increase in their motivation (Fonseca et al., 2012).

Regarding the use of game-based tasks in educational contexts, it is considered a strategy for increasing student engagement (Dichev & Dicheva, 2017). This refers to the application of elements present in games in other activities outside the usual contexts, with great potential in education and training (Deterding et al., 2011; Kapp, 2012), as it generates levels of involvement like those achieved during games (Fardo, 2014) and promotes higher levels of motivation. The game elements that are considered to have high potential in an educational context include complying with rules, establishing clear objectives, rewarding achievements through scoring systems or trophies (reward and return system), and presenting challenges, developing actions according to levels of difficulty to stimulate performance.

Game-based tasks have a positive impact on students' productive engagement, as they cand improve specific skills (e.g., observation, data organization, found patterns, argumentation, teamwork, among others), which optimize students' learning (Smiderle et al., 2020). Other studies (Ivala et al., 2013) also claim that motivation and engagement in learning tasks are the main drivers for the adoption of this kind of strategies, since they make learning more attractive, captivating, and consequently more effective (Yıldırım & Şen, 2019). According to Fleischman and Ariel (2016), this effectiveness arises from the fact that instant and frequent feedback assumes an important role in students' autonomy and self-regulation, leading to positive outcomes.

Regarding the main topic of this case study, the activities developed are aligned with two of the 17 Sustainable Development Goals defined in 2015 by the United Nations, namely the objectives number 4 and 12: Quality Education and Sustainable Production and Consumption, respectively (Rieckmann, 2017). The activities carried out in this study provided a fresh and innovative perspective on sustainable environmental education and were conducted using active learning strategies such as fieldwork, experimental activities (visualization and manipulation of benthic macroinvertebrates), problem-based learning (PBL), gamification, active discussion, critical analysis, collaborative work, and creation of visual representations.

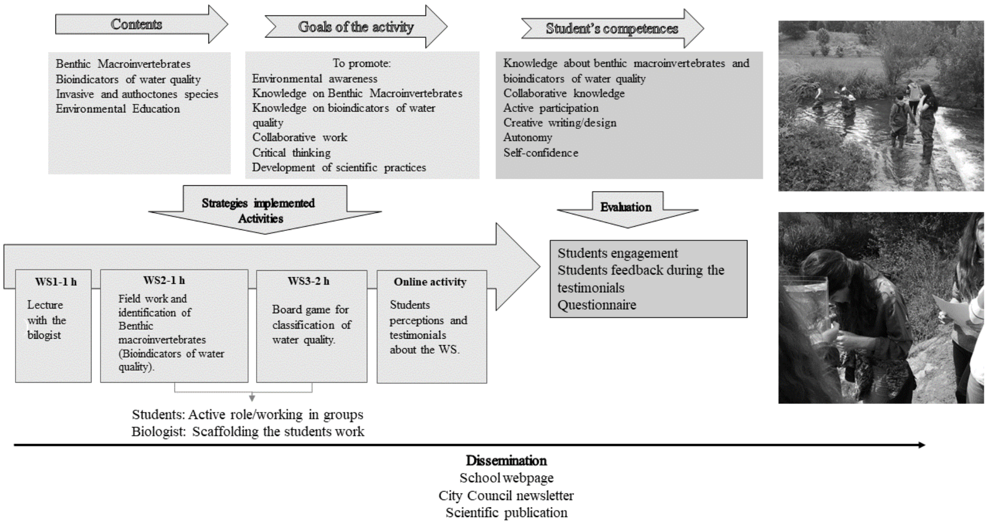
Given this theoretical foundation, our primary objective is to enhance and integrate scientific activities into the students' curriculum, aiming to promote a more sustainable approach to education. Besides the fact that this case study is focused on the implementation of field activities and gamed-based tasks, and their role in the development of students' knowledge and competences, we also intend to provide empirical foundations for school and classroom approaches that can foster a meaningful education for sustainability mainly through collaboration among students, teachers and scientists. The specific research questions are as follows: a) Do the implemented activities instigate collaboration for a more sustainable education? b) Do the implemented activities increase scientific curiosity and develop critical thinking and attitudes? c) Do the implemented activities increase students' knowledge concerning aquatic resources, such as benthic invertebrates?

Methodology and Methods

The schematic description of this case study is presented in Figure 1. In a real-life scenario, students had the opportunity for learning about the procedures of sampling collection and preservation of the natural initial state of the ecosystem. Also, they performed some important scientific practices, such us observation and description, identification of species using dichotomous keys and formulating hypotheses about the quality of the river water. During the second part of the activity, through the gamed-based tasks, the biologist "transported" again into the river context and expanded their knowledge about classification of species and water quality. This was important to systematize the concepts and consolidate some important scientific practices related to data organization, found patterns, argumentation, teamwork, and validation of knowledge produced.

Figure 1

Project Flowchart – Schematic Description of the In-Class Activity



The activities performed with the students included three steps: first, an invited biologist performed a lecture about benthic macroinvertebrates and their effect on ecosystems; then, the students went to a branch of a local river, located at the city park, near the school, and performed field activities such as collection of water samples and observation of the presence/absence of biological indicators. Finally, in the classroom, the students were proposed to play a board game with cards, simulating the river conditions in order to extend students' knowledge about the topic of biological indicators and also about taxonomy. Each session was developed as described further in the paper.

Description of Work Sessions

The first session of this work was performed by the biologist (a co-author of this study) during a Natural Science class with the presence of the science teacher (Figure 2). Students from two 8th grade classes attended the class activity namely "Benthic Macroinvertebrates: Bioindicators of Water Quality".

Figure 2

Lecture About "Benthic Macroinvertebrates: Bioindicators of Water Quality"

During the exploration and discussion of PowerPoint presentation and video, the students had the opportunity to become familiar with native plant species and characteristics of Portuguese riverbanks and riverbeds, recognizing their importance for river ecosystems. They also delved into what benthic macroinvertebrates are, i.e., small animals that mostly correspond to larval forms of insects and live associated with the bottom of the river or aquatic vegetation. Students learned about macroinvertebrates' lifecycle and morphological adaptations. In this stage, students had the opportunity to visualize and manipulate benthic macroinvertebrates, like the ones presented in Figure 3, which are two exuvias of benthic macroinvertebrates specimens (dragonflies). It was discussed that these living beings, in addition to being crucial for the river's food chain, are bioindicators of water quality, as many of these organisms are sensitive to pollution and other environmental changes. Thus, through active discussion and observation of Petri dishes containing benthic macroinvertebrate exoskeletons (exuviae), the students learned that these small animals help to assess water quality in rivers.

Figure 3

Exuvias of Benthic Macroinvertebrates Specimens (Dragonflies): Boyeria irene (Family Aeshnidae) and Cordulegaster boltonii (Family Cordulegastridae)

For second work session, a river branch near the school was selected because it was easy to access the riverbed, as well as safety conditions were ensured. Also, the environmental condition and level of anthropic intervention were the criteria for the selection of this river branch. The students were equipped with appropriate clothing (i.e., water boots; fisherman's suits with chest-high pants for going into the water). They also had their own fishing net for capture, like those used for aquarium, and buckets to collect the samples (Figure 4).

Figure 4
Several Moments During the Field Activity

The students were invited to observe the surroundings of the river section, looking for native riparian species, macrophytes, and any kind of human activity (e.g., sewer pipes, industries, houses). The students were able to identify some native riparian species, applying in nature what they learned in the classroom. This interpretation allowed for a conversation between the students and the biologist about the importance of riparian vegetation and macrophytes as a food source and hiding places for macroinvertebrates, as well as the consequences of human activities on the stream's health.

The biologist explained to the students the working methodology and adopted the following protocol: 1) Students collect macroinvertebrates at the provided location in the river, using sampling techniques explained at school during the first session; 2) students carefully store the macroinvertebrates collected in a tray/aquarium full of water; 3) students examine macroinvertebrates under a magnification glass and with the assistance of an identification guide, identify the orders of macroinvertebrates; 4) students proceed to count the different species; 5) students classify the water quality using the available tables; 6) after the observations, all the macroinvertebrates collected are to be released back into the river. Sampling has minimal impact on the resident biota and rapid assessment protocols were used to qualitatively characterize the resource under evaluation, i.e., to establish a score indicating the state of water quality. The students utilized an adapted Biological Monitoring Working Party (BMWP) table, scored by Alba-Tercedor and Sánchez-Ortega (1988), to evaluate water quality in the field. This table allows for quick and simple identification of macroinvertebrates based on their Order rather than their Family. Although this adapted scoring system is less accurate than the BMWP score, it provided the students with a basic understanding of water quality evaluation procedures through macroinvertebrates, which was crucial for the third working session, a game-based activity. The most commonly collected species were Water Boatmen (Order: Hemiptera), Mayflies (Order: Ephemeroptera), Stoneflies, Dragonflies (Order: Odonata), and Caddisflies (Order: Trichoptera).

After identification and registration of the collected macroinvertebrates, the students assessed the water quality. In this case, they used the simplified BMW, and the water quality was qualified as very clean. The reasons justifying this classification were discussed with the students. For example, there is a stretch of rapids with a small waterfall in the river, so the water is stirred and aerated, which enhances its freshness; the samples were collected in the early spring, and the flow is still strong; and the river branch was recently rehabilitated using nature-based solutions, such as planting willows along the banks.During the third working session, the biologist with the presence of the science teacher developed a game-based activity "Classification of Water Quality" based on the presence or absence of bioindicators. During this activity, a challenge was proposed using a board game (see Figure 5).

Figure 5

Results From the Board Game Performed Collaboratively (task and score not translated)

BIOLOGICAL WATER QUALITY INDEX BMWP'

(Alba-Tercedor & Sánchez-Ortega, 1988)

Scoring Table – Families

Pontos	Ephem	Plecop	Odonat	Heterop	Trichop	Coleop	Diptera	Crust	Mollus	Outros	Pontuação
10	Siphl Heptg Leptoph Potam Ephem	Taenop Leuctr Capn Perlod Perlid Chlorop		Aphel	Phyg Molan Bera Odont Lept Goerd Lepid Brach Seric Thremmt		Ather Blepha				
8			Lest Calopt Gomph Corduleg Aesh Cordul Libell		Psych Philop Glosso			Astc			
7	Ephemer Proso	Nemour			Ecn Rhyac Polyc Limnph						
6			Plact Coeng		Hydroptil			Gamm Atyid	Nerit Vivip Ancyl Union Thiar		
5	Olignr Polym				Hydrops Helycops	Dryop Elm Heloph Hydra	Tipul Sumld			Planarid Dendro Duges	
4	Baeti Caen					Halip Chrys	Taban Stradi Empid Dolich Dixid Cerato Anthom Limond Psych			Sialid Piscic	
3				Velii Mesovel Hydrom Gerrid Nepid Naucor Pleid Notonec Corix		Helod Hydroph Dytisc Gyrinid Hygrob		Asell	Valvat Hydrob Lymn Physid Planorb Bithy Sphaer	Glossi Hirud Erpobd	
2							Chiron Culic Thaumal Ephydr				
1							Syrph			Oligo	
Pontuação Total	7	—	14	–	20	4	14	—	6	5	70

class II

The biologist who mediated this activity created a didactic game to determine the quality of the water and evoked details and information from the observations made by the students during the field activity to the local river. For the implementation of the board game, the students were divided into groups of approximately five students and received ten cards. Each group had a "real-life simulation" of a stream sampling, with different species. Each card represented a family of benthic macroinvertebrates, according to the table of BMWP used during the fieldwork with the score system published by Alba-Tercedor and Sánchez-Ortega (1988). Working collaboratively, the students needed to complete the table according to the cards distributed, based on the presence/absence of benthic macroinvertebrate families. Each family was only counted once (regardless of the number of specimens), and the points shown in the table were assigned.

Each order has different families with distinct sensitivity/tolerance to pollution ranging from 1 (very tolerant) to 10 (very sensitive). After completing the table and assigning the correct score to each image (family), students made the final sum. The sum obtained rated the water quality of the river section of each group according to the scale: I > 150, Very clean water (101–120), non-contaminated water; II (61–100), Some contamination effects are evident; III (36–60), Contaminated waters; IV (16–35), Highly contaminated waters; V <16, Heavily contaminated waters (Alba-Tercedor & Sánchez-Ortega, 1988).

Figure 6

Image From the Table Used by the Students During the Collaborative Task

Study Design

This is a qualitative research based on a case study (Cohen et al., 2002), involving two classes of 8th grade students (13–15 years old) who participated in activities using fieldwork and a gamification approach, where students faced some challenging tasks. However, quantitative methods such as questionnaires were also used.

Participants and Context

The activities that lead to this case study were developed during the school year of 2020/2021 and involved thirty-nine 8th grade students (21 male and 18 female) from a public low secondary school. This group was selected, since their science curriculum includes global issues such as ecosystem protection and management. The study was approved by the school management and conducted as part of the activities developed at the school STEM Club.

Data Collection and Research Methods

The students were asked to write a small testimonial and/or produce a visual representation about the activities implemented. They also filled a grid for self-assessment of their knowledge concerning the topic, before and after the activities.

Furthermore, the students filled out a pre-validated questionnaire (Poels et al., 2007) to evaluate their degree of satisfaction and attitudes towards the tasks proposed.

The research methods were the following: i) Content analysis (Krippendorff, 2004) of students' testimonials collected after the activities; ii) student's self-assessment about their achievements, before and after the activities, adopting a Likert Scale, where the students expressed their knowledge about the use of bioindicators to evaluate the water quality from "None" to "Very Good"; iii) Questionnaire adapted from Poels et al. (2007) that assessed the students' experiences and attitudes towards the activities, mainly the ones related with the game-based task proposed.

These triangulation approaches enhance reliability of the research findings and provide a more comprehensive understanding. By combining qualitative (content analysis) and quantitative (self-assessment and questionnaires) approaches, we intent to achieve diverse perspectives and reduce method bias. This approach enriched the analysis and ensured more robust and credible conclusions. Triangulation mitigates biases, confirms findings through multiple lenses, and offers a detailed view of the impact of educational activities on students' knowledge and attitudes.

The results of the content analysis allowed collecting evidence regarding the students' perceptions about pedagogical strategy, students' knowledge, motivation, and development of 21st-century competencies, such as creativity, critical thinking, and communication. Also, the triangulation with the grid used for students' self-assessment confirmed the acquisition of knowledge. The results from the questionnaire about psychological aspects (Poels et al., 2007) allowed for the identification of the students' feelings, motivations, and engagement in the activity, mainly during the game-based task. Content analysis of the students' testimonials, questionnaires, and results from the students' self-assessment (pre- and post-activity) provided more insights to answer the research questions.

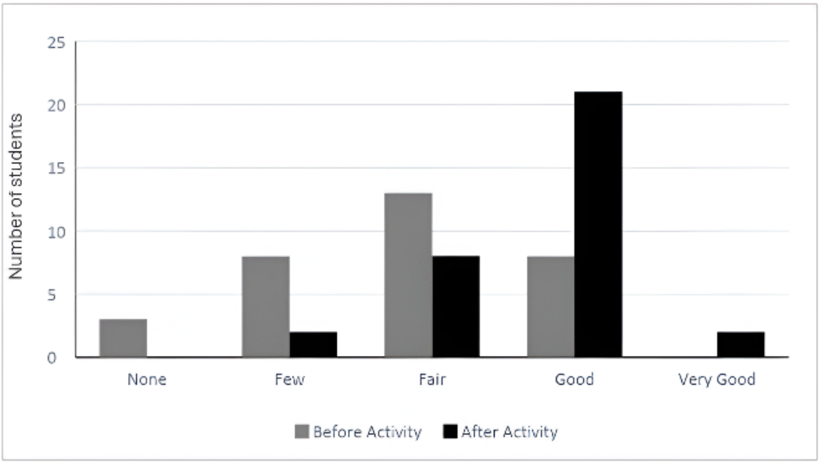
Results

According to the students' self-assessment, before and after the activities, it is possible to infer learning gains. As Figure 7 highlights, the number of students who increased their knowledge is considerable. After the activity, all students confirmed that they increased their knowledge concerning the topic of benthic macroinvertebrates, their roles in ecosystems concerning water quality. A progressive knowledge gain was observed throughout the study.

At the end of the activities, the number of students who self-assessed their knowledge as "Good" and "Very Good" increased substantially (Figure 7).

After the sessions, the students wrote about their perceptions/opinions about the work sessions and expressed their thoughts, feelings, and ideas. The content analysis of the students' testimonials allowed for identification of some categories that emerged from the data. The content analysis was data-driven, and the research team identified important categories concerning motivation, engagement, feelings, perception of the pedagogical strategy, student learning, critical thinking, and creativity.

Figure 7
Students' Self-Assessment (Pre- and Post-Activity)



The results of the content analysis are presented in Table 1 along with a brief description and some examples from the students' writing testimonials. Some students complemented their writing with drawings and visual representations. The content of the drawings and visual representations are presented in Table 2, which also allows us to infer about students' knowledge, since some of them are illustrations of the benthic macroinvertebrate species. The students elaborated figurative representations of the river and its landscapes, and more abstract representations such as a sectional view of the river highlighting the ecosystem and their biodiversity. This last representation includes some magnification and the "visualization" of the bioindicator species in the river. However, some students included drawings of other species, even not related with benthonic macroinvertebrates.

These drawings are important to understand students' misconceptions about benthonic macroinvertebrates and their use to evaluate water quality, since they are not in line with the topic of the activity. Moreover, the students' draws and visual representations showed a positive perception of the river's ecosystem and biodiversity. The illustrations of the fly (Diptera) and a ladybug (Coleoptera) allow understanding that in some cases there are some misconceptions that persist. Although ladybugs are not considered benthic macroinvertebrates, it shows that the students acquired the concept related with order Coleoptera as benthic macroinvertebrates families (e.g., Haliplidae).

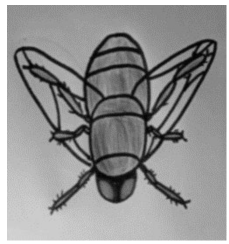
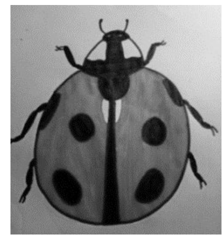
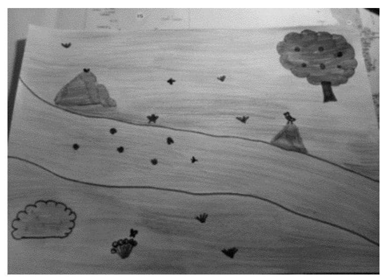
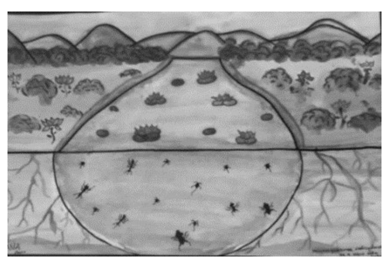
After analyzing the questionnaire, the first factor that emerged was "Sensory and Imaginative Immersion" (Table 3). The results obtained were very positive since the mean value for all the tested items was above 3.0 (ranging between 3.13 and 3.72).

Table 1
Content Analysis: Results and Examples from Students' Testimonials

Categories	Description	Examples from students' testimonials
Motivation	Expression of enthusiasm to learn and appreciation about the work developed.	*"The activity was 5 stars"; "This class was great"; "It was very interesting to go to the river and the game was fantastic"; "The game was fantastic/spectacular"; "It was an incredible experience being at the river"; "I was motivated that have someone else to teach us"; "I found that the names of benthic macroinvertebrates are very funny"; "These activities should be done more often in schools".*
Engagement	Refers to the degree of attention, curiosity, interest, optimism, and passion.	*"I was very engaged in the work"; "The contents were very interesting"; "I was very enthusiastic about the river activity"; "I really enjoyed the group work"; "My team was fantastic"; "I really enjoyed seeing and manipulate the benthic macroinvertebrates"; "The game was fun".*
Students' feelings	Expressions of happiness, amusement, excitement, satisfaction, joy, contentment.	*"I felt happy"; "It was very funny"; "I really enjoyed this activity".*
Perception about pedagogical strategy (game)	Students understanding about context, resources, teacher language and actions, etc.	*"The game was very realistic and was like being in the river again"; "Field work allowed us to learn some methods"; "The contents were transmitted in a very clear way"; "With the game I felt familiar with the contents discussed in the river"; "I didn't think the rivers were so complex"; "The strategies used were very interesting"; "The PowerPoint presentation, the photos and the questions done during the activities helped me to understand"; "The game was very important since allowed to know if we had noticed the matter"; "The game allows testing the knowledge transmitted".*
Student learning	Students' perceptions about abilities, skills, achievements, attitudes, among others.	*"I learned to classify river waters as to their purity"; "I learned more about rivers, the animals that live there and their functions"; "I learned how I can use living beings to classify river waters"; "The activity made me aware of the importance of rivers and the need for their preservation"; "I found that I have a lot to learn"; "I learned many things that I was not aware".*
Critical analysis	Recognition of the importance of the epistemic pathway from practices to theories.	*"Science should start by manipulation and practical activities, and then move on to theory".*
Creativity	Students expressed their thoughts through artistic production, demonstrating different levels of abstraction and conceptual understanding.	The evidence from this category is expressed in the students' drawings (see Table 3).

The second factor that emerged was termed "Tension" (Table 3). The item loadings ranged between 0.13 and 1.00, and the mean value was 0.44. The minimum values were never observed for this category.

Table 2
Students' Visual Representations

Categories	Students' visual representations
Illustrations of macroinvertebrates species not related to the activity. This could be understood as students' low achievement about the topic, or even some misconceptions.	 
Figurative representations of river and river landscapes. This representation includes the representation of macroinvertebrates on the water, but the level of abstraction and cognition is low.	
Sectional view of the river with representation of ecosystem and biodiversity, including macroinvertebrates. This representation includes some abstraction and magnification of some species.	

For the third category analyzed "Competence", four items were selected (Table 3). All the items had factor loadings above 3.0, with loadings ranging from 3.03 to 3.25, which is demonstrative of the skills developed.

For the fourth category "Flow", five items were selected (Table 3). The results obtained are very positive, since the mean attained was 2.8. Only the item "I forgot everything around me" was less scored, the mean was 1.72.

Table 3
Results for All Categories of Psychological Effects Regarding the Activities

Category	Questions	Mean (question)	SD (question)	Min (question)	Max (question)	Mean (category)	SD category)
Sensory and Imaginative Immersion	I was interested in the activity	3.72	0.46	3.00	4.00	3.38	0.74
	I felt that I could explore things	3.13	0.83	1.00	4.00		
	I found it impressive	3.25	0.88	1.00	4.00		
	It felt like a rich experience	3.44	0.80	2.00	4.00		
Tension	I felt restless	1.00	1.19	0.00	4.00	0.44	0.69
	I felt annoyed	0.44	0.84	0.00	3.00		
	I felt irritable	0.13	0.35	0.00	1.00		
	I felt frustrated	0.19	0.40	0.00	1.00		
Competence	I felt skilful	3.06	0.72	2.00	4.00	3.13	0.70
	I was good at it	3.03	0.78	2.00	4.00		
	I felt successful	3.25	0.76	2.00	4.00		
	I was fast at reaching the targets	3.13	0.70	2.00	4.00		
Flow	I felt completely absorbed	3.03	0.59	2.00	4.00	2.80	0.32
	I forgot everything around me	1.72	1.05	1.00	4.00		
	I lost track of time	2.84	1.39	0.00	4.00		
	I was deeply concentrated in the tasks	3.22	0.79	2.00	4.00		
	I was fully occupied with the tasks	3.19	0.69	2.00	4.00		
Positive Effects	I felt content	3.56	0.62	2.00	4.00	3.62	0.04
	I felt good	3.59	0.71	1.00	4.00		
	I enjoyed it	3.66	0.70	1.00	4.00		
	I thought it was fun	3.66	0.70	1.00	4.00		
Negative Effects	I thought about other things	0.78	0.87	0.00	3.00	0.53	0.11
	I was distracted	0.47	0.67	0.00	2.00		
	I found it tiresome	0.34	0.70	0.00	3.00		
Challenge	I felt that I was learning	3.75	0.44	3.00	4.00	2.33	0.20
	I thought it was hard	0.81	0.90	0.00	3.00		
	I felt stimulated	2.75	0.88	1.00	4.00		
	I felt challenged	2.81	0.86	1.00	4.00		
	I had to put a lot of effort into it	1.53	0.88	0.00	3.00		

Scale Range from 0 to 4

Concerning the fifth category "Positive Affects" (Table 3), it demonstrates the feeling of fun and enjoyment of gaming. All the items were very well scored, the minimum score for the item was 3.56 and the maximum 3.66.

In the sixth category "Negative Effects" (Table 3), the items loaded low on this factor (Mean= 0.48). This implies that most of the students enjoyed the tasks with the game and that they understood how to play it.

The last category was termed "Challenge" (Table 3) and most of the students felt they were learning (Mean= 3.75), and a large percentage of students felt stimulated and challenged (Mean 2.75 and 2.81, respectively). A small number of students thought it was hard (Mean= 0.81) and few had put a lot of effort into it (Mean=1.53).

Table 4
Basic Indicators for All the Categories

	Mean	SD	Min	Max
Sensory and Imaginative Immersion	**3.38**	0.74	1.00	4.00
Tension	0.44	0.69	0.00	4.00
Competence	2.80	0.32	0.00	4.00
Flow	**3.44**	0.80	2.00	4.00
Positive	**3.62**	0.04	1.00	4.00
Negative	0.53	0.11	0.00	2.00
Challenge	2.33	0.20	0.00	4.00

Scale Range from 0 to 4

Scores on most items were high to moderate and ranged the full scale (Table 4). The highest scores were obtained in the categories "Sensory and Imaginative Immersion", Flow" and "Positive Affect". Scores for "Negative Affect" and "Tension" were low.

Discussion

The idea of sustainable development emerged during the 1970s and 1980s as a response to global acknowledgment of challenges in social and scientific progress, finite natural resources, and environmental concerns. Sustainable development was defined as progress that ensures present actions and the fulfilment of contemporary societal needs do not jeopardize future generations, but rather strike a harmonious balance between them (Brundtland, 1987). In this scenario, Trusina and co-author (2024, p.) believe that education plays an essential role in the life of every person and especially in the understanding of sustainable development in its broadest sense.

A transformative education for sustainable development needs both skills and knowledge. As outlined by Bedford (2022), it encompasses students' experiences, fosters awareness of social and environmental concerns, and encourages active engagement in the teaching and learning process. Students need to develop skills through result-oriented, creative, stimulating, and challenging activities. Such educational approaches must emphasize motivation, collaboration, curiosity, critical thinking, and positive attitudes as fundamental components.

We believe that the lack of motivation is a decisive factor for failure and consequent school dropout. Therefore, it is essential to keep students motivated by using innovative practical activities (Marques et al., 2021) in order to increase their knowledge.

Considering the progression of students' knowledge throughout the study, the results of their self-assessment revealed that at the beginning, only a few students had good knowledge about the role of benthic macroinvertebrates to evaluate water quality. However, after the implemented activities, most students self-assessed their knowledge as "good" or "very good". While these qualitative results are indicative of relevant learning gains, they are in line with literature that highlights the importance of implementing innovative practical activities in environmental education (H. Azevedo et al., 2022; M. M. Azevedo et al., 2015).

Environmental education within schools can be fundamental for intellectual growth. By presenting social alternatives and exposing their advantages and disadvantages, environmental education ultimately enhances awareness of environmental problems, promoting a change in students' attitudes and competences (Steg & Vlek, 2009). Providing activities wherein students engage with their own region and its natural resources is crucial for developing local knowledge and fostering collaboration aimed at protecting the local natural heritage, as claimed by Chen and Kitagawa (2023). Furthermore, activities that involve hands-on learning encourage student motivation, improve the quality of science education and promote environmental awareness (H. Azevedo et al., 2022), which are crucial to promote education for sustainability. This is essential in the context of basic education, which is the focus of our study, as "important concepts may be integrated into the core learning areas, especially within the Science curriculum" (Maimad et al., 2023).

The findings of this study clearly show a noteworthy improvement in learning regarding environmental science, as reflected in the content analysis of students' sentences, for example: "I learned to classify river waters according to their purity"; "I learned more about rivers, the animals that live there, and their functions"; "I learned how I can use living beings to classify river waters".

The students involved in this study were motivated and satisfied with engaging in scientific activities, both in the field and in the classroom, as well as with completing a game-based task. The results are very positive, as a strong collaborative teaching/learning process was observed between the biologist/students and students/students. Students participated dynamically in information exchange and collaborative work, asking questions, interpreting data, and solving problems. In this case, the implementation of hands-on activities is a great element for student motivation, not only by improving the quality of science education but also by awakening environmental and ethical awareness. The opportunity of direct contact with living organisms provides information and experiences that are not accessible by reading, viewing pictures, or examining models (Deterding et al., 2011). The results of this study are in line with the ones reported by H. Azevedo et al. (2022) who claimed that fieldwork improved students' attitudes toward environmental protection and knowledge construction.

For the development of a deeper understanding of the nature of scientific knowledge and the process of their construction, it is pivotal that students have the possibility to be engaged in epistemic practices, as claimed by some authors (Aleixandre & Crujeiras, 2017; Berland et al., 2016). For that reason, it is important that learning about scientific concepts should not be separated from learning about the practices used in the construction of scientific knowledge (Duschl & Grandy, 2013), as considered in this study.

Teaching and learning science require significant and productive engagement in social practices for knowledge construction (Engle & Conant, 2002; Mortimer et al., 2014). Students must have opportunities to elaborate theories and models, to argument and to use different forms of communication and representation of concepts or phenomena (Duschl et al., 2013). Furthermore, students need to have opportunities for learning how to observe and describe, formulate hypotheses, collect, and organize data, interpret and discuss results. Such practices are grounded in the efforts of scientists in generating scientific knowledge. Throughout this study, the students had the chance to engage in essential scientific practices mirroring those employed by scientists for investigating and constructing knowledge in this field. The students' engagement in scientific practices grants them greater authority and enhances their competence in applying scientific knowledge in real-world contexts (Lopes et al., 2011), as verified in this study.

In the same way, the integration of collaborative work through a board game fosters the development of students' knowledge and competences, playing a crucial role in promoting the growth of critical thinking, interpretation, analysis, and problem-solving skills (Brockmyer et al., 2009; Ijsselsteijn et al., 2007; Norman, 2013). Additionally, this activity consolidates the epistemic practices related to data organization, identifications of patterns, argumentation, teamwork, and validation of knowledge.

A previous study conducted by Dichev and Dicheva (2017) also stressed that game strategies used in the educational context increased engagement by incorporating game elements into the educational environment. Some studies similarly highlight the importance of implementing game approaches in educational contexts in terms of retention, knowledge, engagement, and cooperation (Hakulinen & Auvinen, 2014; Tvarozek & Brza, 2014). The study performed by Smiderle and co-workers (2020) shows that integrating games into education can increase students' engagement, enhance fundamental skills, thus optimizing the learning process. The game strategy employed in this study maintains the task as a challenge, resulting in positive effects on student engagement, as claimed by Cunha et al. (2014).

Moreover, the games offer stimulating experiences, aiming to promote competitiveness and dedication, thereby rendering the task both challenging and exhilarating (Pires, 2018), as reflected in this study. The experience with games goes far beyond playfulness and encompasses other determining factors, such as continuous feedback, a taste for competition, the possibility to evolve quickly, the search for rewards, and obtaining pleasing results (Pires, 2018). Another important aspect of this study is the fact that the game was played in groups. Using games that entail collaboration, such as team-based activities, elicits emotions more frequently and with greater intensity compared to individual games (Lazzaro, 2009), which aligns with our findings.

The students enrolled in this study showed enthusiasm and satisfaction in carrying out scientific activities, both outdoors and in class, including taking part in a game-based task. These results are important for integrating local content into the curriculum and promoting sustainability education, emphasizing the significance of sustainability within education.

Conclusions

The findings of this study have reaffirmed the effectiveness of these pedagogical strategies (i.e., fieldwork, collaboration, gamed-based tasks) in nurturing knowledge and fostering scientific thinking skills, which can be further enhanced through constructive feedback, incentives, and immersive learning experiences. The utilization of benthic macroinvertebrates not only instils fascination among students due to their novelty, morphology, and life cycle, but also serves as a valuable tool for introducing a multitude of ecological concepts, including adaptations, food webs, bioindicators, and aquatic ecology. Moreover, it offers an avenue for discussing pollution impacts, the significance of pristine aquatic ecosystems, and the management of natural waters, thereby promoting an understanding of environmental sustainability.

Fieldwork provides students with immersive experiences and opportunities to develop essential hands-on skills, enabling them to grasp scientific practices within the context of ecological research methodologies. Similarly, the integration of a board game in the classroom serves to reinforce learning by "transporting" students back to the river environment, consolidating their fieldwork experiences and deepening their understanding of data organization, interpretation, and taxonomy. The overwhelmingly positive feedback from students regarding the impact of this learning activity underscores its effectiveness in promoting critical and scientific thinking concerning aquatic ecosystem monitoring, techniques, and their broader implications for public health. Thus, these integrated approaches not only enhance academic achievement but also underscore the significance for a more sustainability education in preparing students to address real-life environmental challenges.

Limitations

This research is a qualitative study, based on a case study, which led to significant results. However, for more consistent results, this strategy should be conducted in more classes, schools, and countries, since the number of students of this study is limited. The time for the development of these activities should also be extended. The absence of control group is another constraint of this work.

Ethics Statement: The consent for students' participation in the study was obtained from the students' guardians, on their behalf. They were informed about the use of their data and were told they could terminate their participation at any point and gave their consent before the study. All data were anonymized. Also, the study was approved by the School Board in January 2020. There were no further ethics requirements from our institution.

References

Alba-Tercedor, J., & Sánchez-Ortega, A. (1988). A simple and quick method to evaluate biological quality of running freshwater based on Hellawell (1978). *Limnetica*, *4*(5), 1–56.

Aleixandre, M. P. J., & Crujeiras, B. (2017). Epistemic practices and scientific practices in Science education. In K. S. Taber & B. Akpan (Eds.), *Science education. New directions in Mathematics and Science education* (pp. 69–80). SensePublishers.

Azevedo, H., Soares-Silva, I., Fonseca, F., Alves, P., Silva, D., & Azevedo, M. M. (2022). Impact of educational gardens and workshop activities on 8th-grade student's perception and knowledge of plant biology. *Education Sciences*, *12*(9), 619–635. https://doi.org/10.3390/educsci12090619

Azevedo, M. M. (2008). *Toxicity of metals in aquatic hyphomycetes: Cellular targets and defense mechanisms* (PhD Doctoral Thesis, University of Minho).

Azevedo, M. M., Duarte, S., Paiva, S., & Johansson, B. (2013). Implementation of a laboratory teaching module on human physiology to Portuguese students in regular Biology classes. *Educational Research Journal*, *3*, 180–191.

Azevedo, M. M., Fonseca, F., Andrade, R. P., & Palmeirim, I. (2012). The impact of alternative science education methodologies on the motivation and acquisition of scientific concepts. *Educational Research Journal*, *2*(5), 132–137.

Azevedo, M. M., Pinheiro, C., Dias, A., Pinto-Ribeiro, F., & Baltazar, F. (2015). Impact of an educational hands-on project on the antimicrobial, antitumor and anti-inflammatory properties of plants on Portuguese students' awareness, knowledge, and competences. *International Journal of Environmental Research and Public Health*, *12*(3), 2437–2453. https://doi.org/10.3390/ijerph120302437

Azevedo, M. M., Ricardo, E., Teixeira Dos Santos, R., Pina-Vaz, C., & Rodrigues, A. G. (2020). "Filling a gap: knowledge in health related science for middle school students in formal and informal contexts. *Journal of Biological Education*, *54*(2), 129–146.

Bedford, T. (2022). Constructing a transformative sustainability pedagogy: Teacher empowerment for a sustainable future. *Journal of Teacher Education for Sustainability*, *24*(1), 5–18. https://doi.org/10.2478/jtes-2022-0002

Berland, K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082–1112. https://doi.org/10.1002/tea.21257

Bonwell, C. C., & Eison, J. A. (1991). *Active learning: Creating excitement in the classroom*. The George Washington University, School of Education and Human Development.

Briede, L., & Drelinga, E. (2020). Personal sustainability and sustainable employability: Perspective of vocational education students. *Journal of Teacher Education for Sustainability*, *22*(2), 40–48. https://doi.org/10.2478/jtes-2020-0015

Brockmyer, J. H., Fox, C. M., Curtiss, K. A., McBroom, E., Burkhart, K. M., & Pidruzny, J. N. (2009). The development of the Game Engagement Questionnaire: A measure of engagement in video game-playing. *Journal of Experimental Social Psychology*, *45*(4), 624–634. https://doi.org/10.1016/j.jesp.2009.02.016

Brundtland, G. H. (1987). Our common future: Call for action. *Environmental Conservation*, *14*(4), 291–294.

Chen, Y., & Kitagawa, K. J. S. (2023). Locally based architectural construction strategies in rural China: Textual analysis of architects' design thinking. *Sustainability*, *15*(13), 10573. https://doi.org/10.3390/su151310573

Cohen, L., Manion, L., & Morrison, K. (2002). *Research methods in education (5th ed.)*. Routledge.

Coimbra, C., Graça, M., & Cortes, R. (1996). The effects of a basic effluent on macroinvertebrate community structure in a temporary Mediterranean river. *Environmental Pollution*, *94*(3), 301–307. https://doi.org/10.1016/s0269-7491(96)00091-7

Costa, M. J., & Rangachari, P. K. (2009). The power of interactive teaching. *Biochemistry and Molecular Biology*, *37*, 74–76. https://doi.or/10.1002/bmb.20270

Cunha, A. E., Saraiva, E., Santos, C. A., Dinis, F., & Lopes, J. B. (2014). Teacher mediation actions and students' productive engagement during the use of computer simulations in physical science classrooms. *Procedia Technology*, *13*, 76–85. https://doi.org/10.1016/j.protcy.2014.02.011

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: defining" gamification". In A. Lugmayr, H. Franssila, O. Sotamaa, C. Safran, & T. Aaltonen (Eds.), *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments* (pp. 9–15). Association for Computing Machinery.

Dichev, C., & Dicheva, D. (2017). Gamifying education: What is known, what is believed and what remains uncertain: A critical review. *International Journal of Educational Technology in Higher Education*, *14*(1), 1–36. https://doi.org/10.1186/s41239-017-0042-5

Duschl, R. A., & Grandy, R. J. (2013). Two views about explicitly teaching nature of science. *Science & Education*, *22*, 2109–2139. https://doi.org/10.1007/s11191-012-9539-4

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition & Instruction*, *20*(4), 399–483.

Fardo, M. L. (2014). *Gamification as a pedagogical strategy: A study of elements from games applied in teaching and learning processes* (Master's Thesis, Universidade de Caxias do Sul).

Fleischman, K., & Ariel, E. (2016). Gamification in science education: Gamifying learning of microscopic processes in the laboratory. *Contemporary Educational Technology*, *7*(2), 138–159. https://doi.org/10.30935/cedtech/6168

Fonseca, M. J., Santos, C. L., Costa, P., Lencastre, L., & Tavares, F. (2012). Increasing awareness about antibiotic use and resistance: A hands-on project for high school students. *PloS One, 7*(9), e44699. https://doi.org/10.1371/journal.pone.0044699

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. https://doi.org/10.30935/cedtech/6168

Furtak, E. M., & Kunter, M. (2012). Effects of autonomy-supportive teaching on student learning and motivation. *The Journal of Experimental Education*, *80*(3), 284–316. https://doi.org/10.1080/00220973.2011.573019

Graça, M. A. S., & Ferreira, R. C. F. (1995). The ability of selected aquatic hyphomycetes and terrestrial fungi to decompose leaves in freshwater. *Sydowia-Horn*, *47*, 167-222.

Hakulinen, L., & Auvinen, T. (2014). The effect of gamification on students with different achievement goal orientations. In A. Pears (Ed.), *2014 International Conference on Teaching and Learning in Computing and Engineering (LaTiCE)* (pp. 9–16). IEEE Computer Society.

Hines, J. M., Hungerford, H. R., & Tomera, A. N. (1987). Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. *The Journal of Environmental Education*, *18*(2), 1–8. https://doi.org/10.1080/00958964.1987.9943482

Ijsselsteijn, W., De Kort, Y., Poels, K., Jurgelionis, A., & Bellotti, F. (2007). Characterising and measuring user experiences in digital games. In R. Bernhaupt & M. Tscheligi (Eds.), *Proceedings of the International Conference on Advances in Computer Entertainment Technology – ACE 2007* (pp. 1–4). Association for Computing Machinery.

Ivala, E., Gachago, D., Condy, J., & Chigona, A. (2013). Enhancing student engagement with their studies: A digital storytelling approach. *Creative Education*, *4*(10), 82–89. http://dx.doi/10.4236/ce.2013.410A012

Kapp, K. M. (2012). *The gamification of learning and instruction: Game-based methods and strategies for training and education*. John Wiley & Sons.

Kelly, G. J., & Licona, P. (2018). Epistemic practices and science education. In M. R. Matthews (Ed.), *History, philosophy and science teaching: New perspectives* (pp. 139–165). Springer International Publishing.

Khoo, H. E. (2005). Teaching biochemistry to medical students in Singapore – from organic chemistry to problem-based learning. *Annals of the Academy of Medicine, Singapore*, *34*(6), 79C–83C.

Krippendorff, K. (2004). *Content analysis: An introduction to its methodology (2nd ed.)*. Sage Publications.

Lazzaro, N. (2009). Human-computer interaction: Designing for diverse users domains. In A. Sears & J. A. Jacko (Eds.), *The human-computer interaction handbook: Fundamentals, evolving techniques, and emerging applications* (2nd ed.) (pp. 679–700). CRC Press.

Lopes, J. B., Branco, J., & Jimenez-Aleixandre, M. P. (2011). 'Learning experience' provided by science teaching practice in a classroom and the development of students' competences. *Research in Science Education*, *41*(5), 787–809. https://doi.org/10.1007/s11165-010-9190-5

Maimad, M. T., Dupa, H. J. P., & Villegas, J. P. (2023). Parental involvement and academic achievement: Keys to translating no poverty and quality education SDGs in Philippine peripheral communities. *Journal of Teacher Education for Sustainability*, *25*(2), 76–88. https://doi.org/10.2478/jtes-2023-0017

Marques, F., Pinto, L., Azevedo, M. M., Sampaio-Marques, B., Areias, A. C., Salgueira, A., Costa, M. J., Rodrigues, F., & Ludovico, P. (2021). Innovative, integrative, and interactive in-class activity on metabolic regulation: Evaluating educational impacts. *Biochemistry and Molecular Biology Education*, *49*(6), 870–881. https://doi.org/10.1002/bmb.21569

Merian, E., & Clarkson, T. W. (1991). *Metals and their compounds in the environment*. VCH-Verlag.

Metcalfe-Smith, J. (1994). Biological water-quality assessment of rivers: use of macroinvertebrate communities. *Environmental Pollution*, *60*, 144–170. https://doi.org/10.1016/0269-7491(89)90223-6

Morris, B., Croker, S., Zimmerman, C., Gill, D., & Romig, C. (2013). Gaming science: The "Gamification" of scientific thinking. *Frontiers in Psychology*, *4*, 607–623. https://doi.org/10.3389/fpsyg.2013.00607

Mortimer, E. F., Quadros, A. L., Silva, A. C. A. da., Sá, E. F. de., Moro, L., Silva, P. S., Martins, R. F., & Pereira, R. R. (2014). Interactions between semiotic modes and the making of meaning in lessons oh high education. *Ensaio Pesquisa em Educação em Ciências*, *16*(3), 121–146. https://doi.org/10.1590/1983-21172014160306

Norman, K. L. (2013). Geq (game engagement/experience questionnaire): A review of two papers. *Interacting With Computers*, *25*(4), 278–283. https://doi.org/10.3389/fpsyg.2013.00607

Parikh, A., McReelis, K., & Hodges, B. (2001). Student feedback in problem based learning: A survey of 103 final year students across five Ontario medical schools. *Medical Education*, *35*(7), 632–636. https://doi.org/10.1046/j.1365-2923.2001.00994.x

Pires, C. (2018). *The potential of gamification as a pedagogical strategy: Encouraging participation through the use of the Moodle platform.* (Master Thesis, Instituto Superior Tecnico, Universidade de Lisboa).

Platts, W. S., Megahan, W. F., & Minshall, G. W. (1982). *Methods for evaluating stream, riparian, and biotic conditions* (Vol. 138). US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Poels, K., de Kort, Y., & IJsselsteijn, W. (2007). *D3.3: Game Experience Questionnaire: Development of a self-report measure to assess the psychological impact of digital games*. Eindhoven. Technische Universiteit Eindhoven.

Prince, K. J., Van Eijs, P. W., Boshuizen, H. P., Van Der Vleuten, C. P., & Scherpbier, A. J. (2005). General competencies of problem-based learning (PBL) and non-PBL graduates. *Medical Education*, *39*(4), 394–401. https://doi.org/10.1111/j.1365-2929.2005.02107.x

Rieckmann, M. (2017). *Education for sustainable development goals: Learning objectives*. UNESCO Publishing.

Rosenberg, D. M. (1992). Freshwater biomonitoring and Chironomidae. *Netherland Journal of Aquatic Ecology*, *26*(2), 101–122. https://doi.org/10.1007/BF02255231

Sé, A. B., Passos, R. M., Ono, A. H., & Hermes-Lima, M. (2008). The use of multiple tools for teaching medical biochemistry. *Advances in physiology education*, *32*(1), 38–46. https://doi.org/10.1152/advan.00028.2007

Smiderle, R., Rigo, S. J., Marques, L. B., Miranda Coelho, J. A., & Jaques, P. A. (2020). The impact of gamification on students' learning, engagement and behavior based on their personality traits. *Smart Learning Environments*, *7*(1), 1–11. https://doi.org/10.1186/s40561-019-0098-x

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology*, *29*(3), 309–317. https://doi.org/10.1016/j.jenvp.2008.10.004

Tripp, B., Voronoff, S. A., & Shortlidge, E. E. (2020). Crossing boundaries: Steps toward measuring undergraduates' interdisciplinary science understanding. *CBE-Life Sciences Education*, *19*(1), ar8. https://doi.org/10.1187/cbe.19-09-0168

Trusina, I., Jermolajeva, E., Abramov, V., & Gopejenko, V. (2024). World development assessment in an invariant coordinate system of energy units: The newly industrialized economies perspectives. *Journal of Infrastructure Policy and Development*, *8*(3), 3110–3131. https://doi.org/10.24294/jipd.v8i3.3110

Tvarozek, J., & Brza, T. (2014). Engaging students in online courses through Interactive badges. In M. B. Nunes & M. McPherson (Eds.), *Proceedings of the International Conference on e-Learning 2014* (pp. 89–95). International Association for Development of the Information Society.

UNESCO. (2021). *Reimagining our futures together: A new social contract for education*. Educational and Cultural Organization of the United Nations.

Yıldırım, İ., & Şen, S. (2019). The effects of gamification on students' academic achievement: A meta-analysis study. *Interactive Learning Environments*, 1–18. https://doi.org/10.1080/10494820.2019.1636089

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