Stories that educate: Problem/project-based learning and storytelling in raising awareness for sustainability

[1]**Afsaneh Hamedi d'Escoffier,** [2]**Jessica de Oliveira Santiago e** [1]**Luiz Ney d'Escoffier**

[1]Instituto Oswaldo Cruz, Rio de Janeiro, Brasil. [2]Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, Rio de Janeiro, Brasil.

Abstract: Education for sustainable development aims to prepare new generations to face contemporary challenges, whether ecological, social, or economic. The problem/project-based learning methodology has proven effective for education for sustainable development, although the broad scope of sustainability requires complementary pedagogical strategies to develop all necessary competencies. This study proposes a workshop that combines problem/project-based learning with storytelling to verify whether storytelling serves as a complementary strategy to enhance the process of raising sustainability awareness among first-year high school students. We describe the development of the workshop and its evaluation through moderated participant observation, semi-structured questionnaires, analysis of documents called position reviews, and assessment of the product generated at each stage. The results indicate that, although the storytelling stage did not increase the knowledge acquired in the problem/project-based learning stage, it facilitated the development of additional competencies, such as greater engagement and creativity. We conclude that the combination of the two methodologies was successful and can be replicated for other themes and academic levels.

Keywords: active methodologies, problem/project-based learning, storytelling, sustainability.

Introduction

In today's world, we are increasingly facing multifaceted challenges, whether ecological, economic, social, or health-related, which demand significant changes in the organization of society and social practices. Globalization has revealed a fully interconnected world, yet social inequalities and environmental issues make these challenges ever more complex and difficult to solve.

Education for Sustainable Development (ESD) is pivotal in preparing new generations to tackle these challenges. Rooted in the principle of sustainability, ESD is about "using resources in a way that allows future generations to also have access to them" (World Commission on Environment and Development, 1987). The primary goal of ESD is to foster individual and social transformations that promote sustainable development.

ESD advocates for an educational pedagogy that engages students in knowledge creation within interactive learning environments focused on real-world problems (Beagon et al., 2023). It supports interdisciplinary approaches centered on problem-solving, with collaborative learning among

students and the community, emphasizing a holistic approach to learning that encompasses knowledge, emotions, and goals (Guerra, 2017).

The Problem-Based Learning (PBL) and Project-Based Learning (commonly abbreviated as PjBL, although the acronym PBL is also widely used. For consistency, and do to its prevalence in scientific literature, we will use the acronym PBL throughout this article to refer to Project-Based Learning) methodology aligns well with the aims of ESD, which is a key component of the United Nations' 2030 Agenda for Sustainable Development - a global action plan adopted by all UN Member States to promote prosperity while protecting the planet (UN, 2015). By fostering critical thinking, collaborative problem-solving, and learner agency, PBL supports the development of the knowledge, skills, values, and attitudes needed to contribute to the achievement of the 17 Sustainable Development Goals (SDGs), including goals related to quality education (SDG 4), health and well-being (SDG 3), gender equality (SDG 5), reduced inequalities (SDG 10), and climate action (SDG 13), among others. PBL encourages students to identify real issues affecting their community, seek solutions, and develop prototypes, working collaboratively in small groups with guidance from tutor-teachers. By the end of the project, students will have autonomously acquired the necessary knowledge.

This methodology is applicable across various educational levels, from elementary to postgraduate education, although its systematic application remains limited to short-term experiences. This limitation hinders a deeper understanding of the topic. Moreover, assessing PBL's effectiveness is complex and often relies on self-assessments and satisfaction surveys, which do not clearly indicate whether long-term objectives were achieved, especially in short-term projects. In our high school education experience, students often focus more on producing the prototype than on the project theme, which becomes secondary.

Sustainability is a broad topic, making it impossible to cover all its elements and achieve full knowledge and competency acquisition in a single workshop. However, it is feasible to raise awareness about sustainability. This involves making students aware of environmental issues, introducing the concept of sustainability, highlighting its importance, increasing their understanding of its relevance and impact, and sparking their interest and curiosity for deeper learning or further development of related competencies. In this process, it is essential to emphasize that sustainability encompasses not only environmental concerns but also social and economic dimensions, as outlined in Elkington's Triple Bottom Line framework (Elkington, 1997). This holistic perspective encourages learners to consider the interdependence between ecological integrity, social equity, and economic viability, fostering a more comprehensive and responsible understanding of sustainability.

To address this challenge, we propose a hybrid model that combines PBL with the Storytelling methodology. Storytelling aims to revisit and consolidate the concepts developed during the PBL phase by creating a story script. This proposal is guided by the question: How does the incorporation of Storytelling, which introduces a hybrid dimension to a PBL-based workshop, contribute to the development of sustainability

competencies? Additionally, we will investigate whether Storytelling serves as an effective means to review and reinforce sustainability-related knowledge and concepts acquired during the PBL phase, by examining if the students' narratives reflect the concepts and insights developed through their experiential learning.

In light of the points discussed above, this article aims to address the following objectives:

General Objective

To analyze how the integration of Storytelling into a PBL-based workshop contributes to the development of sustainability competencies in students.

Specific Objectives

1. To investigate whether Storytelling serves as an effective tool for revisiting and reinforcing sustainability-related concepts introduced during the PBL phase.

2. To examine whether students' narratives reflect the sustainability knowledge and competencies acquired through experiential learning.

3. To explore the role that Storytelling plays within the overall structure of the workshop, especially in relation to student engagement and conceptual consolidation.

4. To assess changes in students' understanding or perspectives on sustainability throughout the different phases of the workshop.

In this work, we present the methodology used and discuss the benefits of employing this hybrid model to enhance awareness and understanding of sustainability through education.

Theoretical Framework

Sustainability has emerged as a central concept in global development, encompassing practices that seek to balance human needs with the environment's capacity to support these demands over the long term. Sustainability refers to the ability to meet present needs without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987).

In the contemporary context, the importance of sustainability is increasingly recognized in light of growing evidence of climate change, environmental degradation, and the depletion of natural resources. These global challenges underscore the need for a paradigm shift in how society uses and manages natural resources. This urgency is reflected in the United Nations General Assembly Resolution 70/1 (UN, 2015), which adopted the 2030 Agenda for Sustainable Development. At its core are the 17 Sustainable Development Goals (SDGs), a comprehensive framework that calls for integrated action across social, environmental, and economic dimensions to promote prosperity while protecting the planet. The SDGs emphasize the interconnectedness of global challenges and highlight the role of education, innovation, and inclusive approaches in achieving a more sustainable and equitable future for all. In line with the SDGs' integrated

vision, sustainability is understood today as a multidimensional concept that extends beyond environmental concerns.

Sustainability is not only an environmental issue but also encompasses economic and social dimensions, ensuring that economic development and social well-being are achieved equitably and sustainably (Elkington, 1997). This includes the use of renewable energy and biodiversity conservation (Dyllick & Hockerts, 2002), circular economy practices (Bocken et al., 2016), the promotion of decent working conditions, gender equity, and social inclusion (Sachs, 2015).

Education for sustainability is an essential component for promoting sustainable practices and raising awareness about the importance of balanced development (UNESCO, 2012; Huckle & Sterling, 2014). It aims to equip individuals and communities with the knowledge, skills, attitudes, and values necessary to make informed and responsible decisions that consider social, economic, and environmental implications, thus encouraging active and responsible citizenship (Tilbury, 2011). Furthermore, education for sustainability promotes the development of essential competencies such as systems thinking, problem-solving, and ethical decision-making (Wiek et al., 2015).

Given that sustainability is inherently a multidisciplinary area, it requires the integration of knowledge from various fields such as biology, economics, sociology, and political science. Therefore, sustainable education must be holistic, systemic, and interconnected, providing a deep understanding of the complex relationships between humans and the environment (Sterling, 2001). Similarly, UNESCO (2017) emphasizes that education for sustainability should be integrated at all levels of education and should include interdisciplinary, collaborative, and practical approaches. This form of education seeks to foster a culture of sustainability, promoting innovation, creativity, and critical capacity in individuals to address contemporary environmental challenges.

In this context, active methodologies represent an interesting teaching strategy by placing the student at the center of the learning process, promoting greater engagement, autonomy, and the development of critical skills. These methodologies aim to transform the student's role from a mere receiver of information to an active agent in the construction of knowledge. Problem/Project-Based Learning (PBL) is a student-centered pedagogical approach that uses complex real-world problems as a starting point for developing skills, knowledge and the exercise of active citizenship. In PBL, students work in teams to solve authentic problems, promoting collaboration, critical thinking, and self-directed learning (Barrows, 1986; Graaf & Kolmos, 2007).

PBL promotes the development of transversal competencies essential for education for sustainability. Skills such as critical thinking, problem-solving, collaboration, and communication are fundamental to addressing contemporary environmental and social challenges. According to Savery (2006), PBL allows students to integrate knowledge from different disciplines, promoting a holistic view of sustainability issues. It can also increase student engagement and motivation by connecting learning with real and relevant problems, where they apply theories and concepts to real-

world situations, providing authentic and contextualized learning (Jonassen, 2011). This is particularly important in education for sustainability, where the practical relevance of the topics can stimulate greater awareness and commitment to environmental issues (Hmelo-Silver, 2004), preparing students to deal with the complexity and uncertainty inherent in environmental and social problems.

Empirical studies have demonstrated the effectiveness of PBL in education for sustainability (Krogh Hansen et al., 2014; Cörvers et al., 2016). For example, a study by Ribeiro and Mizukami (2005) on the application of PBL in environmental engineering courses showed that students had a greater ability to solve complex problems and a more integrated view of sustainable challenges. Another study by Dochy et al. (2003) indicated that students who participated in PBL-based courses developed a deeper and more lasting understanding of sustainability principles. Guerra (Guerra et al., 2022) identified multiple sources of student agency related to personal values, such as motivation and efficacy beliefs when working systemically with PBL for sustainability. Kanyesigye, Uwamahoro & Kemeza (2023) concluded that problem-based learning (PBL) significantly improved students' achievement in mechanical waves compared to traditional instructional methods (TIM), with the experimental group showing higher learning gains and large effect size. Additionally, the study recommended the adaptation of PBL by teachers, considering the positive impacts observed across various factors like gender, age, school type, and subject combinations.

To further strengthen the pedagogical impact of PBL, complementary approaches such as storytelling have been increasingly recognized for their potential to humanize complex issues and foster deeper emotional engagement and cognitive integration of content. Storytelling is a communication technique that involves creating and narrating stories to entertain, inform, or persuade an audience. According to Bruner (1991), stories are a fundamental form of human thought, allowing people to organize and understand their experiences and the world around them. Fisher (1987) proposes the "narrative paradigm," suggesting that humans are essentially "storytellers", and that narrative understanding is a primary form of knowledge.

In education, storytelling can be used as a powerful tool for teaching and learning. Egan (1986) argues that using stories in education can make learning more meaningful and memorable. Stories engage students emotionally, facilitating the comprehension and retention of complex information. They also promote critical thinking and creativity by allowing students to explore different perspectives and contexts.

Storytelling can play a crucial role in education for sustainability by promoting emotional engagement with the topic, facilitating internalization and action (Morgan & Dennehy, 1997), as well as supporting contextualization and relevance (Gough, 2008), and modeling behaviors through narrative examples (Bandura, 1977). Additionally, stories can reflect and value cultural diversity, promoting a more inclusive and equitable understanding of sustainability. According to Hall (1997), culture is a central component of identity, and cultural stories can strengthen

students' connection to sustainability values. Moreover, narratives of challenges and overcoming can inspire students to develop innovative solutions to environmental problems. Storytelling, by fostering creativity and critical thinking, can be a catalyst for sustainable innovation (Sawyer, 2011).

Several projects and initiatives have utilized storytelling as a tool in education for sustainability. Educational programs such as "Eco-Schools" (https://www.ecoschools.global/) and "Green School Bali" (https://www.greenschool.org/bali/) incorporate narratives into their curricula to engage students in sustainable practices. Additionally, digital and multimedia platforms, such as videos and podcasts, have been used to tell sustainability stories in an accessible and engaging manner. The work of Wajdi (Wajdi et al., 2022) describes how the production of comic books associated with PBL had a positive effect on the environmental literacy of biology undergraduate students in Indonesia, in a similar initiative to ours.

Considering the above, the integration of PBL and storytelling is justified as it creates a more dynamic, relevant, and effective learning environment, enhancing students' cognitive, social, and emotional development. This approach prepares students to face real-world environmental challenges with creativity and empathy.

Methodology

Research Design

The study involved developing a workshop for high school students, using a pedagogy based on Project-Based Learning (PBL), integrated with Storytelling. The methods of analysis included moderate participant observation (Spradley, 1980; Shin & Miller, 2022), semi-structured questionnaires (Adams & Cox, 2008), analysis of documents called "position reviews," and evaluation of the product generated at the end of each stage.

Given the qualitative nature of the research (Adams & Cox, 2008), the empirical data were subjectively analyzed by the researcher, seeking to relate the findings to the concepts of sustainability and sustainable development, to verify if there was an increased awareness of the topic.

Participants

The workshop involved 35 first-year high school students from a private school in Rio de Janeiro, Brazil. The inclusion criteria were voluntary participation and signing of assent forms, following the Human Research Ethics Committee's guidelines.

Questionnaire

The questionnaire was answered individually and was structured around a fictional yet controversial scenario involving the deforestation of a local area to construct a football stadium (Appendix 1). This approach aimed to recognize a problem within a real-world context, seeking to raise students' awareness. While the proposed construction project entailed significant environmental degradation, it also promised economic benefits such as job creation and regional development.

Following the scenario description, students were asked to respond to a set of open- and closed-ended questions designed to explore their perceptions of the issue. These questions addressed short- and long-term environmental impacts, as well as potential advantages and disadvantages of the stadium's construction for both the municipality and its population.

The main objective of the questionnaire was to assess students' understanding of sustainability-related themes aligned with the Sustainable Development Goals (SDGs) (UN, 2015) at different points during the workshop. By administering the same questionnaire at multiple stages, the study aimed to investigate whether students' opinions evolved over time based on the knowledge acquired, and to analyze the extent to which they demonstrated a sustainable perspective, including how they justified their views within the framework of sustainability.

The same questionnaire — following the structure and question types described in the previous paragraph and presented in the appendix — was administered at three distinct points: (1) before the PBL phase, (2) at the end of the PBL phase, and (3) at the end of the Storytelling workshop, to track development throughout the phases.

Position Review Documents

Position review documents were used to monitor and record the progress of activities. Forms containing questions about the project's development, such as current status, encountered difficulties, pending tasks, and next steps, were completed by the groups at the end of each workshop stage (PBL and Storytelling phases). This allowed the teacher to devise strategies to assist delayed groups and maintain the workshop's schedule.

Workshop Development

The workshop was conducted within the students' scheduled class time with the teacher/researcher (hereafter teacher) from March to May 2023. It was divided into two phases, comprising a total of 15 sessions, each lasting 1 hour and 20 minutes. The first phase was dedicated to the implementation of PBL, and the second phase focused on constructing the Storytelling component.

<u>PBL</u>

This phase was subdivided into three stages with increasing complexity, following the PBL methodology. The development format was inspired by the SCRUM methodology (Schwaber & Sutherland, 2020), where tasks are to be completed by specific deadlines. Groups could only advance to the next stage when all tasks, both their own and those of the other groups, were completed. This ensured that all students progressed to the next stage together. To facilitate this, the teacher, acting as a mentor, provided constant feedback and dedicated extra time to delayed groups. At the end of each stage, students were asked to prepare a "position review," where they reported the group's progress, difficulties, and the next steps they planned to take.

<u>*Stage 1.*</u> This initial stage lasted for 3 sessions and was dedicated to group formation, responses to the pre-questionnaire, presentation, and selection of themes, mapping of problems related to the theme in their

communities, and presentation of their themes and perceived problems to the class based on the collected information.

Seven groups were formed, each consisting of five students, and the themes were assigned by drawing lots. These themes were referenced to the UN's SDGs, tailored to the students' realities, and aimed to address the three dimensions of sustainability, as outlined in Table 1.

N.	SDG	Theme	Definition
1	6	Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all.
2	7	Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable, and modern energy for all.
3	11	Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient, and sustainable.
4	12	Responsible Consumption and Production	Ensure sustainable consumption and production patterns.
5	13	Climate Action	Take urgent action to combat climate change and its impacts.
6	14	Life Below Water	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.
7	15	Life on Land	Protect, restore, and promote sustainable use of terrestrial ecosystems, manage forests sustainably, combat desertification, and halt biodiversity loss.

Table 1. themes distributed to groups with their definitions.

Source: The authors, based on UN (2015).

Stage 2. In this stage, which lasted two sessions, each group received individualized support to discuss their proposed solutions and their feasibility, considering the three pillars of sustainability: environmental, social, and economic.

Stage 3. Throughout four sessions, the groups developed a prototype of their solution. This could take various forms, such as models, drawings, computer simulations, artifacts, etc. The objective was to test the practical viability of the proposed solution and to identify any inconsistencies in the project to make necessary adjustments.

At the end of this stage, which marked the conclusion of the PBL phase, the students completed the questionnaire again to assess whether there was increased awareness about sustainability through the PBL development process.

Storytelling

This phase was conducted over five sessions. Students were invited to produce a story related to the problem and the solution they had found, culminating in the creation of a video. This activity aimed to encourage students to reflect on their projects, organize their ideas, review concepts, and reassess the feasibility of their solutions.

During this phase, the teacher introduced concepts related to the elements of Storytelling, such as scriptwriting, storyboard production, and finally, video creation.

On the last day, students presented their videos to the groups, followed by discussions on the themes, problems, and solutions. At this point, the students completed the questionnaire again to observe the effects of Storytelling on raising awareness about sustainability.

Results

To facilitate better understanding, the results will be presented according to the phase and stage that was developed.

During the PBL Phase

Students encountered difficulties in clearly defining the problem. Initially, they confused the theme with the problem (e.g., the theme of clean water and sanitation with the problem of lack of sanitation and clean water; the theme of health with the problem of lack of health, etc.). This may be related to a lack of a systemic view of the theme, focusing only on one aspect and failing to analyze the whole. They also initially thought on a very large scale, at the national or global level, making the solution overly complex. After the teacher signaled for them to focus on their immediate surroundings, the work flowed better.

By the third meeting, when the problems were better defined, students began to take an interest in the themes of other groups, realizing that although they were seemingly distinct, they had connections between them, with intersections of problems and solutions.

There were also exchanges of information at the group management level, with groups that were behind schedule modeling their organization methodology after other groups to achieve their objectives on time.

This initial evolution in students' thinking laid the groundwork for the subsequent stage of the workshop—the prototyping phase—where they were challenged to translate their ideas into practical solutions.

During the Prototyping Phase

It was not always possible to create a physical prototype, although one group managed to make a water filter for obtaining clean drinking water. Therefore, sketches of the solutions were developed, facilitating the analysis of feasibility. The main discussion raised was regarding economic viability (high initial investment), although environmental infeasibility was also observed.

At the end of the PBL phase, groups shared with the rest of the class the problem encountered for their theme, the solution, its viability, and the presentation of the prototype. It was possible to observe that systemic thinking became evident, as was the case with the group responsible for the theme of "clean water and sanitation." Although their prototype was the construction of low-cost water filters for the general population, they raised the issue of charging for basic citizen rights. They were also able to associate the pursuit of rights with education.

With the PBL phase completed and the foundational knowledge established, the workshop progressed to the Storytelling phase. This next stage aimed to reinforce and extend students' understanding by engaging them in a creative reinterpretation of their learning.

During the Storytelling Phase

In this phase, the importance of the previous phases for creating the story to be told was emphasized. In other words, the development of the story (problem in the PBL), the middle, and the end (solution in the PBL) were already in place, requiring only the creation of a plot and characters. It was precisely in the creation of the plot that students were required to revisit the concepts developed in the PBL phase to exemplify, in the form of a story, the problem, and the proposed solution.

Building on the groundwork laid during the PBL phase, students now turned their attention to crafting narratives that would reflect the problems and solutions previously developed.

Regarding the Video Production

From the stories created, the groups produced short videos, each about 2 minutes long. In this exercise, it became evident that students had difficulty summarizing their ideas and presenting the central points.

Before presenting the videos to the rest of the class, groups were asked to explain their theme, problem, and solution. Throughout the presentations, it was possible to observe that students who were less participative in the PBL phase revealed active participation in the Storytelling workshop.

Creativity was also evident, not only in the productions but also in resolving setbacks that arose during the process, such as technical difficulties in video production.

To assess how students' perceptions evolved throughout the workshop, a questionnaire was administered at three key moments. The data revealed notable patterns in how students evaluated environmental impact over time.

According to the responses from the questionnaire administered, when asked about the short-term and long-term environmental impact caused by a fictional scenario, there was a significant increase in the number of students who thought the short-term impact would be large after the PBL stage. However, there were no differences in responses regarding other magnitudes of impact or long-term impact (Table 2).

Time points	Short term					Long term				
	N	VS	S	L	VL	N	VS	S	L	VL
1	2	0	13	9	4	2	0	3	14	11
2	0	0	9	17	5	1	0	4	14	12
3	0	0	8	17	6	0	1	5	14	11

Table 2. Number of responses regarding students' opinions on the magnitude of environmental impact at the three points during the workshop.Note: N – none; VS – very small; S – small; L – large; VL – very large.

Regardless of when the questionnaire was administered, the students' views focused on the environmental dimension of sustainability, as evidenced by their responses shown in Figure 1.

Moment	Impact	Justification
1	None	- *"Because it will not cause any significant damage."*
1	Small	- *"In the short term, the construction of the stadium would affect the animals in the deforested area and cause disruption in the region, but this is an impact of little significance to the residents for now."*
		- *"If a strict law prohibiting littering is enforced, the inconvenience would be small."*
2		- *"Because they have already deforested to make an entrance to a military area."*
		- *"Because the field would be prepared in advance to prevent severe damage."*
3		-*"There will be the removal of a small part of the plants, but it will not have a major impact."*
		- *"If people are hygienic and educated."*
1	Large	- *"The animals that live there will lose their habitat, and the plants in that park will be extinct."*
		- *"Because it would take time for the animals to return to the area."*
2		- *"Increased heat, no more pure air, large deforestation, extinction of species* - *"The stadium would be there for years, generating mountains of trash."*
3		-*"Increase in trash, worse air quality, among other environmental impacts."* -*"The trash generated would harm the environment and kill the plants."*
1	Very Large	-*"Deforestation would cause many animal losses."*
		-*"Considering that the short-term impact would be significant, in the long term it would be even greater."*
2		- *"Yes, because the increase in the number of vehicles in the area and the large amount of energy would affect the local fauna."*
		-*"Over the years, nature will change due to the flow of people and reduced space. The park could no longer be the lungs of the city."*
3		-*"Because many things around this construction would increase in value, and pollution would also be much more noticeable."*
		-*"Because we don't have the necessary education to deal with the generated trash."*

Figure 1: Justifications for the responses to the questionnaire question "In your opinion, would the construction of the stadium have a short-term environmental impact...". The numbers refer to the time points when the questionnaire was administered, as described in the "Methodology" section.

On the other hand, when we look at the responses related to the long-term impact, although the focus remains on the environment, the perspective has become more holistic. Initially centered on deforestation, after the PBL stage, issues such as waste, energy consumption, local inflation, and temperature increase began to be discussed.

Moment	Impact	Justification
1	None	-*"Because it would be used daily."*
1	Very Small	-*"It won't change much."*
1		-*"It won't change much."*
2	Small	-*"After some time, there won't be as many impacts, mainly because citizens will already be accustomed to the changes and the environment will be normalized, with its trees, plants, etc."*
2		-*"Because despite the environmental impact being large, it will be for a short period of time, after the stadium's construction."*
3		-*"Because over time, more trees could be planted around the stadium and we would probably have more trees than before."*
1	Large	-*"The animals living there will lose their habitat and the plants in that park will become extinct."*
1		-*"Because it would take time for the animals to return to the area."*
2		-*"High heat, impure air, extensive deforestation, species extinction."*
2		-*"The stadium would be there for years and years generating mountains of waste."*
3		-*"Increased waste, worsened air quality, among other environmental impacts."*
3		-*"The waste that would be taken out would damage the environment and kill plants."*
1	Very Large	-*"Deforestation would cause many animal losses."*
1		-*"Considering that the short term would have an impact, the long term would be even greater."*
2		-*"Yes, because the increased number of vehicles in the area and the large amount of energy would affect the local fauna."*
2		-*"Over the years, nature will change due to the flow of people and the smaller space. The park could cease to be the city's lungs."*
3		-*"Because many things around this construction would increase the value of things, pollution would be much more noticeable as well."*
3		-*"Because we do not have the necessary education to know how to deal with the waste generated."*

Figure 2: Justifications for responses to the question "In your opinion, would the construction of the stadium have a long-term environmental impact...". The numbers refer to the moments when the questionnaire was administered, as described in the "Methodology" section.

In addition to environmental considerations, students' understanding of the economic dimension of sustainability also evolved. Their responses to questions about economic feasibility revealed a shift in perspective.

When asked how the impacts could be avoided or reduced, at all moments the solutions found were divided between not building the stadium, replanting trees, avoiding deforestation, and proper waste management. However, from the PBL stage onwards, their responses began to reflect vocabulary more aligned with the theme discussed. For example,

words like sustainability, or its concept, and recycling appeared in their responses, such as "sustainable consumption and recycling of generated waste," "environmental assessment, urban planning, and proper environmental implementation," and after the Storytelling stage, "recycling, waste collection, etc.," "using recyclable materials," "awareness and conservation programs," "adopting greater sustainability methods," or "using sustainable measures and materials."

When asked if the investment would be economically worthwhile, the majority of students across all three stages chose to answer affirmatively. However, before the workshop, they viewed the project as a source of income for the stadium owner, in this case, the government. From the PBL stage onward, the reasons for the project's economic worth shifted to job creation and tourism, attracting people from other municipalities, and thereby impacting the local economy. They began to adopt a more comprehensive view of the economic aspect of sustainability, envisioning benefits not only for entrepreneurs but also for the local population.

Beyond vocabulary and conceptual alignment, a deeper change was observed in the maturity of students' proposed solutions.

Through the students' responses, it is possible to observe progress throughout the process. Initially, solutions were based on naïve criteria such as the goodwill of the government and businesses, fundraising through donations, and access to education simply by providing more schools. As the work progressed, their responses became more mature, identifying problems such as the lack of qualified professionals, public policies, and resources. They also expanded the concept of education from formal education to one focused on citizenship, enabling the population to identify their problems and demand solutions from the government.

Additionally, they began to imagine solutions that did not require significant financial investment, such as constructing water purification filters using disposable materials, producing energy with solar panels made from PET bottles, and installing strategically placed trash bins made from recyclable materials for the collection of recyclables. They also considered ways to multiply these initiatives by creating a workshop to teach and encourage social entrepreneurship, funded by donations of non-perishable food items.

Since the work was carried out in stages and progression required participants to complete each stage before advancing to the next, as documented in the "position review" forms, this procedural milestone was successfully achieved. When asked what still needed to be done, the responses indicated that most of the tasks had already been completed or that very little was left to finish. Additionally, according to the same documents, the main challenges faced were a lack of inspiration and knowledge about the subject, as well as reports of internal relationship problems. However, it is important to highlight that these relationship issues were resolved without hindering the progress of the work.

Discussion

Traditional teaching methods demonstrate increasing inefficiency compared to active methodologies, where students are encouraged to actively participate in the construction of knowledge. This is particularly relevant in STEM (Science, Technology, Engineering, and Mathematics) education, where the interdisciplinary nature of these fields requires more dynamic and integrative approaches. Additional studies also point to the effectiveness of active methodologies in STEM education, reinforcing the need for a paradigmatic change in the teaching of these disciplines (Mondagron et al., 2023; Martín-García, Álvarez & Afonso, 2024; Yachin & Barak, 2024).

The PBL methodology has been successfully utilized not only to encourage students to actively seek interdisciplinary knowledge but also to develop specific competencies. However, because it is conducted over a relatively extended period, some studied concepts may be overlooked in favor of more practical concerns, such as feasibility studies and prototype development. On the other hand, in Storytelling, it is necessary to contextualize a situation to produce a story with a beginning, middle, and end. Thus, Storytelling can be an interesting tool for students to review the concepts and knowledge acquired during a PBL project. This work aims to assess whether Storytelling effectively contributed to revisiting sustainability concepts, and, if not, to analyze the role it assumed in the overall dynamics of the workshop.

The workshop was structured into phases with scheduled deliverables, which proved crucial for its success. Due to the limited time available, efficiency in task execution was essential to complete the work on schedule. At this stage, the process drew inspiration from the SCRUM methodology (Schwaber & Sutherland, 2020), breaking down work into cycles. Shorter stages and continuous deliveries made the process dynamic, facilitating quick feedback from the mentor teacher and keeping all groups aligned, thus promoting collaboration and interaction. It was observed that groups falling behind often mirrored the organizational methods of more advanced groups, which had a positive impact on student performance (Fernandes, Dinis-Carvalho & Ferreira-Oliveira, 2021; Devincenzi et al., 2022). However, it's important to note that our adaptation of the SCRUM methodology lacked the original strictness and structure, such as the absence of a Scrum Master and Project Owner.

During the PBL phase, students developed a systemic view of problems, recognizing connections among various issues. This competency aligns with the defining characteristics of sustainability and the sustainable education paradigm, emphasizing systemic thinking, interdisciplinarity, and collaboration (Guerra & Holgaard, 2019; Guerra & Smink, 2019; Sterling, 1996, 2001).

This holistic perspective was also evident after PBL, where responses to the questionnaire no longer focused solely on the environmental dimension. This shift is significant, as sustainability is based on the interdependent environmental, social, and economic dimensions (Elkington, 1997). This

awareness is essential to ensure that sustainability actions are balanced, inclusive, and sustainable in the long term.

In the pre-workshop questionnaire responses, students used informal language. However, starting from the PBL phase, their vocabulary became more aligned with the workshop theme, incorporating terms like sustainability and recycling. Independent research, group discussions, and peer feedback characteristic of PBL facilitated the acquisition and integration of new vocabulary. This enriched their ability to communicate precisely, clearly, and effectively, enhancing critical reading and argumentation skills.

Following the PBL phase, we observed a critical reflection on sustainability, as evidenced by students' responses to the questionnaire— particularly in the sections where they were required to justify their answers. The economic dimension, previously seen only in terms of business profits, now extended to its impact on society, generating income for the population. Similarly, students realized they don't need to rely solely on governments and businesses. Through developing their prototypes, they understood their capacity to identify problems and find solutions themselves, in collaboration with their community. However, they also recognized that while individual actions are important and can contribute to positive changes, addressing the scale and complexity of problems requires coordinated and collaborative efforts involving governments and businesses.

The analysis of the produced videos and the discussions sparked by their presentation in the classroom indicated that students were sensitized to sustainability issues. The video narratives often depicted everyday problems within the students' community, showcasing solutions that frequently involved community members and authorities, thereby serving as compelling examples of sustainability in action.

Considering the above, PBL fulfilled its role in generating knowledge and fostering citizenship among students (Christiansen, 2013; Tuke, Kapur & Ashour, 2021). However, there was no observable increase in sustainability-related knowledge during the Storytelling phase. This may be attributed to the short duration of the PBL phase (Savery, 2006), meaning that the information acquired was likely still fresh in the students' minds, leaving little opportunity for them to form new connections.

Other hypotheses can also be considered, for example, that the Storytelling phase may have been perceived more as a recreational activity than a reflective one, resulting in excessive focus on technical aspects such as scriptwriting, character development, and narrative structure, while placing less emphasis on the sustainability content itself.

To address this, we suggest that future implementations include a "cooling phase" between the PBL and Storytelling stages, involving short activities aimed at synthesizing the knowledge gained. Additionally, at the beginning of the Storytelling phase, reflective prompts should be introduced, which students are required to incorporate into their narratives.

Nevertheless, Storytelling positively contributed to skills development. Initially, students struggled with summarizing ideas and presenting central points during the Storytelling phase. However, their participation increased significantly. Research by Haven (2007) has shown that using Storytelling in

the classroom enhances student engagement and motivation. Students reported finding classes more interesting and felt more motivated to actively participate.

Moreover, during Storytelling, students demonstrated creativity not only in producing videos but also in overcoming challenges such as accessing image editing software, narration, subtitles, etc. According to Amabile (1996), creativity involves generating new and useful ideas. Storytelling, by presenting challenges and dilemmas within a narrative framework, encourages students to explore multiple perspectives and solutions, thus enhancing their creative skills. Creating a safe and motivating environment encourages students to experiment, further boosting creativity (Robinson, 2011; Runco, 2007; Yang & Wu, 2012).

The guidelines for sustainability education emphasize principles such as transdisciplinarity (Lang et al., 2012; Barth et al., 2023), active learning (Sterling, 2004), community engagement (Tilbury, 2011), development of sustainability competencies (Wiek et al., 2011), innovation, and creativity (Barth et al., 2007). Therefore, the workshop's approach to promoting sustainability education through PBL followed by Storytelling proved effective.

While there are no specific studies investigating whether using two or more active methodologies simultaneously offers substantive advantages, potential benefits can be inferred. Firstly, combining different approaches can cater to diverse learning styles, providing a more inclusive and personalized learning experience. For instance, combining PBL with flipped classroom techniques allows students to independently explore complex problems before engaging in group discussions, facilitating a deeper and more collaborative understanding of the topics (Biggs, 2020).

Furthermore, the hybrid approach can foster the development of multiple skills in students. While PBL strengthens teamwork and problem-solving skills, storytelling enhances creativity and engagement. Combining these methodologies not only diversifies the learning experience but also prepares students to tackle complex real-world challenges, where interdisciplinary problem-solving skills are often required (Jenkins et al., 2019).

The variety of methodologies also allows educators to adjust teaching strategies to the specific needs of each content area or group of students, enhancing the overall flexibility and effectiveness of the educational process.

In our case, integrating different pedagogical approaches provided a richer and more diverse education, addressing gaps such as creativity development and increased engagement facilitated by Storytelling. With a growing focus on personalized education and the development of skills beyond theoretical knowledge, this approach promises to remain a significant area of educational research and implementation.

Conclusions, Limitations and Recommendations

This study presented results from a workshop using PBL as a methodology, followed by Storytelling, to teach sustainability to high school students at a Brazilian school. Based on peripheral observations,

questionnaire analyses, and position review forms, our findings indicate that the workshop successfully instructed students on sustainability when they actively sought knowledge on the subject. There was also an enhancement in sustainability competencies such as systemic thinking, cooperation, creativity, and adaptability, among others.

Although Storytelling did not significantly increase knowledge about sustainability compared to the PBL phase, it effectively filled gaps left by this workshop phase. Increased engagement and stimulation of creativity were notable outcomes.

We acknowledge limitations in this study. Firstly, the short development time of the workshop, especially in the PBL phase, hindered the analysis of our hypothesis regarding Storytelling as a tool to revisit and consolidate concepts. Conducting the study with only one high school class resulted in a small number of participants and limited diversity in terms of cultural aspects. However, we are confident that this limitation did not compromise our results, as multiple data sources were used for triangulation, enhancing reliability and providing rich and detailed data.

Based on the discussion above, practical recommendations can be proposed. These include replicating the study across multiple classes and educational levels to determine if there are differences among them. Additionally, extending the workshop duration would enrich the student's experience and provide a more precise analysis of our initial hypothesis regarding the role of Storytelling. Conducting focus groups with students after the experience is also a strategy to deepen the analysis of results. For educators interested in applying the PBL/Storytelling combination, it is recommended to clearly define the learning objectives for each phase, incorporate a brief "cooling phase" between PBL and Storytelling to promote knowledge consolidation, and introduce reflective prompts to guide the narrative construction. Furthermore, the opportunities for peer feedback and adequate time allocation for each stage can help ensure that both content mastery and creative engagement are effectively achieved.

References

Adams, A. & Cox, A. L. (2008). Questionnaires, in-depth interviews and focus groups. In: Cairns, Paul and Cox, Anna L. eds. *Research Methods for Human Computer Interaction* (pp. 17-34), Cambridge, UK: Cambridge University Press.

Amabile, T. M. (1996). *Creativity in Context*. Westview Press.

Bandura, A. (1977). *Social Learning Theory*. Englewood Cliffs, NJ: Prentice Hall.

Barrows, H. S. (1986). A Taxonomy of Problem-Based Learning Methods. *Medical Education*, *20*(6), 481-486.

Barth, M., Godemann, J., Rieckmann, M., & Stoltenberg, U. (2007). "Developing key competencies for sustainable development in higher education." *International Journal of Sustainability in Higher Education*, *8*(4), 416-430.

Barth, M., Jiménez-Aceituno, A., Lam, D.P.M., Bürgener, L & Lang, D.J. (2023). Transdisciplinary learning as a key leverage for sustainability transformations. *Current Opinion in Environmental Sustainability*, 64:101361.

Beagon, U.; Kövesi, K.; Tabas, B.; Nørgaard, B.; Lehtinen, R.; Bowe, B.; Gillet, C.; Spliid, C.M. (2023). Preparing engineering students for the challenges of the SDGs: what competencies are required? *European Journal of Engineering Education*, 48(1), 1-23.

Biggs, J. B., & Tang, C. (2020). *Teaching for Quality Learning at University*. McGraw-Hill Education.

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308-320.

Bruner, J. (1991). *Acts of Meaning*. Cambridge, MA: Harvard University Press.

Christiansen, E. T., Kuure, L., Mørch, A., & Lindström, B. (Eds.) (2013). *Problem-based Learning for the 21st Century: New Practices and Learning Environments.* (1 ed.). Aalborg Universitetsforlag.

Cörvers, R.; Wiek, A., de Kraker, J., Lang, D.J. & Martens, P. (2016). Problem-based and project-based learning for Sustainable development. In: Heinrichs, H., Martens, P., Michelsen, G., Wiek, A. (eds) *Sustainability Science*. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-7242-6_29.

Devincenzi, S.S., Kwecko, V.R., Bicho, A.L., Tolêdo, F.P. & Botelho, S.S.C. (2022). SRUM applied to Problem-based learning; a hybrid model for managing the teaching-learning process. *Proceedings of the 2022 IEEE Frontiers in Education Conference (FIE)* (pp. 1-7).

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of Problem-Based Learning: A Meta-Analysis. *Learning and Instruction*, *13*(5), 533-568.

Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment*, *11*(2), 130-141.

Egan, K. (1986). *Teaching as Story Telling: An Alternative Approach to Teaching and Curriculum in the Elementary School*. Chicago: University of Chicago Press.

Elkington, J. (1997). *Cannibals with forks: The triple bottom line of 21st-century business*. Capstone.

Fernandes, S., Dinis-Carvalho, J. & Ferreira-Oliveira, A.T. (2021). Improving the performance of student teams in Project-based learning with Scrum. *Education Sciences*, *11*(8), 444.

Fisher, W. R. (1987). *Human Communication as Narration: Toward a Philosophy of Reason, Value, and Action*. Columbia: University of South Carolina Press.

Gough, S. (2008). Context, Complexity, and Curriculum: A Pragmatic View of Transdisciplinary Learning for Sustainability. *Environmental Education Research*, *14*(1), 17-29.

Graaf, E. & Kolmos, A. (2007). History of problem-based and project-based learning. In Graaf, E. & Kolmos, A. (Eds.), *Management of Change* (pp. 1-8). Rotterdam: Sense Publ.

Guerra, A. (2017). Integration of sustainability in engineering education Why is PBL an answer? *International Journal of Sustainability in Higher Education*, v. 18, n. 3, pp. 436 – 454.

Guerra, A. & Holgaard, J. E. (2019). Contextual Learning for Sustainability. In *Encyclopedia of Sustainability in Higher Education* (pp. 1–11). Springer International Publishing.

Guerra, A., Jiang, D & Du, X. (2022). Study agency for Sustainability in a systemic PBL environment. *Sustainability*, *14*(13728).

Guerra, A., & Smink, C. K. (2019). Students' Perspectives on Sustainability. In *Encyclopedia of Sustainability in Higher Education* (pp. 1–9). Springer International Publishing.

Hall, S. (1997). *Representation: Cultural Representations and Signifying Practices*. London: Sage.

Haven, K. F. (2007). *Story Proof: The Science Behind the Startling Power of Story*. Libraries Unlimited.

Hmelo-Silver, C. E. (2004). Problem-Based Learning: What and How Do Students Learn? *Educational Psychology Review*, *16*(3), 235-266.

Huckle, J. & Sterling, S. (2014). *Education for Sustainability*. Routledge ed.

Jenkins, A., Breen, R., & Lindsay, R. (2019). *Reshaping Learning: Frontiers of learning technology in a global context*. Springer.

Jonassen, D. H. (2011). *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments.* Routledge.

Kanyesigye, S.T., Uwamahoro, J. & Kemeza. I. (2023). The impact of problem-based learning on students' achievement in mechanical waves in secondary scholls. *Research in Science Education, 53*, 1013-1033.

Krogh Hansen, K., Dahms, Mona-Lisa, Otrel-Cass, K. & Guerra, A. (2014) *Problem-based learning and Sustainability: practice and potential*. Faculty of Engineering and Science, Aalborg University.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., ... & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, *7*(1), 25-43.

Martín-Garcia, J., Álvarez, M.E.D. & Afonso, A.S. (2024). Understanding Science teachers' integration of active methodologies in club settings: an exploratory study. *Education Sciences, 14*, 106.

Mondragon, N.I., Beloki, N., Yarritu, I., Zarrazquin, I. & Artano, K. (2023). Active methodologies in higher education: reasons to use them (or

not) from the voices of faculty teaching staff. *Higher education*, https://doi.org/10.1007/s10734-023-01149-y

Morgan, S. J., & Dennehy, R. F. (1997). The Power of Organizational Storytelling: A Management Development Perspective. *Journal of Management Development*, *16*(7), 494-501.

Ribeiro, L. R. C., & Mizukami, M. da G. N. (2005). Problem-Based Learning: A Student Evaluation of an Implementation in Postgraduate Engineering Education. *European Journal of Engineering Education*, *30*(1), 137-149.

Robinson, K. (2011). *Out of Our Minds: Learning to be Creative*. Capstone Publishing.

Runco, M. A. (2007). *Creativity: Theories and Themes: Research, Development, and Practice*. Academic Press.

Sachs, J. D. (2015). *The age of sustainable development*. Columbia University Press.

Savery, J.R. (2006). Overview of Problem-based Learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-based Learning*, *1*(1), 9-20.

Sawyer, R. K. (2011). *Explaining Creativity: The Science of Human Innovation*. Oxford: Oxford University Press.

Spradley, J. P. (1980). *Participant Observation*. Orlando, Florida: Harcourt College Publishers.

Schwaber, K. & Sutherland, J. (2020) The SCRUM guide: The definitive guide to SRUM: the rules of the game. In https://scrumguides.org/docs/scrumguide/v2020/2020-Scrum-Guide-US.pdf#zoom=100, accessed in em 06/17/2023

Shin, S. & Miller, S. (2022). A review of the participant observation method in journalism: designing and reporting. *Review of Communication Research*, *10*, 114-145.

Sterling, S. (1996). Education in Change. In John Huckle & Stephen Sterling (Eds.), In *Education for Sustainability* (pp. 18–39), Earthscan.

Sterling, S. (2001). *Sustainable Education: re-visioning learning and change*. Green Books-The Schumacher Society.

Sterling, S. (2004). Higher Education, Sustainability, and the Role of Systemic Learning. *Higher Education and the Challenge of Sustainability*, 49–70.

Strobel, J.; van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-based Learning*, *31*(1), 44-58.

Tilbury, D. (2011). *Education for sustainable development: An expert review of processes and learning*. UNESCO.

Tuke, G., Kapur, S., & Ashour, K. (2021). Global citizenship cultivation through the COIL-PBL model: a case study of the Great Debates course. *Journal of Virtual Exchange*, *4*, 80-91

UN (2015). *Transforming our world: The 2030 agenda for sustainable development*, A/RES/70/1.

UNESCO. (2012). *Education for Sustainable Development: Sourcebook*. United Nations Educational, Scientific and Cultural Organization.

UNESCO. (2017). *Education for Sustainable Development Goals: Learning Objectives*. United Nations Educational, Scientific and Cultural Organization.

Yachin, T., Barak, M. (2024). Science-based educational escape games: a game design methodology. *Research in Science Education, 54*, 299 -313.

Yang, Y. T. C., & Wu, W. C. I. (2012). Digital Storytelling for Enhancing Student Academic Achievement, Critical Thinking, and Learning Motivation: A Year-Long Experimental Study. *Computers & Education*, *59*, 339-352.

Wadji, M., Jamaluddin, A.B., Nurdiyanti, N & Magfirah, N. (2022). The effectiveness of problem-based learning with environmental-based comics in enhancing student's environmental literacy. *International Journal of Evaluation and Research in Education*, *11*(3), 1049-1057.

Wiek, A., Bernstein, M.J., Foley, R.W., Cohen, M., Forrest, N., Kuzdas, C., Kay, B. & Withycombe Keeler, L. (2015) Operationalising Competencies in Higher Education for Sustainable Development, In Barth M, Michelsen G, Rieckmann M, Thomas I (Eds.) *Routledge Handbook of Higher Education for Sustainable Development*, (pp. 241-260), Routledge: London and New York.

Wiek, A., Withycombe, L., & Redman, C. L. (2011). "Key competencies in sustainability: A reference framework for academic program development." *Sustainability Science*, *6*(2), 203-218.

World Commission on Environment and Development (1987). *Our Common Future*. Oxford University Press.