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Digital culture in environmental education: exploring the *STEAM methodology* according to Gagné and Papert[1]

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ABSTRACT

With the support of Gagné and Papert's learning theories, together with active methodologies and the STEAM approach, this research sought to raise awareness among young students about the importance of reusing and correctly disposing of common and electronic waste. Following Gagné's learning hierarchy and Papert's constructionist theory, the students built an electrical maze, using electronic components and repurposed materials. The activity was developed with 11 students from the 6th to the 9th year of Elementary School in two meetings, after school, lasting 4 hours. Participants responded to two questionnaires, before and after the activity, which made it possible to verify the learning gain in the process. Thus, through practical exploration and knowledge construction in a real and meaningful context, we develop problem-solving skills and creativity in students. The results showed that this combination of pedagogical approaches was effective in raising students' awareness of the importance of sustainability. Furthermore, the STEAM curriculum sparked students' interest in creating new technologies, paving the way for innovative

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solutions that contribute to reducing the impacts of electronic and common waste on the environment.

KEYWORDS: *STEAM* curriculum. Sustainability. Electronic waste. Electronics. Technology.

Cultura digital na Educação Ambiental: explorando a metodologia STEAM segundo Gagné e Papert

RESUMO

Com o apoio das teorias de aprendizagem de Gagné e Papert, juntamente com metodologias ativas e a abordagem STEAM, esta pesquisa buscou conscientizar jovens estudantes sobre a importância do reaproveitamento e descarte correto de resíduos comuns e eletrônicos. Seguindo a hierarquia de aprendizagem de Gagné e a teoria construcionista de Papert, os estudantes construíram um labirinto elétrico, usando componentes eletrônicos e materiais reaproveitados. A atividade foi desenvolvida com 11 estudantes do 6º ao 9º ano do Ensino Fundamental em dois encontros, no contraturno escolar, com 4 horas de duração. Os participantes responderam a dois questionários, antes e após a atividade, o que permitiu verificar o ganho de aprendizagem no processo. Assim, por meio da exploração prática e da construção de conhecimento em um contexto real e significativo, desenvolvemos habilidades de resolução de problemas e criatividade nos alunos. Os resultados mostraram que essa combinação de abordagens pedagógicas foi eficaz para conscientizar os alunos sobre a importância da sustentabilidade. Além disso, o currículo STEAM despertou o interesse dos estudantes pela criação de novas tecnologias, abrindo caminho para soluções inovadoras que contribuem para a redução dos impactos do lixo eletrônico e comum no meio ambiente.

PALAVRAS-CHAVE: *STEAM* currículo. Sustentabilidade. Lixo eletrônico. Eletrônica. Tecnologia.

Cultura digital en Educación Ambiental: explorando la metodología STEAM según Gagné y Papert

RESUMEN

Con el apoyo de las teorías de aprendizaje de Gagné y Papert, junto con metodologías activas y el enfoque STEAM, esta investigación buscó concientizar a los jóvenes estudiantes sobre la importancia de reutilizar y disponer correctamente de los residuos comunes y electrónicos. Siguiendo la jerarquía de aprendizaje de Gagné y la teoría construccionista de Papert, los estudiantes construyeron un laberinto eléctrico utilizando componentes electrónicos y materiales reutilizados. La actividad se desarrolló con 11 alumnos de 6° a 9° año de Educación Primaria en dos encuentros, extraescolares, con una duración de 4 horas. Los participantes respondieron a dos cuestionarios, antes y después de la actividad, que permitieron verificar el avance del aprendizaje en el proceso. Así, a través de la exploración práctica y la construcción de conocimientos en un contexto real y significativo, desarrollamos en los estudiantes habilidades de resolución de problemas y creatividad. Los resultados mostraron que esta combinación de enfoques pedagógicos fue eficaz para concienciar a los estudiantes sobre la importancia de la sostenibilidad. Además, el plan de estudios STEAM despertó el interés de los estudiantes en la creación de nuevas tecnologías, allanando el camino para soluciones innovadoras que contribuyan a reducir los impactos de los desechos electrónicos y comunes en el medio ambiente.

PALABRAS CLAVE: Currículo STEAM. Sostenibilidad. Correo basura. Electrónica. Tecnología.

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Introduction

Ranks first in quantity, harmfulness, and decomposition time among all man-made materials that end up in marine ecosystems, representing 85% of the total waste present in the oceans (Geographic, 2023). Although often used as synonyms in some informal situations, there is a technical distinction between garbage and residue, especially in the environmental field. Trash generally refers to discarded materials without immediate use or economic value, while waste is a broader term that includes materials that can be reused, recycled, or recovered in some way. Therefore, waste often has the potential to be transformed into useful resources, while garbage is seen as disposable without any direct future use (Vieira, 2011).

It is estimated that, annually, around 11 million tons of plastic are dumped into the sea. According to research published in 2018 by South Korea, in partnership with Greenpeace, it is possible to conclude that the impacts of marine pollution are not restricted to animals in this environment, but also extend to humans since the presence of microplastics was found in 36 of the 39 brands of table salt analyzed in various regions of the world (Kim, 2018).

The irregular disposal of waste also triggers another problem that deserves special attention, namely, electronic waste *(e-waste)*, that is, all discarded electronic equipment, including computers, cell phones, tablets, televisions, printers, and household appliances in general, among others. The problem with disposing of these materials in an inappropriate place is that they contain chemical elements that are harmful to humans, such as lead, mercury, and cadmium. When these substances are dumped in inappropriate places and incinerated, they pollute the air; when deposited in landfills, they contaminate the soil and groundwater. As a consequence of this disposal process, it is currently possible to find evidence of the presence of these metals in agricultural or manufactured products available for export (Robinson, 2009), reaching an incalculable number of people.

According to the report *The Global E-waste Monitor* (Forti, 2020), in 2019, 53.6 million tons of electronic waste were generated worldwide, representing an increase of 21% compared to 2014. Of this amount, only 17.4% was properly collected and recycled. According to the report, Brazil produced more than 2.1 million tons of electronic waste, ranking 5th most polluting country in the *world*. As most electronic waste ends up being disposed of inappropriately, there are several negative impacts on the environment and human health resulting from this activity.

Faced with complex and urgent environmental challenges, environmental education has become a relevant issue in our society. The need to form conscious citizens, capable of understanding and acting sustainably, has driven the search for innovative approaches in teaching this topic. In this context, the *STEAM* methodology, which integrates science, technology, engineering, arts, and mathematics, emerges as a transformative approach, as it emphasizes interdisciplinarity, problem-solving, and practical learning (Mauri, 2009). By bringing these different disciplines into the context of environmental education, the *STEAM methodology* seeks to promote a comprehensive approach, connecting theoretical and practical knowledge, and stimulating creativity and innovation.

In national and international literature, it is possible to find studies that seek to work on the interdisciplinarity proposed in the *STEAM methodology,* associated with students' environmental awareness. Robert *et al.* (2018), for example, show that the relationship between mathematics teaching and vegetable production can lead students to associate mathematical problems with everyday situations, improving their environmental awareness. Bergamaschi *et al*. (2022) show how the use of the *STEAM methodology*, together with *design thinking*, favors an interdisciplinary approach to socio-environmental themes, as well as reinforcing the potential of using digital technologies in the classroom. Despite the examples cited, research that focuses on raising environmental awareness through the construction of new technologies, and reusing common or electronic waste, is rare.

Aiming to contribute to the environmental education of young students, we developed a workshop to demonstrate the counterproductive impacts arising from the irregular disposal of waste (electronic and common), in addition to showing how we can, through the reuse of some of these materials, develop new technologies. To this end, the concepts of robotics and, in an introductory manner, the basic concepts of electronics were presented to the apprentices. At the end of the workshop, the students built an electrical labyrinth, as their first project, based on the reuse of waste/ *e-waste*, in which all the concepts covered during the workshop were put into practice.

Our objective with this experience was to discuss and promote sustainable practices in the classroom, from the perspective of environmental education, in the context of the use of active methodologies, through the *STEAM approach*, as well as to raise awareness among young students about the importance of reusing or correctly disposing of trash. The work also presented the contributions of the *STEAM* curriculum to the learning of basic electronics concepts and procedures, with a view to awakening, in this audience, interest in the creation of new technologies, that can minimize some environmental problems caused by electronic waste.

The proposal presented here meets the guidance given by the National Common Curricular Base (Brasil, 2018), bringing in competency number five guidance so that, in addition to understanding and using it, students are encouraged to create digital information and communication technologies in an ethical, meaningful, critical and reflective way, enabling the resolution of problems in today's society.

The principles of learning according to Gagné and Papert

Robert Mills Gagné and Seymour Papert are two educational theorists who address different but complementary perspectives on how people learn. Although their theories can be considered distinct, there are points of connection between them.

Seymour Papert is considered the creator of constructionist theory: an educational approach based on the idea of actively constructing knowledge, through interaction with the world and the construction of tangible objects. This theory argues that individuals learn best when they are involved in practical, challenging, and meaningful activities, in addition to that such knowledge is obtained through concrete action and the construction of tangible products. By creating and manipulating physical objects, students have the opportunity to explore complex concepts in a concrete and personalized way (Papert, 1980).

The practical application of Papert's constructionist theory was evidenced in the research conducted by Souza (2020), where it was possible to verify the success in the process of teaching concepts of electricity and hydrostatics. The researcher adopted the educational robotics approach, allowing students to build various prototypes as an integral part of the scientific learning process. At the end of this experience, the benefits in the development of learning became evident, highlighted by the connection between the practice of building prototypes and the assimilation of the concepts of electricity and hydrostatics.

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Robert Mills Gagné was a renowned American psychologist and educator, very influential in the 60s and 70s, standing out through his hierarchical learning theory that identifies a series of learning conditions or events necessary for the acquisition of new knowledge.

This author understood learning as a procedure for transforming behavior that occurs through a sequence of hierarchical phases or stages. He categorizes it as an "essential incident of learning" the moment in which information is incorporated into short-term memory to later be stored in long-term memory (GAGNÉ, 1980). This moment is preceded by some events and followed by others. The first episodes are linked to external stimulation, impacting the learner, while the last ones refer to internal activities, taking place in the student's central nervous system. This sequence of events constitutes the "Act of Learning" concept (cf. Gagné, 1980), composed of eight terms: motivation, apprehension, acquisition, retention, recall, generalization, performance, and *feedback*.

Gagné also supported the idea that more complex cognitive skills were anchored in others of less complexity. From this perspective, the development of a high-level solution would only be achieved through mastering less complex skills. Thus, it would be up to the educator to propose activities that help students develop less complex skills, which would serve as a basis for students' progression towards more complex skills. This perception about the existence of a kind of scale of skills resulted in the method known as “Learning Hierarchy” (Borges, 2020, p. 11).

The research carried out by Siqueira (2020) showed that the adoption of the learning principles proposed by the North American psychologist enabled the development of computational thinking skills and the teaching of basic computer programming concepts to students in Youth and Adult Education. This study highlighted that by respecting the learning hierarchy proposed by Gagné and the learning phases, with special attention to student motivation, it is possible to achieve surprising results in the learning process, including in challenging environments, such as in prison institutions, where the practice of the study faces great adversities.

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Despite different approaches, theorists emphasize the importance of providing children with a learning environment with appropriate teaching tools and strategies. Both recognize the importance of active student participation and the need to adapt teaching to each student's individual needs. Although Gagné focuses on sequential teaching strategies and Papert advocates constructivist and practical learning, their theories complement each other in highlighting the relevance of providing a stimulating and adapted learning environment to promote learning.

STEAM as *a* curriculum integration approach

Recent social, economic, and environmental transformations have shown that changes in society imply changes in the educational sphere, demanding responses to the urgencies of this new era. The emergence of new technologies, professions, and work relationships has boosted the search for creative professionals, not only in the field of cognition but also in skills and abilities in the productive and socio-emotional dimensions (Bacich; Holanda, 2020b).

Active learning methodologies emerge in this context of educational emergencies, not only in Brazil but throughout the world. The appreciation of experience and doing has always been present in debates in the educational field. Dewey (1950), for example, was critical of traditional educational thought. For Dewey, we can explain and transform this world through experience. His ideas take us to a philosophy of experimental and active education. In the last twenty years, it is possible to see how these ideas are gaining strength through the digital technological revolution.

There is sufficient evidence within the scope of research in psychology and education (Dewey, 1950; Piaget, 1978; Moran, 2018; Bacich; Holanda, 2020a) that the learning process is a phenomenon of an active nature. For meaningful learning to happen, the student needs to be involved and engaged in a process of research, investigation, and resolution, just like a problem or a project. According to Moran (2018, p. 41), "active methodologies are teaching strategies focused on the effective participation of students in the construction of the learning process, in a flexible, interconnected and hybrid way".

In this context, we highlight *STEAM* as a possibility for an active methodology. The acronym *STEAM* is the English acronym for Science, Technology, Engineering, Arts and Mathematics. From the perspective adopted by this study, the concept of *STEAM* is associated with a proposal for curricular integration, whose active learning methodology that drives the work is Project-Based Learning (PBL), in which, through careful planning, students Students will have the opportunity to establish links between knowledge from different disciplines, to seek solutions to challenges of an intricate nature (Holanda; Bacich, 2020).

Project-Based Learning (PBL) has a transdisciplinary perspective, involving two or more curricular components, and is designed based on a problem situation or research question related to the students' context. The methodological path followed by students follows the same steps as the scientific experimentation method: observation, formulation of hypotheses, experimentation, and validation of results. Another important characteristic of ABP is the product resulting from the project development process. In this scope, *STEAM* contributes in different ways, namely, to the integration of the different curricular contents that are articulated in the project, as well as to the process of solving problems creatively, characteristic of engineering and design (Bacich; Holanda, 2020b).

Environmental education

Environmental Education is a multidisciplinary area that involves different worldviews and approaches to promote reflections and actions in favor of sustainability and care for the environment. The concept of sustainable development, which originated in 1987 in the UN Brundtland Report, implies meeting present needs without compromising future generations. This model requires consideration of environmental, economic, and sociopolitical aspects, recognizing that all natural resources, such as water, air, soil, forests, and oceans, require care to persist. Thus, economic and sociopolitical sustainability is only viable if environmental sustainability is maintained (Torres, 2010).

At different times, Environmental Education was discussed in conservationist, ecological, and critical conceptions, among other nomenclatures and understandings that result in different pedagogical approaches. Layrargues (2004) states the need to understand the political-pedagogical foundations of each of these conceptions. This study is supported by a concept of Environmental Education that emphasizes the preservation of natural resources and biodiversity. From this perspective, the study intended to discuss with students the adoption of practices and behaviors that minimize the impacts of modern life on the environment.

Environmental Education appears, in national legislation, as an important transversal theme to be worked on in different modalities and levels of education (Brasil, 1996). Countless environmental issues can address school content in an integrated way, through projects, from a *STEAM perspective*. Among them, the impact of irregular disposal of common waste and electronic waste stands out. Therefore, promoting Environmental Education, from this perspective, goes beyond exposing a diagnosis of the environmental problems of the modern world, it is about enabling students to actively build sustainable knowledge, values, skills, and attitudes.

Discussions about the importance of the educational process for overcoming the environmental issues of our time were not restricted to the legal scope. Countless academic contributions in the area of education and teaching address Environmental Education with the development of projects from an interdisciplinary or transdisciplinary perspective (Bergamaschi et al., 2022; Campos; Gonçalves, 2020; Muline; Campos, 2016).

We highlight the work of Bergamaschi *et al.* (2022) which brings initial results from a study on the use of the *STEAM methodology* in the classroom in the dimension of Environmental Education in the curriculum. The authors reinforce the importance of the interdisciplinary nature of Environmental Education and pedagogical practices focused on research and experimentation. His study covered environmental, social, and economic content with the use of digital technologies, expanding discussions on the principles of Environmental Education.

In research developed by Campos and Gonçalves (2020), the authors point out possibilities for the development of a Critical Environmental Education, understanding human beings and social relations as an integral part of nature, as recommended by the Law of Guidelines and Bases of National Education [LDB 9394/96] and by PNEA. In this conception, environmental education has a broader focus, addressing social, political, and economic issues related to the environment. It seeks to analyze the structural causes of environmental degradation and promote a paradigm shift in sustainable development (Carvalho, 2004; Guimarães, 2016).

The concern with developing interdisciplinary pedagogical proposals that broaden students' vision, making them distinguish environmental issues as everyone's problem, is also addressed by Muline and Campos (2016). For the authors, among the various principles of Environmental Education, the use of interdisciplinary pedagogical approaches stands out, exploring the specific contents of each discipline to build a global vision, thus giving meaning to educational practice for the student (Muline; Campos, 2016).

The principle of interdisciplinarity in Environmental Education is strongly associated with the development of projects from the *STEAM perspective*, proposed by this study, based on the theme of reusing common and electronic waste. This study aims to promote sustainable experiments in the classroom, within the scope of environmental education, using active methodologies, based on the *STEAM approach*. Furthermore, we seek to raise awareness among young students about the importance of appropriate reuse or correct disposal of waste. Additionally, the research aims to analyze the contributions of *STEAM* to the learning of basic electronics concepts and procedures, as well as to awaken the interest of the public in the creation of technologies that can, eventually, help in solving the environmental problems caused by electronic waste.

Digital Culture

Araújo and Gouveia (2020) seek the ethnographic meaning of the word culture, expressed in "the whole complex that includes knowledge, beliefs, art, morals, laws, customs or any other capacity or habits acquired by man as a member of a society" (Araújo; Gouveia, 2020, p. 364). Digital Culture, in turn, manifests the complexity of these dimensions of social practices that take place in digital environments, online or offline, but also intertwines and reverberates actions outside the networks. Corroborating this concept, Lucena and Oliveira (2014) state that digital cultures are "forms of use and appropriation of virtual spaces made by cultural subjects" (Lucena; Oliveira, 2014, p. 38). The concept of cyberculture is associated with the idea of digital culture. For Lévy (1999), cyberculture "is the set of techniques (material and intellectual), practices, attitudes, ways of thinking and values that develop together with the growth of cyberspace" (Lévy, 1999, p. 17). Reflections like this reveal the importance of pedagogical practices beyond the use of technologies as tools to smooth complex curricular content or entertain students. They imply thinking about the critical and reflective use of digital technologies that are part of human culture, and specifically of this generation, called digital natives.

The National Common Curricular Base (BNCC) addresses digital culture and digital technologies as transversal themes, due to the way they are articulated with social practices and how they can be associated with the different contents of the school curriculum throughout Basic Education. The document establishes one of the general competencies for this academic stage:

> Understand, use, and create digital information and communication technologies in a critical, meaningful, reflective, and ethical way in different social practices (including school ones) to communicate, access, and disseminate information, produce knowledge, solve problems, and exercise protagonism and authorship in life personal and collective (Brasil, 2018, p. 9).

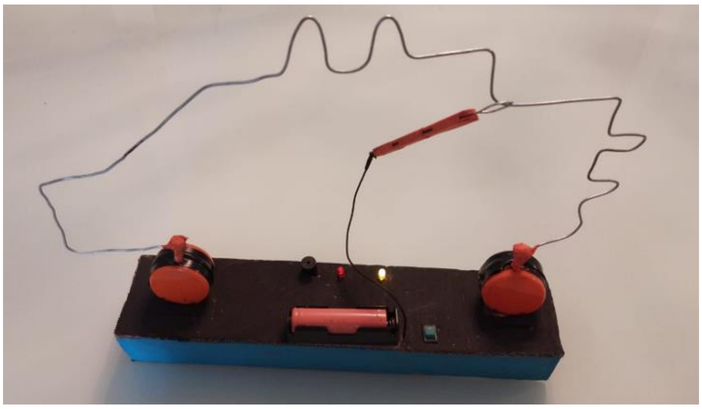
In the fifth general competence, three dimensions of the insertion of digital technologies in the lives of young people in different contexts, school, and non-school, stand out: (i) dimension of understanding digital technologies - students must understand the concepts, functioning, and possibilities offered by different technologies, such as computers, smartphones, internet, applications, and social networks; (ii) dimension of use - students must be able to use these technologies reflectively and critically, considering their social, ethical and cultural impacts, carrying out research, curating and organizing the information they find on the network; and (iii) dimension of the creation of digital technologies - students need to be prepared to advance about the use of digital technologies, achieving the possibility of understanding the construction logic for creating solutions to personal and collective problems, becoming authors of content, sharing your ideas and knowledge.

Furthermore, literacy and digital citizenship enable the discussion of topics about technology and society and point out possibilities for solutions to sensitive topics such as the reuse of common waste and electronic waste.

Pedagogical Methodology

The pedagogical strategy of this workshop was supported by the learning concepts of the North American psychologist Robert M. Gagné (Gagné, 1980). Therefore, the first step adopted was to define the highest level of cognition expected to develop in students. For this practice, this level of learning includes the construction of an electrical maze, using the reuse of paper, PET bottle caps, popsicle sticks, wire, and threads, as seen in the example in Figure 1.

FIGURE 1: Example of an electrical labyrinth



Source: Prepared by the authors (2023)

The Electric Maze is a physical electronic game to challenges the player to transport the metal ring from one end of the metal path to the other. The one who manages to go through the entire maze without letting the hoop touch the wire path wins the competition. It is a dynamic that uses electricity to create a navigation challenge. When the ring touches this structure, the electrical circuit closes, triggering a sound or visual response, such as a horn or a light, among other types of signals. Based on this definition, a strategy was designed to allow students to reach this desired level of knowledge.

Research Methodological Path

This research is qualitative, as it sought to understand a particular learning situation, experienced by the researchers and subjects involved, described in detail, and analyzed in an interpretative way (Gil, 2021). According to Gil (2021), qualitative research "seeks to discover concepts and relationships between data and organize them into an explanatory scheme" (Gil, 2021, p. 15).

The research involved the participation of two different audiences, aiming to validate the proposal in different contexts. The first group, formed by eight doctoral students from a class at the Federal Institute of Espírito Santo (IFES), had the function of validating and refining the proposal. The second group, made up of eleven students from the 6th to the 9th year of elementary school in the municipal network of Vitória-ES, made it possible to evaluate the learning produced through the proposal in basic education. This study presents the results obtained in the application of the pedagogical proposal with the second group.

The eleven students are part of the project "The Innovation School of Vitória, ES: Robotics, Digital Manufacturing, and Active Methodologies (re)Inventing Education". They are students of both sexes, aged between 10 and 14 who attend different school levels, including one student in the sixth, five in the seventh, one student in the eighth, and four in the ninth year of elementary school. The workshop was implemented in two moments, the first on 06/13/2023 and the second on 06/27/2023. Both occurred at the Innovation School, located in the city of Vitória-ES, between 1:30 pm and 5:30 pm.

Data were collected using a multimodal approach. Initially, the direct observation technique was used, recording events and behaviors during the experiment in detail. Furthermore, to obtain information about prior knowledge and knowledge acquired during the process, participants answered two questionnaires in the format of closed questions, before and after the class. The survey contained eight questions on the following topics: irregular disposal of electronic waste, ocean pollution, and basic notions of electronics. Through the answers to the questionnaire, it was possible to verify the prior knowledge of those involved in the workshop and whether there were learning developments after the practice of producing the electronic maze. This record contributed to the observation of the participant's performance during the resolution of the proposed challenges. This approach of collecting data at two different times provided a comprehensive and detailed view, allowing a more complete analysis of the results obtained in the activity.

In this way, we now detail the progress of the workshop: the first day began with the presentation of the researchers and the subject to be worked on with the students. Then, a questionnaire began to be distributed to check the students' prior knowledge of the topic covered. After the eight students present filled out the questionnaire, the theoretical presentation took place, contextualizing the problems arising from the irregular disposal of garbage and *e-waste*. After presenting the proper way to dispose of common rubbish and electronic waste, the

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students had the opportunity to see the *Interceptor*, a robot boat used to collect rubbish in some rivers around the world. The objective of this presentation was to expand knowledge about how robotics can contribute to the process of cleaning up the marine environment.

Next, it explained what is considered a robot, how it is present in our daily lives, and the pillars of robotics: mechanics, electronics, and computer programming. Although the focus of this workshop does not address the development of a project, using the three pillars of robotics, the basic concepts of electronics were explained to the class. At this point, the students used the *Tinkercad simulator* to build the first electronic circuits.

After the participants' first contact with the production of circuits in *Tinkercad*, a dynamic was carried out with the students using the *Plickers tool*. *Cards* were created with questions containing images of circuits made in *Tinkercad*, with the aim of provoking participants' reflection on their operation, aiming to verify whether they were correct or not.

Plickers tool, including the growth of interest in the topics covered in the classroom and greater student involvement. With this, we hope to verify advances in learning and clarify any doubts that could harm the construction of the electrical maze.

After the dynamics with the *Plickers tool* and a moment to clarify possible doubts, the participants formed pairs and put into practice the concepts of electricity, electronics, and circuits learned in the workshop, designing and building their electrical maze. To do this, each group received the following materials: A 3.7 V battery with support, a buzzer, a screw, 50 centimeters of metal cable to build the maze route, a roll of insulating tape, a plastic bottle cap, and cardboard.

Figure 2 allows us to observe how each of the disciplines that make up the STEAM approach is present in this workshop, while in Table 1, it is possible to identify each of the phases that make up the *Learning Act* (Gagné, 1980).

FIGURE 2: Application of disciplines in the workshop

Source: Prepared by the authors (2023)

TABLE 01: Workshop Learning Act

PHASE AND DEFINITION	STRATEGY DESIGNED FOR THE WORKSHOP
01. Motivation Phase: In this stage, expectations are created in students, awakening interest and motivation to learn.	By presenting an example of an electric maze built from the reuse of materials and informing that at the end of the workshop, based on the concepts that would be taught, the students built their maze, it was possible to awaken the participants' motivation for the content.

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02. Apprehension Phase: In this phase, it is important that the learner is attentive and concentrated on what will be presented. Therefore, at this point, the educator must use resources that help the student not to lose focus on the content taught.	During the workshop, slides were used that favored the display of images rather than textual information. As a way of retaining the participant's attention to the exposed content, we looked for playful or impactful images. Two short videos were presented, lasting six and eight minutes. The first explained what electronic waste is and the second demonstrated how robotics can be used to combat marine pollution.
03. Acquisition Phase: The moment in which the new content is recorded in the learner's short-term memory to later be transported to permanent memory.	To facilitate the process of storing the theoretical content covered in the workshop, we chose to use images, believing that participants would pay more attention to the concepts covered in class. For example, using figures that show people deformed as a result of different types of cancer. Regarding the content involving electronics, it was decided to carry out practical activities with the participants using the T*inkercad simulator*.
04. Retention Phase: Moment in which information is definitively recorded in long-term memory.	
05. Recall Phase: In this phase, the learner is encouraged to remember and recall the information that was previously received. The idea is to strengthen memory and make knowledge more lasting.	Participants answered four questions on Plickers (www.plickers.com) to remember the content presented and reinforce the process of storing this knowledge, after presenting the problems arising from waste disposal and the basic concepts of electronics.
06. Generalization Phase: Here, the objective is to apply the knowledge learned in different situations and contexts. The learner is challenged to transfer what has been learned to solve problems and make decisions in real-world situations.	To put the knowledge acquired into practice, the participants used their creativity. They built their electrical mazes using materials that were irregularly discarded on the beach or the street, as well as some electronic components. All materials were made available by educators.
07. Performance Phase: Allows the educator to evaluate whether or not the student has learned.	The participants' learning was noted by the researchers' observation and measured by the activity with the Plickers tool and by the construction of the electronic maze.
08. Feedback Phase: This is an important phase of the teaching process, as it marks the student's perception of the knowledge that was acquired during the learning stage.	Oral feedback on the projects developed, and the creation of electrical circuits with T*inkercad* were fundamental tools for the participants' perception of the new knowledge acquired in the workshop.

Source: Prepared by the authors (2023)

Results and discussions

Table 2 shows the students' responses to the questionnaire administered at the beginning of the class. Based on these responses, it was possible to verify that everyone was unaware of the fact that plastic waste present in the oceans is being ingested by human beings, they did not know how to perfectly explain the difference between common waste and electronic waste, they were unaware of the impacts resulting from irregular waste disposal. electronic, were unaware of basic electronic concepts and believed that electricity was a man-made invention, few students had had the opportunity to build something from the reuse of materials.

TABLE 02: Questions and answers from the initial form

QUESTION	OPTION CHOSEN BY STUDENTS
The trash we throw into rivers and seas harms countless living beings, as it can end up in people's stomachs...	0: Humans 8: Turtles 7: Fish
Do you know how to find the closest location to your home to dispose of electronic waste?	6: No 2: Yes
Do you know how to explain the difference between common waste and electronic waste?	0: Yes, perfectly 6: More or less 2: I don't know
Could you explain why electronic waste harms human health?	1: Yes 4: More or less 3: I don't think so
Electricity is:	0: A form of energy that exists naturally in nature 8: A form of energy invented by man 0: I have no idea
If you receive an LED, batteries, and wires, would you know how to make the correct connection so that this LED stays on?	1: Yes 7: No
Have you ever had the experience of building something from reusing recyclable materials?	3: Yes 5: No
Would you like to have the experience of building something from reusing recyclable materials?	8: Yes 0: No

Source: Prepared by the authors (2023)

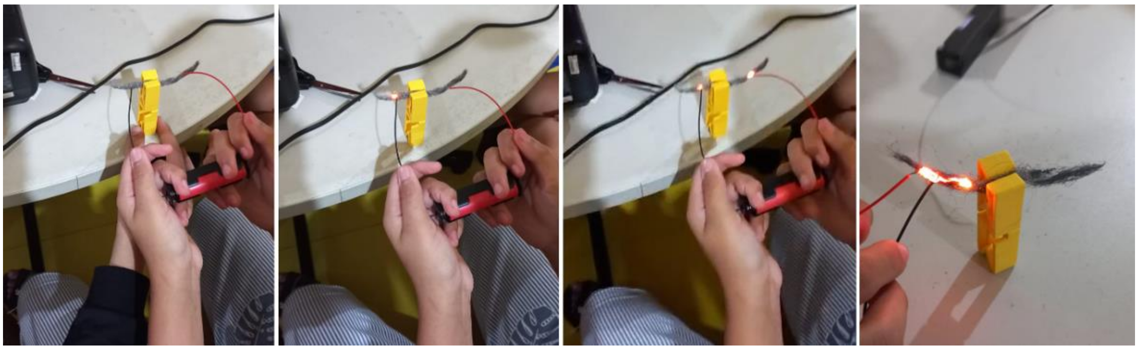
It is important to highlight that only eight students responded to this first questionnaire, as three of them missed the first day of the workshop. The next stage included a presentation of the problems arising from the irregular disposal of electronic waste. Through the material presented, students understood what electronic waste is, and discovered that through the website of the Brazilian Association of Recycling of Electronics and Domestic Appliances, it is possible to identify the closest location to their homes to correctly dispose of this type of material, and Finally, they learned about the negative impacts of improperly disposing of *e-waste*.

Then, the problems arising from the improper disposal of common waste were addressed. Through the *slides*, the students understood that much of the trash deposited improperly on the streets ends up in the ocean and how harmful this can be to humans, in addition to affecting marine life. To conclude the approach to waste, a video was shown that presents a technological solution, the *Interceptor*, a semi-autonomous boat that was designed to collect waste from some of the most polluted rivers in the world. In this way, the pedagogical approach used contributed to raising student awareness, and through the presentation, the class promoted discussions on Environmental Education (Carvalho, 2004; Guimarães, 2016).

Based on the content covered in the video, an example of a "robot boat", students were shown examples of robots that are present in our daily lives, such as ATMs and machines used on public transport buses. From there, it was explained to the students that one of the pillars of robotics is electronics and to study this pillar a little, it was important to understand the concept of electricity and how it was used by man. Therefore, we sought to approach curricular content, such as atomic models and electricity, based on elements of digital culture that are recognized by students, for example, robots (Lucena; Oliveira, 2014; Brasil, 2018).

To demonstrate in practice how electrons move between the poles of a power source, the students used a 3.7V battery and steel wool. Upon seeing that the steel wool "caught fire" when it was in contact with the two poles of the energy source, the students were surprised and were able to see in practice the concept covered in the slides.

FIGURE 3: Experiment with electron displacement



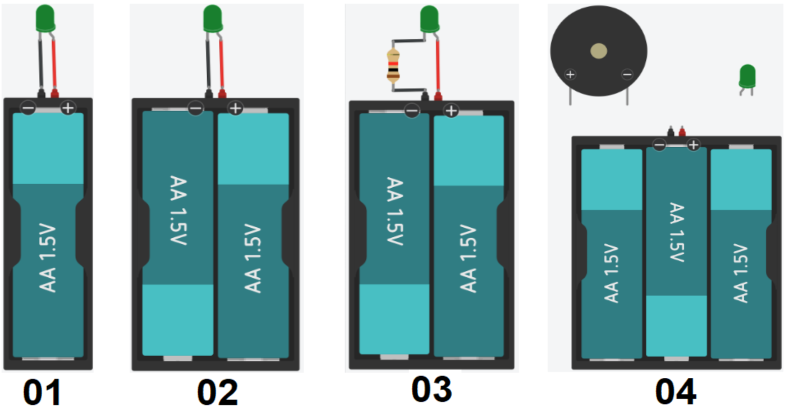
Source: Source: Prepared by the authors (2023)

The second day of the workshop began with a brief review of the concept of electric current. When showing the *slide* that explained the displacement of electrons from the negative pole toward the positive pole of an energy source, it was possible to observe that many students remembered the concepts explained in the previous class. One of the students even reported that he had replicated this experience with steel wool in his home.

The fact that they remember concepts covered two weeks ago and a student's report about reproducing the experience at home reinforce Papert's constructionist theory, that children learn better when they have the opportunity to manipulate physical objects and are involved in activities practical, challenging, and meaningful (Papert, 1980). After this initial moment, the students were taken to the laboratory. There they were divided into pairs and had access to the *Tinkercad tool.*

The intention when using the simulator was for students to be able to build small circuits using *LEDs* and *a buzzer*. They were less complex activities that aimed to prepare students to develop the final activity: the electric maze. Thus, respecting the concept of the Hierarchy of Skills (Gagné, 1980), students were asked to build four circuits, as illustrated in Figure 4.

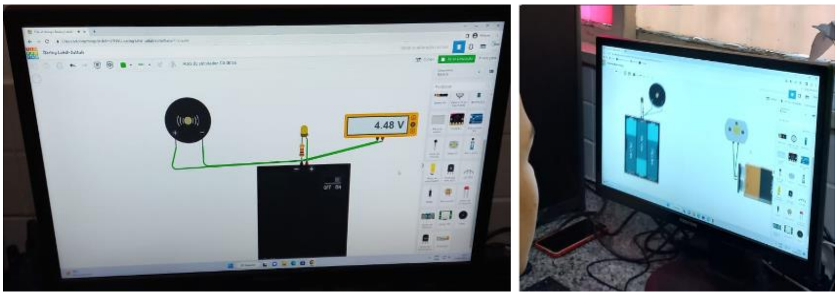
FIGURE 4: Circuits built in the Tinkercad simulator



Source: Prepared by the authors (2023)

It was observed that all pairs managed to build the simulations, including the challenge proposed in the fourth and final circuit. Some students demonstrated more affinity with the tool and greater interest in exploring the content that was being taught in the workshop, so much so that they did not limit themselves to building the simulations proposed in class, nor just using the electronic components taught. In one case, a student modified the configuration of the circuit's battery pack, displaying an on/off switch. Furthermore, we verified the use of other electronic components that were not covered in the workshop, such as motors and voltage meters. The fact that students explored the tool on their own can be considered an indication that the objective initially set out to awaken students' interest in creating new technologies was being achieved, as recommended by the fifth competence of the BNCC (BRASIL, 2018).

FIGURE 5: Students exploring the Tinkercad tool



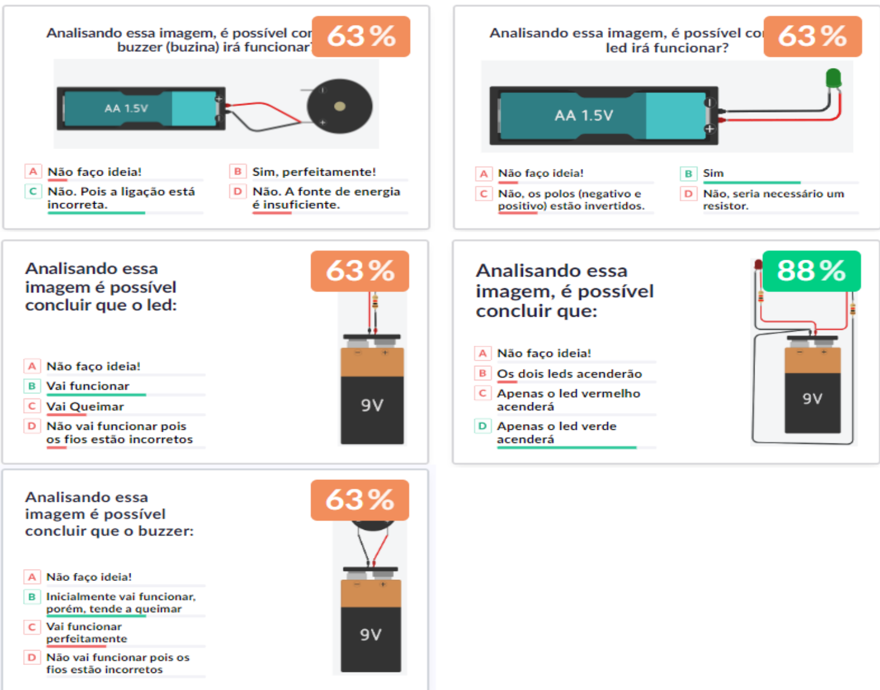
Source: Prepared by the authors (2023)

After completing the stage in the simulator, the students participated in the dynamics with the *Plickers tool*. This moment of the workshop had two objectives: to evaluate the learning process of the content that involves the electronic part and to clarify any doubts the students might have. The dynamic consisted of presenting five questions, all of which related to the creation of electrical circuits. Each question had 4 answer options and there was only one correct alternative.

Figure 6 shows the questions that were used in this dynamic. As you can see, they all had a similar approach, involving the display of an electronic circuit, allowing students to select the alternative that best represented the possible conclusions for that specific scenario. In other words, students should predict what would happen if the electronic component (buzzer or *LED*) was used in that scenario.

Furthermore, in Figure 6, it can be seen that in most of the five questions, students chose the correct answer, highlighted in green, while the other three alternatives are indicated in red. The vertical bars below each question provide an indicator of the number of students who chose each alternative.

Figure 6: Questions used in *Plickers* with percentage of correct answers



Source: Source: Prepared by the authors (2023)

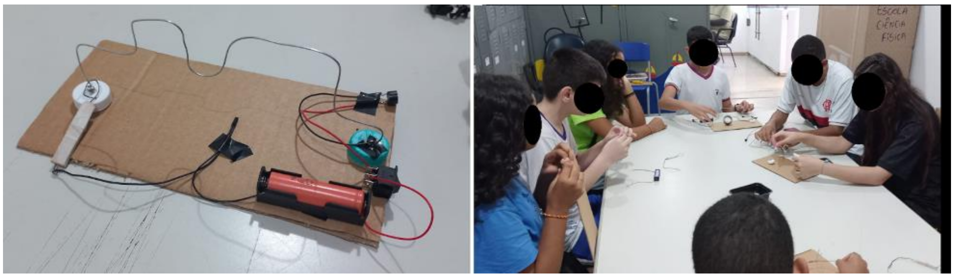
http://doi.org/10.14393/ER-v31e2024-24

Regarding student achievement, two students got all the questions right, one student got 80% right, three got 60% right and the other two got 40% right. During this dynamic, taking advantage of the fact that they were facing the computer, it was possible to observe that some students tried to reconstruct the circuit that was being shown in the question in *Tinkercad*. It turns out that this action was inefficient, as the student did not build the circuit promptly and lost the reasoning behind the question in question. This attitude may be an explanation for the fact that two students achieved only 40% assertiveness in the dynamics.

In addition to evaluating the student's learning process, the dynamics above were essential to clarify doubts raised by students. In some cases, students brought up topics that were not being covered in the workshop, such as: how to know the value of a resistance. After answering all questions regarding the construction of electrical circuits, students were invited to build their electrical maze using reused materials and thus put into practice all the concepts covered.

Initially, the students had difficulty understanding how all the equipment would be interconnected. However, as they persisted, the students understood that the metal cable, as well as the screw, would only act as conductors of electricity in this project, just like the black and red wires that were already being used by them. After consolidating this understanding, the first solutions began to emerge. The students were free to use their creativity and develop the desired shape of the maze, however, most pairs chose not to make much effort in building a more creative project. Finally, all pairs managed to complete their project.

FIGURE 7: Students building an electronic maze



Source: Prepared by the authors (2023)

At the end of the workshop, students were invited to answer the second questionnaire. It is important to highlight that, although eight students were present in the second part of the workshop, only four of them had responded to the first questionnaire. Therefore, only these same four students responded to the second questionnaire.

Despite the small number of students who were able to participate in this second evaluation moment, the responses indicated that there was significant learning in terms of raising awareness about the impacts of irregular waste disposal and electronic waste. All students showed that they understood that the irregular disposal of these materials in nature can result in the development of some types of cancer, and the majority also mentioned soil contamination. Regarding marine pollution, contrary to what was found in the initial questionnaire, all students understood that the plastic present in the ocean directly affects humans, in addition to being responsible for the death of some marine species. The results of this questionnaire show us the importance of developing interdisciplinary activities in a *STEAM approach* and their potential to promote student learning and Environmental Education, as well as the research by Muline and Campos (2016) and Bergamaschi *et al.* (2022).

Regarding questions relating to basic knowledge of electronics, from the answers, it was possible to see that there was consensus on the simplest questions, however, the questions that required a little more reasoning generated doubts in half of the students who answered the questionnaire. However, judging by the observed performance of the students during the workshop, it is believed that if all students present in the second class had answered the final questionnaire, the percentage of correct answers could be higher.

Final considerations

This research work successfully demonstrated the effectiveness of sustainable practices in the context of environmental education, using active methodologies and the *STEAM approach*. As occurred in Siqueira's research

(2020), the application of concepts from the learning theory of North American psychologist Robert Mills Gagné provided an engaging learning environment, where the student felt challenged and at the same time capable of solving problems. proposed, encouraging their active participation and the internalization of concepts related to basic electronics, sustainability, and care for the environment.

Papert's constructionist theory, in turn, allowed students to develop problem-solving skills and creativity through practical exploration and construction of knowledge in a real and meaningful context. These results are similar to those achieved by Souza (2020) in his research, which aimed to teach concepts of electricity and hydrostatics to high school students through the construction of prototypes using traditional and sustainable robotics.

Research has shown that, by involving students in practical and meaningful activities, environmental education gains meaning, becoming more engaging and relevant to students' lives. The research also showed that the *STEAM approach* can be used to promote integration between different disciplines, stimulating critical thinking, creativity, and problem-solving, essential skills for forming conscious citizens committed to sustainability.

In this way, we understand that the main collaboration of this research for education is demonstrating that the combination of environmental education with active methodologies and the *STEAM approach* is an effective strategy for engaging students in understanding environmental challenges and encouraging them to seek Innovative solutions. By sparking young people's interest in creating new technologies, the *STEAM curriculum* can significantly contribute to reducing the impacts of waste and electronic waste on the environment.

Finally, we believe it is essential that educators and policymakers recognize the importance of incorporating sustainable practices and environmental education into classrooms, using innovative pedagogical approaches. Furthermore, it is necessary to provide adequate resources and incentives to promote the integration of environmental education with scientific, technological, engineering, arts, and mathematics disciplines, to form conscious, capable individuals committed to building a more sustainable future.

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