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Weavings and Potential of Climate Literacy, Educational Robotics, and Artificial Intelligence in Basic Education

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Tessituras e potencialidades da Alfabetização Climática, da Robótica Educacional e da Inteligência Artificial na Educação básica

RESUMO

Objetivo – investigou a eficácia de uma Sequência Didática Interdisciplinar (SDI) no Ensino Fundamental II, articulando o uso da Inteligência Artificial (IA) no componente curricular de Robótica Educacional, com foco na Educação Ambiental Crítica para promover a Alfabetização Climática.

Metodologia – consistiu em uma análise descritiva (AD) realizada com alunos e a docente do 9º ano, por meio do desenvolvimento e aplicação da SDI. Os dados foram coletados das produções dos alunos e analisados de forma descritiva.

Originalidade/relevância – O estudo se insere no debate sobre inovações pedagógicas no contexto da crise climática e ambiental, e o uso de tecnologias educacionais, e a estruturação dos novos componentes curriculares(BNCC), propondo alternativas de intervenção e integração curricular, que une território e tecnologia sob a lente da Educação Ambiental Crítica.

Resultados – A SDI proporcionou engajamento e protagonismo estudantil, o que pode promover o desenvolvimento de pensamento crítico, da autoria, da alfabetização tecnológica e climática bem como o fortalecimento da cidadania ambiental frente à crise.

Contribuições teóricas/metodológicas – Evidencia-se a potência do uso de prompts e de ferramentas de IA na mediação da aprendizagem pautada da abordagem da educação ambiental crítica, com vistas a Alfabetização Climática, bem como a contribuição da robótica educacional para a construção de projetos interdisciplinares.

Contribuições sociais e ambientais – O estudo promoveu o protagonismo estudantil, bem como o uso ético da IA para promover a valorização dos saberes locais e o debate público sobre os desafios ambientais reais vividos pela comunidade, posicionando os alunos o cerne da crise e também da mitigação desta.

PALAVRAS-CHAVE: Crise Climática. Tecnologia Educacional. Interdisciplinaridade.

Weavings and Potential of Climate Literacy, Educational Robotics, and Artificial Intelligence in Basic Education

ABSTRACT

Objective – This study investigated the effectiveness of an Interdisciplinary Didactic Sequence (IDS) in Middle School, integrating the use of Artificial Intelligence (AI) in the Educational Robotics curriculum, with a focus on Critical Environmental Education to promote Climate Literacy.

Methodology – A descriptive analysis was conducted with ninth-grade students and their teacher through the development and implementation of the IDS. Data were collected from student outputs and analyzed descriptively.

Originality/Relevance – The study contributes to the discussion on pedagogical innovations in the context of the climate and environmental crisis, the use of educational technologies, and the structuring of new curricular components (BNCC), proposing alternatives for intervention and curricular integration that connect territory and technology through the lens of Critical Environmental Education.

Results – The IDS fostered student engagement and protagonism, which can promote the development of critical thinking, authorship, technological and climate literacy, as well as the strengthening of environmental citizenship in the face of the crisis.

Theoretical/Methodological Contributions – The study highlights the potential of using AI prompts and tools to mediate learning grounded in Critical Environmental Education for Climate Literacy, as well as the contribution of Educational Robotics to the construction of interdisciplinary projects.

Social and Environmental Contributions – The study promoted student protagonism and the ethical use of AI to value local knowledge and foster public debate about real environmental challenges experienced by the community, positioning students at the core of both the crisis and its mitigation.

KEYWORDS: Climate Crisis. Educational Technology. Interdisciplinarity.

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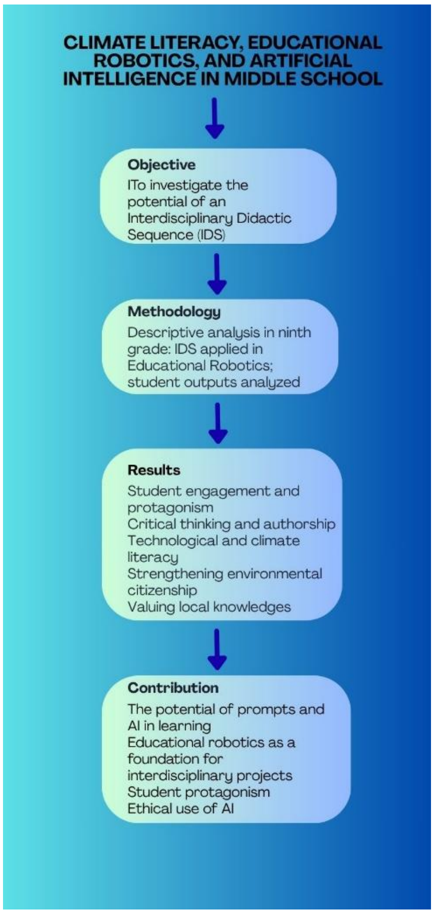
Trazados y potencialidades de la Alfabetización Climática, la Robótica Educativa y la Inteligencia Artificial en la Educación Básica

RESUMEN

Objetivo – Se investigó la eficacia de una Secuencia Didáctica Interdisciplinaria (SDI) en la Educación Secundaria Básica, articulando el uso de la Inteligencia Artificial (IA) en el componente curricular de Robótica Educativa, con enfoque en la Educación Ambiental Crítica para promover la Alfabetización Climática.
Metodología – Consistió en un análisis descriptivo (AD) realizado con estudiantes y la docente del noveno grado, a través del desarrollo y aplicación de la SDI. Los datos fueron recolectados a partir de las producciones de los estudiantes y analizados de forma descriptiva.
Originalidad/relevancia – El estudio se inscribe en el debate sobre innovaciones pedagógicas en el contexto de la crisis climática y ambiental, y en el uso de tecnologías educativas y la estructuración de los nuevos componentes curriculares (BNCC), proponiendo alternativas de intervención e integración curricular que unen territorio y tecnología bajo la perspectiva de la Educación Ambiental Crítica.
Resultados – La SDI promovió el compromiso y el protagonismo estudiantil, lo que puede fomentar el desarrollo del pensamiento crítico, la autoría, la alfabetización tecnológica y climática, así como el fortalecimiento de la ciudadanía ambiental frente a la crisis.
Contribuciones teóricas/metodológicas – Se evidencia el potencial del uso de *prompts* y de herramientas de IA en la mediación del aprendizaje basada en el enfoque de la educación ambiental crítica orientada a la Alfabetización Climática, así como la contribución de la robótica educativa a la construcción de proyectos interdisciplinarios.
Contribuciones sociales y ambientales – El estudio promovió el protagonismo estudiantil, así como el uso ético de la IA para fomentar la valorización de los saberes locales y el debate público sobre los desafíos ambientales reales vividos por la comunidad, situando a los estudiantes en el centro de la crisis y también de su mitigación

PALABRAS CLAVE: Crisis Climática. Tecnología Educativa. Interdisciplinariedad.

GRAPHICAL ABSTRACT


CLIMATE LITERACY, EDUCATIONAL ROBOTICS, AND ARTIFICIAL INTELLIGENCE IN MIDDLE SCHOOL
Objective
ITo investigate the potential of an Interdisciplinary Didactic Sequence (IDS)
Methodology
Descriptive analysis in ninth grade: IDS applied in Educational Robotics; student outputs analyzed
Results
Student engagement and protagonism
Critical thinking and authorship
Technological and climate literacy
Strengthening environmental citizenship
Valuing local knowledges
Contribution
The potential of prompts and AI in learning
Educational robotics as a foundation for interdisciplinary projects
Student protagonism
Ethical use of AI

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1 INTRODUCTION

We are facing the most serious threat to global health in the 21st century and potentially to life on a planetary scale. This reality arises from two major ongoing crises – the climate crisis and biodiversity loss. As collective and interdependent beings, we rely directly on other forms of life and abiotic factors; we cannot exist in isolation. This situation reveals that the enemy we must confront challenges the very model of our way of life, indicating that we are experiencing a civilizational crisis.

In recent years, the emission of greenhouse gases (GHGs) has caused unprecedented increases in temperature, triggering rapid and intense climate changes and increasing the occurrence of extreme events, such as hurricanes and floods. These events have led to significant socio-environmental impacts in affected regions, as well as numerous deaths (Bos; Schwartz, 2023).

The greenhouse effect is a natural phenomenon responsible for maintaining the Earth's temperature within a range compatible with life. The planet receives solar radiation, part of which is reflected back into space as shortwave radiation, while another part is absorbed as longwave radiation by soils, oceans, and living beings and then re-emitted into space. However, part of this re-emitted radiation is absorbed by water vapor and GHGs – primarily CO2, CH4, and N2O, with CO2 being the most significant – which helps maintain the planet's temperature (Zhong; Haigth, 2013).

With the continuous and accelerated increase in GHG emissions, especially CO2, the planet is undergoing a process of global warming. To quantify and compare the influence of each GHG on global warming and climate change, the Intergovernmental Panel on Climate Change (IPCC) developed in 1990 the Global Warming Potential (GWP) index. This index expresses the radiative forcing of 1 kg of a given gas over a specific time horizon relative to the radiative forcing of 1 kg of CO2.

Using a 100-year time horizon, the fifth IPCC report (AR5, 2013–2014) indicated that CH4 has an atmospheric lifetime of 12.4 years and a GWP of 28, while N2O has a lifetime of 121 years and a GWP of 265. Although their concentrations in the atmosphere are lower than CO2, CH4 and especially N2O have global warming potentials 28 and 265 times greater than that of CO2, respectively.

The IPCC's Sixth Assessment Report (AR6, 2021) indicates that the global average temperature increase between 1850–1900 and 2010–2017 ranged from 0.8°C to 1.3°C. Anthropogenic factors, such as the rise in GHG emissions and aerosol use, contributed 0.8°C to 2.0°C to this increase, while natural factors, including changes in solar surface temperature and volcanic activity, contributed between -0.1°C and +0.1°C. The same report states

> [...] Cumulative net CO2 emissions from 1850 to 2019 were 2,400 ± 240 GtCO2, of which more than half (58%) occurred between 1850 and 1989, and approximately 42% between 1990 and 2019. In 2019, atmospheric concentrations of CO2 (410 parts per million) were higher than at any time in at least 2 million years, and methane (1,866 parts per billion) and nitrous oxide (332 parts per billion) concentrations were higher than at any time in at least 800,000 years" (IPCC, 2023, p. 4, our translation).

International agencies identified 2023 as the hottest year on record; however, 2024 reached alarming temperatures during the summer in the Northern Hemisphere (Vianna et al., 2024). Furthermore, in May 2023, the atmospheric concentration of carbon dioxide (CO2) reached a new global record of 424 parts per million (ppm), a level never before recorded in Earth's history (NOAA, 2023). The World Meteorological Organization (WMO) reported that in 2024 the global average temperature was already 1.3 degrees Celsius higher than the average between 1850 and 1900 (World Meteorological Organization, 2025). This scenario makes the last ten years the warmest decade in the history of our planet (World Meteorological Organization, 2025).

According to the WMO (2025, p. 6, our translation*)*

> The increase in atmospheric CO2 concentration, driven by human activities, is the primary driver of climate change. CO2 accounts for approximately 66% of the radiative forcing of all long-lived GHGs since 1750 and about 79% of the increase over the last decade. Current atmospheric CO2 concentrations are the highest in at least 2 million years, while CH4 and N2O concentrations are the highest in at least 800,000 years.

This scenario has a massive impact on the planet, causing desertification, biodiversity loss, and irreversible ecosystem changes, which expose human populations to risks such as food and water shortages and increased disease incidence (Blank, 2015). In Brazil, between 1991 and 2020, there were more than 66,000 climate-related events, resulting in over 4,700 deaths, 228,000 affected people, and public losses estimated at approximately R$ 430 billion (Di Giulio; Gressi; Jacobi, 2024).

1.1 Critical Environmental Education (CEE) and Education for Climate Change (ECC)

Environmental Education (EE) is compelling and essential, as it helps in understanding the climate crisis, which is also a civilizational crisis, and thus supports both collective and individual decision-making (Costa; Loureiro, 2015).

In Latin America, Critical Environmental Education (CEE) has emerged as a response to the complexity of socio-environmental injustices experienced in the region, characterized by historical inequalities and the exploitation of natural resources to the detriment of local populations. This approach recognizes that the ecological crisis cannot be separated from the social structures that sustain it, such as the predatory economic model and the exclusion of traditional communities from decision-making processes. In this sense, educational initiatives seek to integrate the socio-environmental perspective into the formation of individuals, contributing to the development of critical consciousness linked to the realities of their territories (Florencio da Silva *et al.*, 2023).

The construction of environmental citizenship grounded in dialogue and democratic participation is also emphasized as a means to strengthen emancipatory practices in schools (Gunansyah *et al.*, 2023).

Latin American experiences highlight the relevance of educational methodologies that incorporate popular and community knowledge, recognizing their importance in knowledge production and resistance to hegemonic development models. In various contexts, valuing local cultures has helped bring students closer to their territories, fostering identification with environmental issues experienced in their communities.

Saldi *et al.* (2025) emphasize that the dialogue between CEE and political ecology strengthens the understanding of the climate crisis as a structural and multifaceted phenomenon. On the other hand, Florencio da Silva et al. (2023) argue that environmental education must be articulated with the notion of socio-environmental justice, promoting educational practices aimed at equity, respect for diversity, and social transformation.

One of the most consistent contributions of Latin American approaches lies in the articulation between identity, territory, and pedagogical action. By recognizing lived space as a formative dimension, educational processes become more meaningful and capable of mobilizing individuals toward action.

Gunansyah *et al*. (2023) point out that democratic deliberation in the classroom fosters the development of students' critical consciousness, creating spaces for the exercise of active citizenship. Saldi et al. (2025) reinforce that this consciousness must be built through the analysis of social and environmental contradictions that shape everyday life, contributing to the formation of individuals capable of intervening in reality in a critical and proactive manner.

When the climate emergency is treated as a generative theme from a Freirean perspective adapted to Latin American realities, it allows students to understand the interconnection between global environmental phenomena and local living conditions. Florencio da Silva *et al*. (2023) report that youth engagement in socio-environmental projects contributes to the development of competencies related to civic participation, cooperation, and critical thinking. Gunansyah *et al.* (2023) emphasize that environmental citizenship should be understood as a continuous formative process, in which individuals are encouraged to question and transform the relationships between society and nature.

Pedagogical action committed to socio-environmental justice also entails addressing environmental inequalities generated by human activity and exacerbated by the neglect of public policies. Saldi *et al*. (2025) corroborate that peripheral populations and Indigenous peoples are the most affected by the consequences of climate change, requiring an educational approach committed to historical reparation and the strengthening of social struggles. In this regard, Gunansyah *et al*. (2023) argue that CEE must include discussions on power, rights, and justice, enabling students to recognize themselves as historical agents with transformative capacity.

The pedagogical practices emerging from these approaches are characterized by promoting student autonomy, encouraging them to investigate real problems in their communities and propose collaborative solutions. Florencio da Silva *et al*. (2023) state that integrating theory and practice, combined with the critical examination of environmental conflicts, enhances individuals' capacity to understand the complexity of socio-environmental issues and to act critically. Saldi *et al*. (2025) highlight that engagement with social movements and local knowledge strengthens the political dimension of environmental education, transforming schools into spaces of resistance and alternative construction.

Finally, consolidating educational practices aimed at socio-environmental justice in the Latin American context requires recognizing the region's historical, cultural, and environmental particularities. Saldi *et al*. (2025) argue that education should contribute to rebuilding connections between individuals and their territories, promoting a pedagogy rooted in reality and committed to social transformation. Similarly, Gunansyah *et al*. (2023) reiterate that critical environmental citizenship can only be consolidated when formative processes stimulate autonomous thinking and collective action in defense of the common good.

In this context, Hodson (2003) highlights that literacy, here understood as Environmental Literacy, has been emphasized for years in the literature, underscoring the need for knowledge of the basic principles of ecosystem organization and their application in the development of sustainable human communities.

According to Oliveira *et al*. (2015), an environmentally literate citizen in terms of climate is aware of the fundamental relationship between climate and life, evaluating scientific evidence when making decisions. Burandt and Barth (2010) further emphasize that climate literacy requires knowledge and skills to navigate climate change, grounded in critical thinking and the interpretation of interrelations between problems and systemic decision-making.

Mafra and Moreno (2019) argue that promoting attitude and behavior change in favor of the environment is essential, advocating the practice of “Environmental Literacy” to achieve “Climate Literacy.” As Silva, Costa, and Borba (2016, p. 3) state, an “environmentally literate individual” is not only a more informed citizen but also one with greater capacity to consciously solve or contribute to solving environmental problems.

Wise (2010) identifies three approaches to Education for Climate Change (ECC): one situated between instruction and environmental activism, misconceptions about climate change resulting from lack of climate literacy, and classroom activities aimed at fostering youth protagonism.

Kiessling (2018) notes that despite Brazil’s past role as a passive actor in environmental policy, between 2018 and 2022 the country demonstrated little concern for the climate crisis. Despite the 1997 Kyoto Protocol, established during the 3rd Conference of the Parties to the United Nations Framework Convention on Climate Change, with clear GHG reduction targets leading to Legislative Decree No. 144 of 2002 and later the National Policy on Climate Change (PNMC) (Brazil, 2009), only in 2024, with Law No. 14,926 sanctioned in July, were changes made to the PNMC – in Article 2, Section 4 – making it mandatory to include climate change, biodiversity protection, and socio-environmental risks and vulnerabilities in the curricula of basic and higher education in Brazil.

Regarding formal Brazilian education, in December 2017 the National Common Curricular Base (BNCC) was enacted through CNE/CP Resolution No. 2, regulating changes across the national basic education system, including curriculum components, workloads, and educational principles.

Following this regulation, the state of Paraná implemented a new curriculum for its basic education network. The Paraná State Education Network Curriculum (CREP) of 2020 specifies curriculum components for each school year, learning objectives, and content to be developed throughout the state. It emphasizes the importance of interdisciplinary approaches that integrate science, technology, and citizenship, focusing on the development of competencies to address real-world problems (Paraná, 2020).

In this context, Critical Environmental Education (CEE) emerges as a pedagogical approach that recognizes the complexity of relationships between society and nature, proposing the analysis of structural causes of environmental degradation and social inequalities. This approach transforms students’ understanding of reality and mediates their actions and decision-making. Gunansyah *et al*. (2023) reinforce that CEE requires the creation of dialogical school spaces where students can develop critical consciousness and recognize themselves as political actors capable of intervening in their realities.

In light of this scenario, the present study aimed to analyze a Didactic Sequence (DS) developed with ninth-grade students in Middle School, which integrated artificial intelligence (AI) with the climate emergency through investigative projects and digital resources. By combining Critical Environmental Education, digital technologies, and the collaborative production of knowledge, the study sought to explore how these tools can enhance meaningful learning and foster students' civic development in support of Education for Climate Change (ECC) and Climate Literacy.

2 METHODOLOGY

This is a qualitative, applied study focusing on the analysis of pedagogical practices conducted in a school context. The research was carried out through Descriptive Analysis (DA), which aims to investigate a group or phenomenon by describing its characteristics and identifying relationships and variables.

Accordingly, the data were structured around the implementation of an Interdisciplinary Didactic Sequence (IDS), following the principles of Zabala (1993) with descriptive data centered on the experiences of students and the teacher throughout the IDS.

Data considered for analysis included students' outputs (prompts, texts, concept maps, and projects), classroom records maintained by the teacher (before, during, and after lessons, such as lesson plans and field journals), and the materials used in the teaching and learning process.

The analysis was guided by the frameworks of Critical Environmental Education (CEE), Education for Climate Change (ECC), and Climate Literacy, in dialogue with official curricular documents for elementary and secondary education in Paraná, as well as the BNCC and recent scientific publications on the transversal theme under study: the climate crisis.

Thus, the study aimed to elucidate the following research question: "How can an IDS, employing AI, developed based on the CREP and grounded in CEE to promote ECC within the Educational Robotics curriculum for ninth-grade students, contribute to students' Climate Literacy?"

Based on this research problem, the researcher and the teacher collaboratively developed an IDS planned for six lessons, divided into three stages. Additionally, the researcher and teacher held biweekly meetings, which were recorded and transcribed for analysis. Data collected from the aforementioned instruments were analyzed descriptively.

3. DATA PRESENTATION AND ANALYSIS

The IDS was developed and organized based on the principle of interdisciplinarity, since the Educational Robotics curriculum component in the ninth grade is designed to facilitate the use of AI. Accordingly, the teacher's proposal was to incorporate, through the lens of Critical Environmental Education (CEE) and Education for Climate Change (ECC), a didactic sequence aligned with the curriculum component and its specific content, creating a fertile space for Climate Literacy.

According to Zabala (1998, p. 18), a didactic sequence is "a set of ordered, structured, and articulated activities aimed at achieving certain educational objectives, with a known beginning and end for both teachers and students."

Recognizing the transversal nature of climate change, and consequently of ECC and Climate Literacy, the didactic sequence needed to adopt an interdisciplinary premise. According to Mochizuki and Bryan (2015, p. 7, our translation)

> Although technological and financial policies undoubtedly play a role in addressing climate change, broader structural, cultural, perceptual, behavioral, and ideological changes are also necessary. In other words, transformative changes in how we think and act, and in how we relate to present and future generations, are required. It is in this context that education plays a crucial role in climate responses.

This understanding highlights the holistic and multidimensional nature of climate change, making it essential to incorporate this premise into the didactic sequence. Interdisciplinarity was achieved as the teacher sought to integrate knowledge from other fields, including geography, history, biology, mathematics, sociology, and philosophy, proposing the characterization, understanding, and investigation of climate change for student outputs within the Educational Robotics curriculum.

Critical Environmental Education (CEE) originates from the principles of Environmental Education. Thus, a transdisciplinary understanding of the topic, together with its interdisciplinary implementation, provides a teaching and learning process aimed at climate crisis mitigation and adaptation (Fernandes et al., 2016).

The IDS was structured in three stages:

Stage I – Initial Elucidation of the Crisis: This stage consisted of two lecture-discussion lessons on the Climate and Environmental Crisis, conducted in the computer lab, since Educational Robotics classes take place either in the computer or robotics labs. The objective was to understand the fundamentals and premises of the Climate Crisis.

Stage II – Understanding AI: This stage involved one lecture-discussion lesson on artificial intelligence, its premises and foundations, and how it can be used ethically, safely, and responsibly.

Stage III – Development and Structuring of Prompts: Prompts are textual commands given to an AI to perform a specific task or function. This stage aimed at conducting an up-to-date literature review on the climate crisis and identifying current mitigation and adaptation measures. In the continuation of Stage III, which took four lessons, students worked in groups to develop Environmental Projects for implementation in the school, using ChatGPT® or Gemini®. Each group was responsible for a topic related to the climate crisis.

Students then created a Role Prompt to obtain: (1) the project title; (2) an introduction including the relevance of the topic, objectives, justification, and a brief literature review; (3) methodology, detailing how to execute the project and its target audience; (4) expected results; and (5) final considerations.

Throughout the process, the teacher mediated the activities collaboratively, guiding students on the veracity of information, ethical AI use, and the impacts of incorrect or false data in scientific activities. This demonstrated in practice that not all information from AI and

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technology is accurate or scientifically sound, and it is the researcher's role to organize and classify the information.

According to FIA (2019), climate illiteracy, fueled by ambiguous and conflicting information, naive theories, and distorted beliefs and perceptions, leads to climate skepticism, amplified by mass communication. Bos and Schwartz (2023) note that climate science contains terms that are difficult to understand, such as regional and global scales, metrics, and concepts, which complicates Education for Climate Change (ECC) and makes achieving climate literacy in a short time particularly challenging.

In this context, Lombardi and Sinatra (2012), investigating undergraduate students at an institution in the northwestern United States, aged 18 to 66, regarding their perceptions of the causes of climate change, identified difficulties in understanding climate concepts – distinguishing "climate" from annual seasonal variations – "weather" – as well as challenges in differentiating scientific evidence from opinions, which compromised the plausibility of the data related to climate change.

Similarly, Couto, Gonçalves, and Sermeus (2024), in a systematic review of Brazilian research on students' perceptions and conceptions of climate change, found that most students across different educational stages had heard of climate change and recognized that the climate is changing in their daily lives. However, they did not understand how the greenhouse effect occurs, often associating it with air pollution, and lacked comprehension of the relationship between GHGs, global warming, and current lifestyle patterns. The researchers also revealed that students tend to associate individual habits, such as waste disposal, with climate change.

The same study identified that students have difficulty identifying GHGs (Santos et al., 2019; Borges *et al.*, 2021). In addition, Gonçalves and Sermeus (2024) noted that students struggle to understand how the ozone layer functions and its relationship with GHGs and global warming, presenting a reductionist view of both climate change and the environment.

According to Fernandes *et al.* (2007), part of this situation stems from the fact that students' sources of information on climate change beyond the classroom primarily come from television and the internet, highlighting the school's role in fostering autonomy and critical thinking regarding the acquisition, comprehension, and selection of information in the context of Education for Climate Change (ECC).

Following the implementation of the IDS, students produced three projects titled: "Environmental Education, Climate Emergency: An Urgent Global Challenge"; "Protecting Nature, Protecting Life: Urgent Actions to Ensure a Sustainable Future"; and "Clean Transport and Sustainable Mobility, Waste and Environmental Impacts" (Table 1).

The projects were structured to include a title, a brief literature review, objectives, methodological proposal, expected results, final considerations, and references, following the guidelines of the Brazilian Association of Technical Standards (ABNT) for scientific writing.

The development and writing of the projects required an expansion of students' concepts and knowledge regarding climate change. The course teacher reported, during the second meeting after the start of the IDS implementation, that students had little or no scientific understanding of the climate and environmental emergency, aside from the perception that the climate – often understood in analogy to the current weather – was warmer for longer periods throughout the year.

Table 1 – Projects Developed by Ninth-Grade Students in Educational Robotics Classes Based on the IDS.

Title	Objectives	Framework	Methodology	Expected Results
Climate Emergency: Urgent Actions to Ensure a Sustainable Future	Identify the main causes and consequences of the climate emergency in both local and global contexts. Raise community awareness about the urgency of changes in consumption and production habits. Propose and implement practical and sustainable actions that contribute to mitigating environmental impacts.	Scientific articles (Google Scholar); IPCC; Official government websites	Stage 1: Conduct research and gather data on the local and global climate situation. Stage 2: Organize lectures, debates, and educational workshops on climate change and sustainable practices. Stage 3: Develop community projects, such as urban gardens, recycling campaigns, and initiatives to reduce plastic use. Stage 4: Monitor the results, encouraging the continuity of actions over the long term .	Promoting awareness and collective engagement is essential to pressure governments and companies to adopt sustainable policies. Only through coordinated efforts among society, public authorities, and the private sector will it be possible to prevent the worst-case scenarios and ensure a habitable future for all.
Clean Transportation and Sustainable Mobility, Waste, and Environmental Impacts	Promote educational actions on proper waste management and the importance of recycling, enabling students to become multipliers of these practices, transforming not only their immediate surroundings but also contributing to a more conscious and responsible society.	Scientific articles (Google Scholar); IPCC; Official government websites	**1. Awareness and Education:** Conduct lectures and workshops for teachers and students on the environmental impacts of waste and the importance of recycling. Disseminate information on how to properly separate waste and the benefits of recycling. **2. Implementation of Selective Waste Collection:** Distribute color-coded and labeled bins throughout the school for the collection of recyclable materials (paper, plastic, glass, metal) and non-recyclables. Assign a person responsible for the collection and storage of recyclable materials. Promote awareness campaigns, such as the "Zero Waste Challenge," encouraging students to actively participate in waste separation. **3. Partnerships and Practical Actions:**	By educating students, teachers, and staff about the importance of reducing, reusing, and recycling, it is possible not only to minimize material waste but also to transform the school into a center of innovation and environmental responsibility. Through the implementation of selective waste collection systems and the execution of educational activities, we can cultivate more conscious citizens who are better prepared to face the environmental challenges of the future. Addressing these issues within schools not only tackles the waste problem but also fosters a cultural shift that can extend throughout the wider community.

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			Establish partnerships with recycling companies and local NGOs to ensure that collected materials are properly processed and disposed of.	
Protect Nature, Protect Life: Urgent Actions to Ensure a Sustainable Future	Encourage lifestyle changes, particularly reduced consumption and increased use of public transportation.	Scientific articles (Google Scholar); IPCC; Official government websites	No actions were structured to achieve the objectives; only indications of potential scenarios were provided if the global average temperature continues to rise, such as an increase in extreme events and shortages of food and potable water.	Raise public awareness about the financial impacts of climate change – Rising temperatures, extreme weather events, and shifts in climate patterns entail both direct and indirect costs. According to the IPCC and the World Bank, without robust mitigation measures, global GDP could decline by 10% to 20% by 2050.

Source: The authors (2025).

Teacher – *" The students notice that it is hotter; for example, here at school, we were without air conditioning for a period, so it was noticeable on a daily basis. We even held a fundraising campaign to install air conditioners in the classrooms… the students felt the change in climate, but beyond that, regarding the real causes and other impacts, they did not have much information."*

This observation by the teachers reinforces the need to promote Critical Environmental Education (CEE) aimed at Education for Climate Change (ECC), emphasizing the urgency of acquiring appropriate knowledge about climate change to develop skills for transforming human activity patterns, particularly consumption, in favor of more sustainable behavior (Anderson, 2012).

Additionally, Bos and Schwartz (2023) report that the limited data available in the literature on school-aged youths' proficiency regarding climate change suggest that they lack the knowledge, values, or capacity for action to address climate change, as external assessments indicate weaknesses in the teaching and learning processes of science curriculum components.

Furthermore, the reality described by the teacher corroborates the findings of Gonçalves and Sermeus (2024), showing that while students perceive the effects of climate change and can identify its occurrence, they do not clearly understand, based on scientifically supported information, its origins and the processes driving it. This indicates that ECC, and consequently climate literacy, remains underdeveloped among basic education students.

Fernandes, Silva, Costa, and Borba (2016) indicate that while some countries, such as China, incorporate specific knowledge about climate change into their basic education curricula, Brazil still addresses Education for Climate Change (ECC) in an isolated manner, disconnected from discussions and reflections aimed at civic education,

> [...] In the Biology curriculum, climate-related topics are addressed in themes such as ecology and biodiversity. In the case of Physics, instruction generally focuses only on identifying thermology quantities used in climatology studies (Silva; Costa; Borba, 2016, p.184-195)

In contrast, Layrargues and Lima (2014) argue that Education for Climate Change (ECC) should integrate as many curriculum components as possible, adopting an interdisciplinary approach given the transdisciplinary nature of ECC. From this perspective, climate change is addressed across different dimensions and viewpoints, aiding in understanding its origins and proposing measures for mitigation and adaptation.

According to the AR6 (2021), the effects of climate change will be felt throughout society, to varying degrees, depending on the mitigation and adaptation actions implemented by policymakers.

Perceiving climate change in everyday life offers a real opportunity for contextualization and critical discussion within ECC. However, this perception must be complemented by knowledge that enables individuals and communities to visualize and plan feasible and effective actions.

Thus, after in-depth discussions on climate change primarily through research and reading articles from Google Scholar, IPCC reports, and government websites students proceeded to write their projects. As shown in Table 1, the projects were structured in a similar manner, following the teacher's guidance, but each presented different approaches, perspectives, and proposals.

The project "Climate Emergency: Urgent Actions to Ensure a Sustainable Future" aimed to start from an understanding of climate change in order to propose the implementation of practical actions, such as urban gardens, recycling campaigns, and plastic use reduction. It sought to promote initiatives that contribute to the social transformation necessary to address the climate crisis, while monitoring results in the short, medium, and long term.

According to Siegner and Stapert (2020), climate literacy cannot be limited to mere scientific knowledge about the climate and climate change. Education for Climate Change (ECC) must promote recognition of the close almost inseparable relationship between climate change and our consumption habits, production systems, market practices, and dominant ideologies (Oziewicz, 2023).

Furthermore, the author points out that "[...] climate change is not a STEM[1] issue. It is a matter of worldview, intertwined with our values, perceptions, beliefs, and lifestyles" (Oziewicz, 2023, p. 36, our translation) .

Armed with this understanding, the students behind the first project sought to promote awareness through engagement activities such as lectures, debates, workshops, and projects fostering collective participation as organized civil society. This involvement is essential to

[1] STEM is the English term referring to issues or problems related to the fields of Science, Technology, Engineering, and Mathematics).

pressure governments, governance bodies, and the private sector to adopt sustainable policies, recognizing that only through coordinated efforts among society, public authorities, and the private sector can climate change be mitigated and adaptation actions implemented. This, in practice, demonstrates the real potential of ECC.

The second project, "Clean Transportation and Sustainable Mobility, Waste, and Environmental Impacts," focused on reducing waste generation and ensuring its proper disposal (recycling), aiming to train students as multipliers of sustainable practices. The project structured its actions around awareness-raising, implementation of initiatives, and partnerships.

Although this project also proposed actions based on an understanding of the school reality and aimed at impacting that same context, its focus was biased toward waste generation and disposal, presenting a reductionist view of climate change. This supports the notion that we can merely "adapt" our current way of life characterized by neoliberal demand and consumption to the planet's needs.

Climate literacy, beyond knowledge about the climate, requires

> [...] looking beyond the optimistic and progressive self-image projected by global neoliberal civilization to its darker and more oppressive design features: racism, colonialism, extractivism, ecocide, greed, materialist reductionism, immediacy, anthropocentrism, speciesism, and others. Climate literacy involves understanding those implicated, connecting the worst perpetrators with the most innocent victims. In all its forms, it is difficult and uncomfortable knowledge. It demands that we choose truth over convenience, recognizing the ecocidal nature of the global neoliberal system in which we live" (Oziewicz, 2023, p. 35, our translation).

Beyond emergency actions, such as reducing waste generation and implementing selective collection which are important measures it is necessary to achieve a paradigm shift for climate change mitigation, requiring the abandonment of individual-focused responsibility and proposals in favor of collective constructions.

According to Kent (2009), individual or fragmented responsibility in the context of climate change primarily promoted within Western culture is unproductive because it minimizes solutions and, therefore, their impact, generating a process of collective inertia and disinterest.

Mafra and Moreno (2019) emphasize that attitude change, that is, rethinking practices in the face of the climate emergency, requires a holistic understanding of climate change, recognized across its multiple dimensions.

The third project, "Protect Nature, Protect Life: Urgent Actions to Ensure a Sustainable Future," although aiming to promote lifestyle changes toward more sustainable practices, was unable to structure actionable measures that could be applied in the school, revealing weaknesses in Education for Climate Change (ECC).

In this context, it is evident that the lack of understanding of climate change limits the possibilities for action. Students presented alarming and catastrophic data regarding the climate scenario, particularly concerning the production system and income generation with attention to financial impacts but were unable to connect this information to local realities or perceive the subjective dimensions of climate change, and therefore the potential actions (OECD, 2024).

> [...] Being climate literate does not require understanding all the complexities of climate science. Individuals with basic knowledge can communicate effectively about

> climate change and work within their communities to design and implement solutions that address climate change and related social, economic, and environmental challenges. Climate-literate individuals recognize that climate change has social, historical, ethical, legal, economic, psychological, and political dimensions. They understand that different societies, cultures, and traditions have distinct ways of perceiving, documenting, and interpreting environmental changes and their underlying causes; that the impacts of climate change do not affect everyone equally; and that actions taken now to accelerate emission reductions and adapt to ongoing changes can reduce risks for current and future generations (USGCRP, 2024, p. 3, our translation).

Following this process, the students organized presentations using slides created on Canva® to share their work with classmates, aiming to foster collective reflection on the projects for more effective implementation (Figure 1).

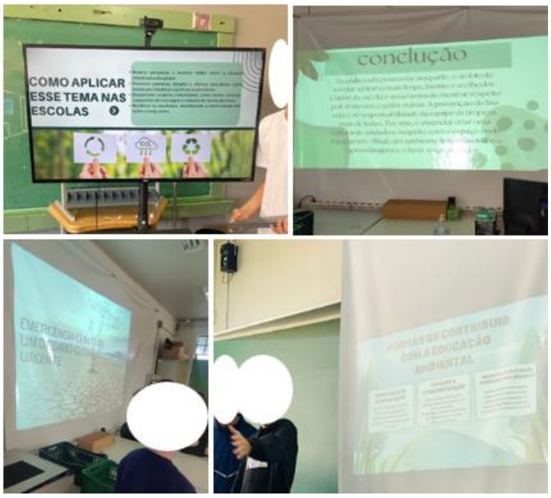
In this third stage socialization of the projects with a view to implementation students presented their projects, explaining the construction process, how AI was utilized, and how each team developed their prompts.

According to the teacher's report, students emphasized the importance of consulting databases such as Google Scholar and the IPCC for information on climate change, as it became evident that, at times, AI alone cannot establish correlations or generate conclusions to guide actionable proposals, especially when the focus is on the community and local realities.

Teacher – Throughout the presentations, we discussed the importance of scientific research and knowing how to conduct research using digital tools. I showed the students that AI, when improperly used, can even fabricate data and references, and that it is very difficult to carry out research ethically and scientifically without consulting reliable databases. We also discussed that AI is not present in the school, does not experience our problems, and does not confront the climate change scenario. Therefore, although it is possible to create a prompt with proposed actions, it is up to each group, which is responsible for the project, to evaluate the ideas and develop their own proposals".

From this perspective, Gooding and Phillips (2025) emphasize that preparing young people to exercise ecological citizenship linked to Education for Climate Change (ECC) depends on the integration of digital competencies and sustainability-oriented values.

Figure 1. Project socialization for collective reflection on implementation.



Source: The authors (2025).

By incorporating discussions on citizenship in the digital age, it is possible to connect the use of technologies with the development of critical awareness regarding the environmental, social, and political challenges of the 21st century. The convergence of digital competencies and environmental values can foster more conscious citizens committed to sustainability. This process relies on educational practices that encourage authorship, collaboration, and ethical use of technologies, promoting student engagement in socially relevant actions (Gooding & Phillips, 2025).

Lozano-Díaz and Fernández-Prados (2020) highlight that digital education guided by the Sustainable Development Goals (SDGs) provides opportunities for exercising critical and activist citizenship, particularly when supported by interactive pedagogical strategies.

In this context, digital literacy linked to AI should include the development of a critical understanding of how algorithms function, the logic of data, and automated decision-making processes. Vieriu and Petrea (2025) show that students exposed to AI-centered pedagogical practices develop both technical skills and metacognitive competencies, enhancing their capacity for analysis, synthesis, and judgment.

Lozano-Díaz and Fernández-Prados (2020) also note that incorporating digital citizenship into the school curriculum stimulates ethical thinking about technology use and strengthens students' social responsibility.

This approach is further supported by the use of generative systems, such as digital assistants that respond to specific commands called prompts. Zhao et al. (2025) indicate that using generative AI can enhance critical thinking by encouraging students to structure questions based on specific objectives and contexts.

Educational practices centered on prompts require intentional guidance from teachers to help students construct clear, contextualized commands aligned with learning objectives. This pedagogical strategy underscores the importance of language as a tool to organize thought and communicate intentions precisely.

Furthermore, Zhao *et al*. (2025) highlight that students who learn to structure effective prompts develop more refined analytical skills, as they must consider the AI's role, the task's objective, and the expected format of the response. Linhares and Reis (2023) add that technology-mediated learning environments promote the development of attributes associated with environmental citizenship, especially when applied in investigative school projects.

Experiences with AI in basic education, when connected to relevant topics such as climate change, foster student engagement in socially meaningful practices. Zhao et al. (2025) observe that combining AI with investigative approaches allows for linking school content to the real-life challenges faced by students. Linhares and Reis (2023) argue that this connection enhances the formation of critical students capable of interpreting and transforming the world, particularly when there is space for experimentation, reflection, and peer dialogue.

Given that computational thinking is increasingly recognized as a key 21st-century competency, robotics emerges as an important methodology to promote it from the early years of schooling. Martínez Rojas *et al*. (2025) conducted a trend analysis of research on robotics in basic education and found that most recent publications address the relationship between robotics and cognitive development, emphasizing critical thinking, creativity, and abstraction skills.

On the other hand, Gubenko *et al*. (2021) emphasize that educational robotics should not be limited to teaching programming but should also integrate cultural, ethical, and creative aspects, enabling students to reflect on the role of technology in society.

Martínez Rojas *et al*. (2025) argue that robotics is more effective when embedded in pedagogical proposals that value student protagonism, collaborative problem-solving, and interdisciplinarity.

Lu et al. (2025), in a comprehensive bibliometric review of over one thousand studies published between 2015 and 2024, demonstrated that educational robotics has increasingly been associated with the Sustainable Development Goals (SDGs). The authors also indicate that robotics projects aligned with the SDGs tend to promote greater student engagement, as they allow students to visualize the social impact of their creations.

Thus, robotics not only supports the acquisition of scientific knowledge but also serves as a means to develop ethical values, environmental awareness, and citizenship. Lu et al. (2025) highlight that working on SDG-oriented projects expands students' cultural and scientific repertoire while fostering empathy, active listening, and cooperation. Trapero-González et al. (2024) note that such practices, when supported by coherent pedagogical planning and continuous teacher training, have the potential to transform how students relate to science and technology.

The pedagogical experience developed with ninth-grade students demonstrated significant impacts in strengthening critical learning practices, particularly through AI-mediated exploration of climate change issues.

Given that the proposal involved the construction of interdisciplinary projects based on prompts created by the students themselves, cognitive competencies related to analysis, synthesis, and argumentation were observed to develop. Aeschbach et al. (2025), in a meta-analysis of 53 educational interventions on climate change, identified positive effects on students' knowledge acquisition and moderate gains in sustainable attitudes and behaviors, reinforcing that well-planned educational experiences produce measurable effects in Education for Climate Change (ECC).

On one hand, using AI tools to structure investigative activities allowed students to experiment with new forms of knowledge production; on the other, it enhanced their ability to critically reflect on the socio-environmental challenges faced in daily life.

According to İzgi Onbaşili and Yalman (2025), involving students in practices that integrate ecological citizenship and digital technologies can generate noticeable changes in how they understand community, environmental justice, and local political action. The same was observed in this study, where students, by taking ownership of their projects, became more consciously able to articulate the social, ethical, and environmental dimensions of the climate problem.

The construction of prompts and critical analysis of AI-generated responses allowed students to understand the limitations and potential of these tools. This practice involved reviewing responses, identifying inaccurate information, and collaboratively rewriting content, which required logical and argumentative reasoning.

Aeschbach *et al.* (2025) note that one of the most important factors contributing to the success of ECC is an active and reflective approach to content, with opportunities for dialogue and collective knowledge building. Validating responses against scientific criteria and subsequently revising them exemplifies how AI can be integrated critically in the school environment.

In the context of producing interdisciplinary projects, using AI helped enhance students' intellectual autonomy, enabling them to define objectives, justify their thematic choices, and plan intervention strategies based on data and references applicable to the local context.

3 FINAL CONSIDERATIONS

The pedagogical practice developed with ninth-grade students, integrating AI, Education for Climate Change (ECC), and the Interdisciplinary Didactic Sequence (IDS), proved to be an innovative and coherent proposal aligned with the principles of Critical Environmental Education (CEE). By combining solid theoretical references, participatory methodologies, and digital technologies, the experience fostered the development of multiple competencies, particularly related to critical thinking, student autonomy, and civic awareness in the face of contemporary environmental urgencies.

The results obtained throughout the process demonstrate that it is possible to integrate theory and practice in real teaching contexts, starting from curricular components not directly or intuitively linked to environmental issues, such as Educational Robotics.

The production of interdisciplinary projects supported by AI and the public sharing of proposals indicate that students understood the content and began mobilizing it to drive concrete transformations in their communities.

The pedagogical proposal also highlighted the importance of a curriculum that values student protagonism, teamwork, multimodal communication, and the ethical use of technologies. Digital resources were employed critically and creatively, not as ends in themselves but as means to promote reflection, dialogue, and transformative action. By appropriating these tools, students expanded their capacity for expression and intervention in the world.

Another relevant aspect was the appreciation of local knowledge and the environmental challenges experienced in students' realities. This connection between school and territory allowed for the re-signification of the curriculum, fostering a sense of belonging and collective responsibility. Topics such as urban effluents and climate change were addressed in a contextualized, interdisciplinary, and dialogical manner, contributing to the formation of active environmental citizenship.

The experience reaffirms the potential of critical, investigative, and technology-mediated educational practices as pathways toward building schools committed to socio-environmental justice and the formation of ethical, participatory, and historically aware individuals. The integration of scientific knowledge, social engagement, and pedagogical innovation is feasible even in challenging contexts, provided there is planning, intentionality, and openness to youth protagonism.

The observed impacts indicate that pedagogical practices grounded in ECC, aimed at promoting Climate Literacy and based on CEE principles, enhance the teaching-learning process and expand the formative horizon of public schools, connecting them to the major challenges of our time and strengthening their role as spaces for social transformation.

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DECLARATIONS

AUTHOR CONTRIBUTIONS

When describing each author's contribution to the manuscript, use the following criteria:

- **Study Conception and Design:** Author Valéria developed the central idea of the study and helped define the objectives and methodology.
- **Data Curation**: Author Daniele Araujo Canazart structured and wrote the article, while author Valéria organized, corrected, revised, and verified the data to ensure quality.
- **Formal Analysis**: Author Daniele applied the methodology described in class, and the data were analyzed by both authors, Daniele and Valéria.
- **Funding Acquisition**: Professor Daniele secured the financial resources necessary for the study.
- **Investigation**: Author Daniele conducted the data collection from students.
- **Methodology**: Professors Daniele and Valéria developed and adjusted the methodologies applied in the study.
- **Writing – Original Draft**: Author Daniele wrote the first version of the manuscript.
- **Writing – Review & Editing**: Author Valéria revised the text, improving clarity and coherence.
- **Review and Final Editing**: Author Daniele reviewed and adjusted the manuscript to ensure it meets the journal's standards.
- **Supervision**: Author Valéria coordinated the work and ensured the overall quality of the study.

CONFLICT OF INTEREST DECLARATION

We, **Valeria Regina and Daniele Araujo, declare that the manuscript entitled "Weavings and Potential of Climate Literacy, Educational Robotics, and Artificial Intelligence in Basic Education**":

1. **Financial Relationships:** We have no financial relationships that could influence the results or interpretation of this work. "No institution or funding entity was involved in the development of this study**".**
2. **Professional Relationships**: We have no professional relationships that could impact the analysis, interpretation, or presentation of the results. "No professional relationships relevant to the content of this manuscript were established".
3. **Personal Conflicts**: We have no personal conflicts of interest related to the content of the manuscript. "No personal conflicts related to the content were identified".