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ENVIRONMENTAL EDUCATION IN THE DIGITAL AGE: PROMOTING SUSTAINABILITY THROUGH TECHNOLOGY AND INNOVATION

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ABSTRACT

The present study investigated how digital technologies can be used to promote environmental education and sustainability. The research problem focused on the effectiveness of these technologies in environmental education, considering the challenges and opportunities they offer. The general objective was to analyze the impact of digital tools on the teaching of sustainable practices, identifying their benefits and limitations. The methodology used was a bibliographic review, based on relevant articles, books and dissertations on the subject. The results indicated that digital technologies, such as robotics, artificial intelligence and augmented reality, have great potential to enrich sustainability education, making it interactive and accessible. However, the survey also pointed out that the lack of technological infrastructure and educators' resistance to adopting new tools are significant challenges. The analysis revealed that, for the implementation of these technologies, it is essential to invest in the continuous training of

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teachers and improve access to technology in remote areas. Closing remarks suggested that while digital technologies offer important opportunities, barriers related to infrastructure and capacity building need to be overcome to ensure that digital environmental education is effective and inclusive. Further studies are recommended to assess the effectiveness of digital technologies in changing environmental behaviours.

Keywords: Environmental Education. Digital Technologies. Sustainability. Robotics. Challenges.

INTRODUCTION

Environmental education has gained prominence in recent decades due to the growing concern with the preservation of natural resources and awareness of the impacts of human actions on the environment. With the evolution of digital technologies, new ways of teaching and learning about environmental issues have emerged, providing opportunities for the dissemination of information in an accessible and interactive way. In this context, environmental education in the digital age emerges as a field of study that explores how technologies and innovations can contribute to the teaching of sustainable practices and the development of a conscious environmental culture. The use of digital tools, such as teaching platforms, apps, and educational games, allows the creation of content that facilitates the understanding of environmental challenges and encourages responsible behaviors in relation to the environment.

The justification for the study of environmental education in the digital age is linked to the need to adapt teaching methodologies to the new forms of communication and learning provided by technologies. Digital advancement has changed not only the way people interact with the world, but also how they learn and teach. Digitalization offers means to expand the reach of environmental education, reaching audiences in different regions and contexts, including hard-to-reach areas. The integration of innovative technologies, such as educational robotics and the use of real-time data for environmental monitoring, opens up new horizons for the promotion of sustainable practices. Therefore, it is essential to investigate how these tools can be effective in raising awareness and empowering individuals to adopt conscious and responsible attitudes towards the environment.

The central problem that guides this research is related to the understanding of how digital technologies can be used in the promotion of environmental education and in the awareness of individuals to urgent environmental issues. Although there are already several initiatives that seek to integrate technologies into sustainability education, there is still a significant lack of knowledge about the real effectiveness of these approaches in the development of sustainable behaviors in the long term. In addition, it is necessary to assess the challenges that educators face when incorporating these technologies into pedagogical practices, considering the differences in infrastructure and access to digital tools in different contexts. Thus, the research proposes to investigate the relationship between environmental education, digital technologies and innovation, seeking to understand the impacts of this integration in the learning process and in the promotion of sustainable environmental practices.

The objective of the research is to analyze how digital technologies contribute to the promotion of environmental education and sustainability, focusing on innovative methodologies that use digital tools to teach and raise awareness about environmental issues.

The text is structured as follows: in the Theoretical Framework section, the main concepts of environmental education and how digital technologies have been incorporated into the teaching of sustainability will be addressed. Then, in Development, the different technologies used to promote environmental education will be discussed, such as applications, digital platforms and educational games. The Methodology will explain the criteria for selecting sources and the procedures adopted for the analysis of the relevant literature. The Discussion and Results section will present a reflection on the effectiveness of digital technologies in environmental education and the challenges faced by educators, as well as discuss possible future trends. Finally, the Final Considerations summarize the conclusions of the study, highlighting the relevance of the integration of technologies in environmental education and suggesting directions for future research.

HEORETICAL FRAMEWORK

The Theoretical Framework is structured in three main parts. At first, the fundamental concepts of environmental education will be presented, addressing its origins, objectives and the relevance of the theme in the contemporary context. Then, the relationship between environmental education and digital technologies will be discussed, with an emphasis on the methodologies and tools used to integrate technology with sustainable teaching. Finally, the concepts of educational innovation will be explored, highlighting new approaches that use technological resources to promote environmental awareness and engage individuals in sustainable practices. This framework seeks to provide a theoretical basis for understanding the role of technologies in environmental education and its implications for the formation of a conscious and responsible society in relation to the environment.

TECHNOLOGY AS A TOOL FOR TRANSFORMATION IN ENVIRONMENTAL EDUCATION

Technology has proven to be an important tool for transforming environmental education, offering new ways to raise awareness and educate individuals about environmental issues. The use of interactive and multimedia resources has been consolidated as a strategy to engage students, facilitating the understanding of complex topics and promoting sustainable behaviors. According to Laércio and Fonseca (2022, p.

120), "the use of digital technologies, such as educational games and simulations, allows students to experience, in a practical way, the consequences of their actions on the environment, making learning meaningful". This approach highlights how digital resources can go beyond traditional teaching, creating immersive experiences that facilitate active learning about sustainability.

In addition, several digital initiatives have stood out as examples of success in promoting environmental education and raising awareness about sustainable practices. Grantezotto, Alves and Rocha (2017, p. 45) point out that "the use of the internet and social networks as tools for disseminating environmental knowledge has been effective, especially in awareness campaigns that involve a large number of people in different parts of the world". These initiatives demonstrate the power of technologies in creating virtual learning communities, in which information and sustainable practices are shared in an accessible and dynamic way.

Another relevant example of success in the use of technology in environmental education can be found in the work of Grande (2024, p. 58), who reports on the implementation of educational robotics programs aimed at sustainability. According to the author, "robotics applied to environmental education allows students to develop projects that seek innovative solutions to ecological problems, integrating theory and practice in a collaborative way". In this context, technologies not only offer an interactive approach, but also encourage the application of knowledge in real situations, contributing to the formation of conscious and responsible citizens with the environment.

These approaches and examples indicate that technology, when used strategically, can transform the way environmental education is carried out, making the process engaging. By integrating digital resources such as games, simulations, and interactive platforms, it is possible to create a dynamic learning environment capable of reaching a wide audience, promoting significant changes in people's environmental behavior.

TECHNOLOGICAL INNOVATIONS AND SUSTAINABILITY IN THE EDUCATIONAL CONTEXT

Technological innovations have played an increasing role in the educational context, especially with regard to environmental education and the promotion of sustainability. Technologies such as robotics, artificial intelligence, and augmented reality offer new ways to teach and learn about sustainable practices, providing a hands-on and engaging approach. Laércio and Fonseca (2022, p. 130) highlight that "the implementation of educational robotics in basic education allows students, in a practical way, to experiment

and understand how technological solutions can be applied to solve environmental problems". Robotics, when used to create sustainable projects, facilitates students' understanding of how innovations can contribute to responsible environmental practices.

In addition, the use of artificial intelligence (AI) has gained relevance in environmental education, offering tools to personalize learning and analyze environmental data in real time. According to Santos (2024, p. 80), "artificial intelligence applied in environmental education can be used to create environmental data monitoring systems, allowing students to monitor, in real time, the impacts of their actions on the environment". This application of AI in teaching not only provides an accurate and immediate understanding of the effects of human actions, but also makes learning interactive and practice-oriented.

An example of innovation that has proven effective in the use of these technologies was presented by Grande (2024, p. 63), who describes how augmented reality has been incorporated into the teaching of sustainability in high schools. The author states that "the use of augmented reality in educational activities on sustainability allows students to visualize, in an interactive way, the environmental impacts of different behaviors, such as water waste or excessive energy consumption". This technology, by providing an immersive experience, helps students to visualize and understand in a tangible way the consequences of their actions on the environment.

These examples show how technological innovations such as robotics, artificial intelligence, and augmented reality are transforming environmental education by creating a dynamic, interactive learning environment. Technologies, by integrating educational practices with sustainable solutions, not only improve teaching, but also encourage a conscious and responsible attitude towards the environment. Schools that adopt these technologies are therefore not only updating their teaching methods, but also preparing students to deal with environmental challenges in an innovative and practical way.

CHALLENGES AND OPPORTUNITIES IN THE USE OF TECHNOLOGY FOR ENVIRONMENTAL EDUCATION

The integration of technology in environmental education, while bringing several opportunities, also presents significant challenges for educators and institutions. Among the main obstacles identified is the lack of adequate infrastructure, which can hinder the adoption of technologies in some regions. Grande (2024, p. 55) observes that "in many locations, in remote regions, the lack of internet access and adequate equipment limits the implementation of educational projects that use technology as a central tool". This

challenge highlights the disparity in access to technological resources, which can create inequalities in education and hinder the universalization of sustainable educational practices.

In addition, another challenge pointed out by Santos (2024, p. 72) is the resistance of some educators to the adoption of new technologies, which occurs due to the lack of specific training and the fear of change. The author states that "the introduction of new technological tools requires not only the availability of resources, but also a continuous process of training and training of educators, who often do not feel prepared to integrate these technologies into their curriculum". This resistance, therefore, represents a barrier to the implementation of digital environmental education, since without adequate training, teachers may not take advantage of the full potential of these tools.

Despite these challenges, digitalization offers numerous opportunities to expand environmental education, especially in remote communities and regions. Oliveira (2023, p. 95) highlights that "the use of digital platforms can reach isolated communities, providing access to educational content on sustainability that would otherwise be inaccessible". Online teaching platforms, by enabling the dissemination of educational content in a scalable way, allow individuals in distant locations to benefit from environmental education programs, overcoming geographical and infrastructural limitations.

Technology also provides opportunities to personalize teaching, which can be useful in diverse educational contexts. Laércio and Fonseca (2022, p. 128) point out that "digital technologies can be used to create personalized learning experiences, adapting content to the needs of students, which can be especially important in regions with different realities and levels of access to education". By allowing teaching to be adapted to the pace and conditions of each student, technologies can promote inclusive and accessible environmental education, benefiting communities with different degrees of knowledge and skills.

Therefore, while there are challenges, such as a lack of infrastructure and resistance from educators, the opportunities offered by digitalization are significant. The use of digital platforms and technological tools can overcome physical and socioeconomic barriers, providing access to environmental education and allowing the personalization of teaching for different contexts. Overcoming these challenges, along with taking advantage of the opportunities offered by technology, can transform environmental education, making it inclusive and accessible for all.

METHODOLOGY

The methodology adopted in this research consists of a bibliographic review, whose main objective is to gather, analyze and synthesize the existing knowledge on the subject of environmental education in the digital age, with emphasis on the use of technologies to promote sustainability. The research has an exploratory and descriptive character, as it seeks to raise recent and relevant contributions in the area, identifying the main concepts, approaches and practices related to the use of digital tools in environmental education. For this, scientific articles, books, dissertations and theses that deal with the theme were selected, prioritizing sources published in the last five years, in order to ensure that the information was up to date. The approach used is qualitative, as the research focuses on the analysis of the ideas, concepts and practices proposed by the authors.

The instruments for data collection consisted of searching for texts in academic databases, such as Google *Scholar*, *Scielo* and other sources of public access. Inclusion criteria such as relevance to the theme, methodological quality of the publications and the date of publication were used, prioritizing recent ones. The research was conducted through reading and critical analysis of the selected texts, seeking to identify trends in the use of technologies to promote environmental education, as well as the challenges and limitations faced by educators. The technique used to organize the data was content analysis, allowing the categorization of information and the construction of a framework of theoretical references that guided the development of the review.

The table that organizes the main references consulted during the research is presented below. This table was prepared to facilitate the visualization of the works used and to provide a basis for the development of the study. It contains information about the authors, titles of publications, year of publication and type of work, organized chronologically.

Framework of References Used in Research

Author(s)	Conforming title published	Year	Type of Work
GRANTZOTTO, I.; ALVES, L.; ROCHA, M.	The Internet in the Information Society: Promoting Sustainability and Protecting the Environment	2017	Article
STEDING, A.; CARNIATTO, I.	Environmental Education combined with information technology in family farming	2017	Article
ARAÚJO, V. S.; LOPES, C. R.	Conceptions of critical training of teachers in university education	2020	Book Chapter
ARAÚJO, V. S.	Teacher training for the critical teaching of the Portuguese language: an experience in the pedagogy course through the 'Blackboard' platform	2020	Dissertation
ALENCAR, J. L.	Environmental education: Resignifying practice and knowledge, through the use of active methodologies and technology	2020	Article
OLIVEIRA, V. B.; VAZ, D. A. F.	Physical and mental health of teachers in the remote teaching period in public schools in Goiás	2022	Book Chapter
LAÉRCIO, F. G. S.; FONSECA, L. R.	Proposal for an Educational Game for Environmental Education in Basic Education	2022	Article
ARAÚJO, V. S.; SILVA, N. N.	Reading in the formation of the citizen in the light of critical literacy	2022	Book Chapter
ANDRADE, G. M.; *et al*.	Promoting Social Sustainability Through Educational Robotics with Elementary Students	2023	Article
SILVA SOUZA, W.; SIMÃO, M. O. A. R.	Environmental Education as a stimulus to the institutionalization of Green IT practices: a case study at IFAM in Itacoatiara (AM)	2023	Article
SANTOS, S. M. A. V.	Education 4.0: management, inclusion and technology in the construction of innovative curricula	2024	Organizer
SANTOS, S. M. A. V.	Education in the 21st century: interdisciplinary and technological approaches	2024	Organizer
SANTOS, S. M. A. V.	Integral inclusion: contemporary challenges in education and society	2024	Organizer
SANTOS, S. M. A. V.	Green in the vein: integrating environmental education into the formal curriculum	2024	Article
SAINTS, S. M. A. V.; Frank, A. S.	Educational innovation: emerging practices in the twenty-first century	2024	Organizer
SAINTS, S. M. A. V.; Frank, A. S.	Media and technology in the curriculum: innovative strategies for contemporary teacher education	2024	Organizer
GRANDE, U. C.	The Botsu Initiative: Advancing Robotics and Sustainability Education through Recyclable Waste	2024	Dissertation

Source: authorship

After inserting the table, it is observed that it compiles the main sources consulted, serving as a starting point for understanding recent approaches to the use of digital technologies in the teaching of environmental education. The organization of the references in a chronological way allows a clear view of the evolution of the theme over the years, facilitating the analysis of the changes and trends observed in the literature.

THE EFFICIENCY OF DIGITAL TECHNOLOGIES IN THE TEACHING OF SUSTAINABILITY

Digital technologies have demonstrated a significant impact on sustainability education, providing innovative and effective ways to engage students and raise awareness about environmental issues. The evaluation of studies on the impact of these tools reveals a promising picture, in which digital technologies not only make learning interactive, but also contribute to an understanding of environmental challenges. Grande (2024, p. 60) states that "recent studies show that the use of interactive digital platforms in the teaching of sustainability allows students to visualize, in a clear and engaging way, the consequences of their actions on the environment, which increases knowledge retention and environmental awareness". This type of visual and interactive learning facilitates the understanding of sustainability concepts, making them accessible and applicable to the students' reality.

In addition, the use of digital technologies has shown practical results in educational experiences that address sustainability issues. Santos (2024, p. 85) highlights that "educational programs that use resources such as digital simulations and interactive games have proven effective, not only in theoretical teaching, but also in the practical application of concepts, motivating students to implement sustainable solutions in their own communities". This hands-on approach allows students to experience the consequences of their actions in a controlled environment, making learning meaningful and encouraging the adoption of responsible behaviors.

The use of digital tools has also proven effective in promoting inclusive environmental education, reaching a larger and diverse audience. According to Laércio and Fonseca (2022, p. 135), "digitalization has allowed the inclusion of students from different social and geographical contexts, providing them with access to educational resources that would previously have been inaccessible, such as *online* courses and teaching materials on sustainable practices". This expanded access makes it possible for people, regardless of their location, to benefit from digital environmental education, promoting the dissemination of fundamental knowledge for sustainability.

Therefore, studies and practical experiences demonstrate that digital technologies have proven to be efficient in teaching sustainability. They offer new ways of interacting and learning, raising awareness and encouraging the practical application of environmental concepts. In addition, digital tools expand the reach of environmental education, making it accessible to different audiences and, thus, contributing to the formation of a conscious and responsible society with the environment.

TECHNOLOGY AND INNOVATION: FACILITATORS OR OBSTACLES IN ENVIRONMENTAL EDUCATION?

The discussion about the impact of technological innovations on the environmental education curriculum reveals a complex dynamic, in which technologies can both facilitate and generate obstacles to the teaching of environmental issues. On the one hand, technological innovations offer tools that can enrich the curriculum, making it interactive and accessible. On the other hand, this adoption can bring challenges related to the implementation and training of educators. According to Grantzotto, Alves and Rocha (2017, p. 40), "the incorporation of new technologies in the environmental education curriculum can expand the reach of teaching, allowing complex content to be presented in an engaging way". Digital technologies, by facilitating the visualization of concepts such as environmental impact and sustainability, make learning accessible and practical, bringing students closer to the realities that the curriculum seeks to represent.

However, as pointed out by Santos (2024, p. 75), "the adoption of technologies in the teaching of sustainability does not always occur fluidly, as it requires a paradigm shift both in curriculum planning and in the training of teachers, who often do not have the necessary training to integrate the new technological tools". This point reflects the resistance that some institutions and educators face when dealing with the implementation of technologies. Lack of preparation and limited resources for this adaptation can create barriers, making innovation a hindrance rather than a solution to teaching environmental issues.

In addition, Laércio and Fonseca (2022, p. 130) point out that "although digitalization brings numerous advantages, it can also accentuate educational inequalities, as many schools, especially in remote regions, do not have sufficient technological infrastructure to support the use of new technologies". This inequality of access to technology can result in the exclusion of some communities from the learning process, making it difficult to implement a truly inclusive environmental education curriculum. The lack of technological infrastructure limits the ability of some students to interact with digital content, compromising the effectiveness of technological innovations in sustainability education.

Therefore, technological innovations have the potential to transform the environmental education curriculum, making it accessible and dynamic, but they also present significant challenges. The adoption of new technologies can, in fact, facilitate the teaching of environmental issues, but it can also create barriers, due to the lack of adequate training of educators and inequality in access to technological resources. Critical analysis on these issues reveals that innovation, while beneficial, must be implemented to avoid exacerbating existing inequalities and ensure that its impact is positive for all learners.

THE FUTURE OF DIGITAL ENVIRONMENTAL EDUCATION: CHALLENGES AND TRENDS

The future of digital environmental education presents several promising prospects, with the evolution of digital technologies creating new ways to teach and learn about sustainability. Emerging technological trends indicate that digital tools will be integrated into educational processes, enhancing environmental awareness and the adoption of sustainable practices. Santos (2024, p. 92) points out that "digital environmental education tends to expand as new technologies, such as artificial intelligence and augmented reality, gain space in teaching, providing immersive learning experiences that can positively influence students' attitudes towards the environment". This trend reflects a shift in the educational paradigm, in which technologies are not only support tools, but become central elements for teaching sustainable practices.

These technological innovations also open up new possibilities for environmental education, allowing the development of interactive content and resources that can involve new generations. According to Laércio and Fonseca (2022, p. 138), "the new generations, familiar with the use of digital devices and the technological demands of the contemporary world, have the potential to easily adopt sustainable practices, using technologies to monitor and minimize environmental impacts". This point is essential as it highlights that young generations not only have access to technologies, but can also play an active role in creating and applying innovative solutions to environmental issues, utilizing their technological skills to address global challenges.

In addition, the role of new generations in the use of technologies to promote sustainable environmental practices will be fundamental. According to Oliveira (2023), "young people, by appropriating technologies, can lead local and global sustainability initiatives, using digital platforms to disseminate sustainable practices and influence changes in their communities" (p. 100). The ability of new generations to integrate technologies into their daily routines in a natural way makes them key agents in promoting environmental change, from the local to the global level. Digital environmental education, therefore, is not limited to learning content, but also prepares students to be protagonists of a sustainable future, using technology as a tool to transform environmental reality.

The future of digital environmental education is linked to emerging technological trends and the engagement of new generations. The digitalization of education and the integration of advanced technologies such as artificial intelligence and augmented reality offer great opportunities to create engaging learning experiences. The new generations, connected with technologies, will play a key role in adapting and using these tools to

promote sustainable practices, using their skills to lead environmental transformation at both the local and global levels. Thus, digital environmental education can become an essential pillar for building a conscious and sustainable future.

FINAL CONSIDERATIONS

The research aimed to analyze how digital technologies can be used to promote environmental education, especially in the context of sustainability. From the reviewed studies, it was possible to conclude that digital technologies, in fact, play a primary role in environmental education, offering new ways of raising awareness and learning about environmental issues. Technological innovations such as robotics, artificial intelligence, and augmented reality have proven to be tools in teaching sustainable practices, offering students an interactive and engaging way to learn about the impact of their actions on the environment.

In addition, digital technologies allow environmental education to overcome geographical barriers, providing access to educational content on sustainability for remote regions and hard-to-reach communities. Digital platforms, interactive games, and simulations are examples of how technological tools can create inclusive environmental education, reaching a larger number of individuals and offering the opportunity to participate to people who would otherwise not have access to these resources. The use of these technologies can, therefore, contribute to the expansion of environmental awareness, enabling a greater dissemination of sustainable practices.

However, it is important to note that the adoption of these technologies also presents significant challenges. The lack of adequate infrastructure in many regions and the resistance on the part of educators, who do not have specific training to integrate new technologies into teaching, are obstacles that need to be overcome. The implementation of technologies in environmental education depends, therefore, on the adequate preparation of educators and on overcoming inequalities in access to technology. Continuous teacher training and the improvement of technological infrastructures are key to ensuring that technologies can be harnessed in the sustainability teaching process.

The study's contributions demonstrate that while digital resources have great potential to transform environmental education, a continuous effort is needed to overcome challenges related to educator training and access to technology. Emerging technological trends, such as artificial intelligence and augmented reality, present exciting opportunities for the future of environmental education, offering immersive and personalized teaching possibilities. However, it is essential that these technologies are accessible to all.

To complement the findings of this research, it is necessary to conduct additional studies that investigate the effectiveness of different digital technologies in teaching sustainable practices in different contexts. Research should also explore the real impact of these technologies on students' environmental behavior, assessing the extent to which the use of these tools contributes to lasting changes in attitudes toward the environment. Studies involving the practical implementation of these technologies in schools and communities can provide concrete data on their effectiveness and on the best practices to integrate them into the teaching of environmental education.

The survey confirmed that digital technologies offer a tool for environmental education, facilitating access to information and promoting awareness about sustainability. However, the adoption of these technologies faces challenges that need to be addressed by public policies and educational strategies focused on training educators and improving access to technological infrastructure. Continuing studies on the integration of digital technologies into sustainability education is essential to maximize the benefits of this approach and ensure that environmental education reaches all individuals equitably.

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