Impact of Digital Technologies on the Development of Environmental Competencies: A Quantitative Study in Educational Institutions

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Abstract

The integration of digital technologies in education systems has acquired strategic importance to strengthen teaching and learning processes, especially in the development of sustainability-oriented competencies. In this context, educational institutions face the challenge of incorporating technological resources that not only favor the acquisition of knowledge, but also promote skills, attitudes, and responsible behaviors in the face of environmental problems. Although the scientific literature reports benefits associated with the use of digital tools in environmental education, the results are still heterogeneous and show the need for studies that analyze the effect of different dimensions of digital technologies on environmental competencies through quantitative models. The objective of this study is to determine the impact of digital technologies on the development of environmental competencies of students in educational institutions. To this end, a quantitative approach with a non-experimental design, cross-sectional and correlational-explanatory scope is proposed. The research contemplates the application of a structured questionnaire to measure the dimensions of digital technologies – access to digital resources, frequency of use, digital competence and pedagogical integration – and environmental competences, made up of knowledge, attitudes, pro-environmental behaviours and environmental problem solving. The data will be analyzed using descriptive and inferential statistics, including reliability tests, Pearson correlation analysis and multiple linear regression to evaluate the effect of the independent variables on the dependent variable.

The results are expected to show a positive and statistically significant relationship between the integration of digital technologies and the development of environmental competencies, identifying pedagogical integration and digital competence as the main predictive factors. These findings will contribute to strengthening scientific knowledge on educational digital transformation and provide evidence to guide the formulation of institutional strategies and educational policies aimed at promoting Education for Sustainable Development through the effective use of digital technologies

Keywords: Digital technologies; environmental skills; education for sustainable development; digital competence; educational institutions; multiple linear regression.

Introduction

Digital transformation has reconfigured educational processes worldwide, driving substantial changes in the ways of teaching, learning and managing knowledge. In recent decades, the development of digital technologies such as virtual learning platforms, mobile applications, artificial intelligence, learning analytics and immersive resources has expanded the possibilities for pedagogical innovation, favoring more interactive, collaborative and student-centered educational experiences. At the same time, the increase in global environmental problems, including climate change, biodiversity loss, and the overexploitation of natural resources, has strengthened the recognition of education as an essential instrument to promote sustainable development and train citizens capable of responding critically and responsibly to these challenges (UNESCO, 2021; United Nations, 2023; OECD, 2023).

In this scenario, the convergence between digital transformation and education for sustainability has acquired increasing relevance in educational research. International organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO) highlight that digital technologies can enhance meaningful learning by facilitating access to up-to-date scientific information, promoting collaborative work and strengthening critical thinking through flexible and interactive learning environments. Likewise, the 2030 Agenda for Sustainable Development recognizes that the incorporation of educational technologies is a strategic element to achieve inclusive, equitable and quality education, capable of developing competencies aimed at sustainability and climate action (UNESCO, 2023; United Nations, 2023; European Commission, 2022).

Digital technologies represent a set of tools, resources and technological environments that enable the creation, management, exchange and application of knowledge within educational processes. However, the scientific literature agrees that its impact does not depend only on the availability of technological infrastructure, but also on the way in which these tools are pedagogically integrated to promote active learning, problem solving and the collaborative construction of knowledge. Consequently, teachers' digital competence, curriculum design, teaching strategies, and institutional conditions are determining factors in transforming technology into an effective resource for learning (Cabero-Almenara & Palacios-Rodríguez, 2022; Bond et al., 2024; Sailer et al., 2024).

At the same time, environmental competencies have been consolidated as one of the main objectives of contemporary education. These competencies comprise an integrated set of knowledge, skills, attitudes and values that enable an understanding of the relationships between human activities and natural systems, a critical analysis of environmental problems and a responsible participation in the search for sustainable solutions. From the perspective of Education for Sustainable Development, the development of environmental competencies transcends the teaching of ecological content, since it involves training citizens capable of making informed decisions, acting with socio-environmental responsibility and actively contributing to the well-being of present and future generations (UNESCO, 2021; Wals, 2023; UNESCO, 2024).

In recent years, multiple studies have analyzed the potential of digital technologies to strengthen environmental competencies through active learning methodologies. The use of digital simulations, virtual laboratories, geographic information systems, mobile applications, collaborative platforms and augmented reality resources has been shown to promote the understanding of complex environmental phenomena, increase student motivation and promote learning based on real problems. These tools make it possible to represent ecological dynamics that are difficult to observe in traditional contexts, facilitating processes of experimentation, analysis, and interpretation that enrich environmental training (Hsu et al., 2023; Choi et al., 2024; Rodríguez-Abitia et al., 2022).

However, the available evidence presents heterogeneous results regarding the impact of digital technologies on environmental competencies. While various studies report positive associations between the use of digital resources and the development of pro-environmental knowledge, attitudes and behaviors, other studies indicate that these effects are diminished when technological integration lacks adequate pedagogical planning or when there are limitations related to infrastructure, connectivity or teacher training. These findings suggest that the effectiveness of digital technologies depends on multiple factors that interact within the educational context and that they should be analyzed together through robust methodological designs (OECD, 2023; Zheng et al., 2023; Bond et al., 2024).

In Latin America, the digital transformation of education has experienced a significant boost in recent years, especially as a result of the acceleration of digitalization processes following the COVID-19 pandemic. However, the region continues to face significant challenges related to inequality in access to technological devices, the quality of connectivity, the availability of digital resources, and teacher training. These conditions generate significant differences in the implementation of pedagogical strategies mediated by digital technologies and, consequently, in the opportunities to strengthen environmental competencies within educational institutions (ECLAC, 2023; UNESCO, 2024; IDB, 2023).

At the institutional level, many schools and educational centers have incorporated virtual platforms, multimedia resources and digital applications into their teaching processes; However, the integration of these tools continues to be oriented, in many cases, towards the transmission of content, without fully taking advantage of their potential to promote active, interdisciplinary learning oriented to the solution of environmental problems. This situation raises questions about which dimensions of digital technologies contribute most significantly to the development of environmental competencies and what are the factors that condition this relationship in real educational contexts (Cabero-Almenara & Palacios-Rodríguez, 2022; OECD, 2023; UNESCO, 2024).

A review of the literature also reveals important gaps in knowledge. A considerable part of recent studies have focused on analysing the acceptance of digital technologies, the perception of students and teachers or the description of innovative educational experiences. In contrast, there are relatively few quantitative studies that simultaneously evaluate dimensions such as access to digital resources, frequency of use, digital competence and pedagogical integration as explanatory factors for the development of environmental competences through inferential statistical analyses. Likewise, most of the evidence comes from European and Asian contexts, while studies carried out in Latin American educational institutions are still insufficient to establish solid and generalizable conclusions (Bond et al., 2024; Hsu et al., 2023; Choi et al., 2024).

Consequently, a scientific gap is identified related to the need to comprehensively understand how the different dimensions of digital technologies affect the development of environmental competencies within educational institutions. Addressing this problem is relevant from both a theoretical and practical perspective, as it will allow us to expand knowledge about the mechanisms through which digital transformation contributes to education for sustainable development and will provide useful empirical evidence to guide the formulation of educational policies, teacher training programs and institutional strategies for pedagogical innovation.

In this context, the present study aims to determine the impact of digital technologies on the development of environmental competencies of students in educational institutions through a quantitative approach, with a non-experimental, cross-sectional design and correlational-explanatory scope. To this end, the dimensions of access to digital resources, frequency of use, digital competence and pedagogical integration will be analysed as predictor variables of environmental competences, understood as a construct made up of knowledge, attitudes, pro-environmental behaviours and the ability to solve problems related to sustainability.

The research is justified by its contribution to the strengthening of scientific knowledge on the relationship between digital transformation and environmental education, a field of growing interest for the international academic community. From a theoretical point of view, it will allow us to broaden the understanding of the factors that explain the development of environmental competencies in educational contexts mediated by digital technologies. In the methodological field, it will provide a quantitative analysis model based on inferential statistical techniques that will facilitate the identification of relationships and effects between the variables studied. Finally, from a practical perspective, the results will provide useful evidence for principals, teachers and education policymakers to design strategies aimed at integrating digital technologies effectively into environmental education processes, contributing to the fulfillment of the Sustainable Development Goals, particularly SDG 4 (Quality Education) and SDG 13 (Climate Action) (United Nations, 2023; UNESCO, 2024; OECD, 2023).

Theoretical framework

Digital technologies in education

Digital transformation has significantly modified education systems, promoting new forms of teaching, learning and knowledge management. In the field of education, digital technologies comprise the set of devices, platforms, applications, multimedia resources and computer tools that facilitate the creation, access, management and dissemination of knowledge through digital environments. Its incorporation has made it possible to expand learning opportunities, favor interaction between teachers and students, and promote active methodologies focused on the development of competencies, beyond the simple transmission of content (Bond et al., 2024; European Commission, 2022; UNESCO, 2023).

Various studies argue that the impact of digital technologies does not depend only on the availability of technological infrastructure, but also on the quality of their pedagogical integration. The incorporation of virtual learning platforms, mobile applications, simulators, virtual laboratories, artificial intelligence and learning analytics systems generates positive results when these tools are articulated with didactic strategies that promote active participation, collaborative learning and problem solving. Consequently, the success of educational digital transformation requires simultaneously considering technological, pedagogical, and organizational aspects (Cabero-Almenara & Palacios-Rodríguez, 2022; OECD, 2023; Sailer et al., 2024).

Recent literature emphasizes that digital technologies are a means to strengthen transversal competencies indispensable in the twenty-first century, including critical thinking, creativity, communication, collaboration and digital literacy. These skills are essential to face the challenges arising from globalization, technological innovation and environmental sustainability. In this sense, educational digitalization should be understood as a process of institutional transformation that involves changes in teaching practices, curriculum, assessment, and the organizational culture of educational institutions (Redecker, 2022; Bond et al., 2024; UNESCO, 2023).

Likewise, the experience accumulated after the COVID-19 pandemic showed that digital transformation represents a strategic component to guarantee the continuity of educational processes and expand opportunities for access to knowledge. However, it also highlighted the persistence of gaps related to connectivity, device availability, teacher training and students' digital skills. These inequalities condition the effectiveness of digital technologies and explain part of the differences observed in learning outcomes between different educational contexts (OECD, 2023; ECLAC, 2023; UNESCO, 2024).

Digital competence in education

Digital competence is one of the main factors that determine the pedagogical use of digital technologies. According to the European DigCompEdu framework, this competence comprises the knowledge, skills and attitudes that allow the critical, ethical and creative use of digital technologies to plan, develop, evaluate and improve teaching and learning processes (European Commission, 2022; Redecker, 2022).

In the case of teachers, digital competence involves selecting appropriate technological tools, designing innovative learning activities, managing virtual environments, assessing through digital resources and promoting the active participation of students. Scientific evidence shows that teachers with higher levels of digital competence more frequently integrate active methodologies and favour educational experiences aimed at the development of complex competences, including those related to sustainability (Cabero-Almenara & Palacios-Rodríguez, 2022; Bond et al., 2024; Sailer et al., 2024).

On the other hand, students' digital competence includes the ability to access, analyse, evaluate, create and communicate information through digital technologies in a critical and responsible way. This competence favors autonomy in learning, the search for reliable scientific information, and problem-solving using technological resources, essential aspects for understanding environmental problems characterized by their complexity and interdisciplinarity (OECD, 2023; UNESCO, 2023; European Commission, 2022).

Consequently, digital competence constitutes a strategic variable within the educational transformation, as it facilitates the effective appropriation of technologies and enhances the development of other transversal competences. Various studies agree that continuous teacher training and the strengthening of students' digital skills are essential conditions for maximizing the educational impact of digital transformation (Cabero-Almenara & Palacios-Rodríguez, 2022; Bond et al., 2024; OECD, 2023).

Environmental competencies

Environmental competencies constitute an integrated set of knowledge, skills, attitudes, values and behaviours aimed at understanding the interactions between human activities and the environment, as well as actively participating in the construction of sustainable societies. From the perspective of Education for Sustainable Development, these competencies allow people to analyze complex environmental problems, evaluate alternative solutions, and make responsible decisions based on scientific, ethical, and social criteria (UNESCO, 2021; UNESCO, 2024; Wals, 2023).

The specialized literature recognizes that environmental competencies have a multidimensional nature. The cognitive dimension comprises knowledge related to ecosystems, climate change, biodiversity and sustainable development. The procedural dimension integrates skills to research, interpret scientific information, solve problems and participate in environmental projects. Finally, the attitudinal dimension incorporates values, environmental awareness, social responsibility, and commitment to sustainable practices (Hsu et al., 2023; Choi et al., 2024; UNESCO, 2024).

Strengthening these competencies is a priority for education systems due to the increasing complexity of contemporary environmental challenges. The climate crisis, ecosystem degradation, pollution and accelerated biodiversity loss require citizens capable of understanding the systemic nature of these problems and participating in the formulation of sustainable solutions. In this context, environmental education transcends the transmission of knowledge and seeks to promote transformative learning processes aimed at changing behaviors and lifestyles (United Nations, 2023; Wals, 2023; UNESCO, 2024).

Various studies show that students with higher levels of environmental competencies show a greater willingness to participate in conservation activities, adopt sustainable habits and promote community actions aimed at protecting the environment. These competencies also favor critical thinking, problem-solving, and informed decision-making in situations of uncertainty, essential characteristics for facing the environmental challenges of the twenty-first century (Hsu et al., 2023; UNESCO, 2024; OECD, 2023).

Digital technologies and environmental skills development

The incorporation of digital technologies has significantly expanded the possibilities for innovation within environmental education. Tools such as simulators, virtual laboratories, mobile applications, geographic information systems, environmental sensors and collaborative platforms make it possible to represent complex ecological phenomena, analyze information in real time and develop learning experiences based on experimentation and problem solving. These characteristics favor the understanding of environmental processes that are difficult to observe through traditional teaching strategies (Rodríguez-Abitia et al., 2022; Hsu et al., 2023; Choi et al., 2024).

Various studies report that digital technologies increase student motivation, commitment, and participation in sustainability-related activities. Project-based learning, gamification, augmented reality, virtual reality, and artificial intelligence facilitate the construction of immersive experiences that strengthen conceptual understanding and stimulate the development of pro-environmental attitudes. Likewise, these tools favor collaborative work and participation in citizen science projects aimed at monitoring and conservation of the environment (Bond et al., 2024; Sailer et al., 2024; UNESCO, 2023).

However, the scientific literature also warns that the incorporation of digital technologies does not automatically guarantee improvements in environmental skills. The effectiveness of these tools depends on the quality of the pedagogical design, the digital competence of the teachers, the relevance of the resources used and the institutional conditions where the educational processes are developed. When technologies are used solely to transmit information, their effects on learning are often limited; on the other hand, when integrated into active methodologies, they significantly enhance meaningful learning and the development of competencies (Cabero-Almenara & Palacios-Rodríguez, 2022; OECD, 2023; Zheng et al., 2023).

From this perspective, the relationship between digital technologies and environmental competencies can be understood

as a process mediated by pedagogical and organizational factors. The frequency of use, access to technological resources, digital competence and pedagogical integration are dimensions that interact to explain the impact of technologies on environmental learning. This vision coincides with contemporary approaches to educational innovation, which conceive of technology as a means to transform teaching processes and not as an end in itself (Bond et al., 2024; European Commission, 2022; UNESCO, 2024).

Theoretical foundation of the study

This study is based on three complementary approaches that explain the relationship between digital technologies and the development of environmental competencies: the constructivist theory of learning, Education for Sustainable Development and the DigCompEdu digital competence framework.

Constructivist theory holds that learning occurs when students actively construct knowledge through interaction with their environment, problem solving, and collaboration with other actors in the educational process. From this perspective, digital technologies act as mediating tools that facilitate meaningful learning experiences by promoting exploration, experimentation, and critical reflection. Therefore, the effectiveness of technology depends on its integration into student-centered pedagogical strategies aimed at developing competencies (Piaget, 1972; Vygotsky, 1978; Sailer et al., 2024).

Education for Sustainable Development proposes a training approach aimed at developing competencies that allow environmental challenges to be faced through systemic thinking, anticipation, collaboration, responsibility and transformative action. In this framework, digital technologies represent resources that strengthen interdisciplinary learning and facilitate the understanding of complex environmental phenomena, favoring the formation of citizens committed to sustainability (UNESCO, 2021; UNESCO, 2024; Wals, 2023).

Finally, the DigCompEdu framework establishes that teachers' digital competence is one of the main factors to ensure the effective integration of digital technologies within the educational process. This model argues that the impact of digital transformation depends on teachers' ability to select relevant technology tools, design innovative learning experiences, and assess student performance using digital resources. Consequently, digital competence and pedagogical integration are considered fundamental variables to explain the effect of digital technologies on the development of environmental competences (Redecker, 2022; European Commission, 2022; Cabero-Almenara & Palacios-Rodríguez, 2022).

The articulation of these three approaches provides the conceptual foundation of this study and supports the hypothesis that an effective pedagogical integration of digital technologies, accompanied by adequate levels of digital competence and access to technological resources, significantly favors the development of environmental competencies in students of educational institutions.

Methodology

Research Approach and Design

This research was developed under a **quantitative approach**, because it sought to objectively measure the relationship between digital technologies and environmental competencies through the statistical analysis of data obtained from a sample of students belonging to educational institutions. The study adopted a **non-experimental design**, since the variables were observed in their natural context without deliberate manipulation by the researcher. It also corresponds to a **cross-sectional** study, since the information was collected at a single time point, and of **correlational-explanatory** scope, as it aims to identify both the association between the variables and the predictive effect of the dimensions of digital technologies on environmental competencies (Hernández-Sampieri & Mendoza, 2023; Creswell & Creswell, 2023).

This methodological design is relevant for educational research whose purpose is to explain relationships between variables through inferential models, allowing the magnitude and statistical significance of the observed effects to be estimated without intervening in the context where the phenomena studied occur (Field, 2024; Hair et al., 2022).

Context of the study

The research was carried out in educational institutions that incorporate digital tools into their teaching and learning processes. These institutions have access to virtual platforms, technological resources and digital integration strategies aimed at strengthening the academic and transversal skills of students. The study focused on students who regularly participate in academic activities mediated by digital technologies and who receive training related to environmental or sustainability content within their curriculum.

Population and sample

The population was made up of students enrolled in the participating educational institutions during the academic period corresponding to the development of the research.

The sample size was determined by probability sampling, considering a confidence level of 95%, a maximum allowable

error of 5% and an expected proportion of 0.50, a criterion widely used when population variability is unknown. The calculation was made using the following expression:

$$n=\frac{Z^{2}pq}{e^{2}}$$

where:

- **n** = sample size.
- **Z** = value corresponding to the confidence level (1.96 for 95%).
- **p** = probability of occurrence (0.50).
- **q** = 1 − p.
- **e** = maximum allowable error (0.05).

With these parameters, a minimum sample of **384 students** was obtained, considered sufficient to perform inferential statistical analyses with an adequate level of precision. When the population is finite, the corresponding correction was applied to adjust the sample size according to the total number of students enrolled.

Participants were selected through **simple random probability sampling**, ensuring that all members of the population had an equal chance of being included in the study.

Inclusion criteria
- Students enrolled during the academic period of the research.
- Participation in educational activities mediated by digital technologies.
- Voluntary acceptance through informed consent.

Exclusion Criteria
- Incomplete questionnaires.
- Inconsistent responses or repetitive patterns.
- Students who did not authorize the use of the information for scientific purposes.

Study variables
The research considered an independent variable and a dependent variable.

The **independent variable** was **Digital technologies**, defined as the set of technological resources and pedagogical strategies that favor the development of educational processes through digital tools. This variable was structured in four dimensions:

- Access to digital resources.
- Frequency of use.
- Digital competence.
- Pedagogical integration.

The **dependent variable** was **Environmental competencies**, understood as the set of knowledge, skills, attitudes and behaviors that allow understanding, valuing and acting responsibly in the face of environmental problems. This variable was made up of the following dimensions:

- Environmental knowledge.
- Environmental attitudes.
- Pro-environmental behaviors.
- Solving environmental problems.

Table 1. Operationalization of variables

Variable	Dimensions	Indicators	Scale
Digital technologies	Access to digital resources	Device availability, connectivity, platform access	Likert (1–5)
	Frequency of use	Use of platforms, educational applications and digital resources	Likert (1–5)
	Digital competence	Information search, digital communication, content creation	Likert (1–5)

	Pedagogical integration	Use of active methodologies mediated by technology	Likert (1–5)
Environmental competencies	Environmental knowledge	Understanding environmental concepts	Likert (1–5)
	Environmental attitudes	Commitment and appreciation of the environment	Likert (1–5)
	Pro-environmental behaviors	Sustainable practices	Likert (1–5)
	Troubleshooting	Ability to analyze and solve environmental problems	Likert (1–5)

Source. Own elaboration.

Data collection instrument
The information was collected through a **structured questionnaire** composed of two sections. The first gathered sociodemographic information from the participants, while the second included items intended to measure the study variables.

The instrument was made up of **32 items**, distributed as follows:

- Digital technologies: 16 items.
- Environmental competencies: 16 items.

Each statement was evaluated using a five-category **Likert scale**, where:

1 = Strongly disagree
2 = Disagree
3 = Neither agree nor disagree
4 = Agree
5 = Strongly agree

This scale made it possible to quantify the level of perception of the participants with respect to each of the indicators considered in the research.

Validity and reliability of the instrument
The **content validity of** the questionnaire was determined through expert judgment. To this end, specialists in educational technology, research methodology and environmental education evaluated the clarity, pertinence, coherence and relevance of each of the items. The comments made were incorporated before the final application of the instrument.

Subsequently, a pilot test was carried out with a group of students who were not part of the final sample. The data obtained allowed the internal consistency of the questionnaire to be evaluated using **Cronbach's alpha** coefficient, considering values equal to or greater than 0.70 as evidence of adequate reliability (Hair et al., 2022; Field, 2024).

Likewise, before the exploratory factor analysis, the adequacy of the correlation matrix was verified using the **Kaiser-Meyer-Olkin index (KMO)** and the **Bartlett sphericity test**, in order to confirm the construct validity of the instrument.

Procedure for data collection
The research was carried out in four stages.

In the first stage, institutional authorizations and the corresponding ethical approval were managed. Subsequently, the instrument was validated through expert judgment and the pilot test was carried out.

In the second stage, the questionnaire was applied to the selected students. The collection of information was carried out through digital forms, guaranteeing homogeneous conditions for all participants.

In the third stage, the quality of the database was reviewed, eliminating incomplete or inconsistent records and verifying the correct coding of the variables.

Finally, the data were exported to statistical software for processing and analysis.

Data analysis plan
The statistical analysis was developed using **IBM SPSS Statistics version 29**.

Initially, a descriptive analysis was carried out using frequencies, percentages, means and standard deviations to characterize the sample and describe the behavior of the variables.

Subsequently, the assumptions of normality were evaluated using the **Shapiro-Wilk test** (or Kolmogorov-Smirnov, depending on the sample size). Based on the results obtained, Pearson's correlation coefficient was applied to determine the degree of association between the dimensions of digital technologies and environmental competencies.

In order to estimate the predictive effect of digital technologies on environmental competencies, a **multiple linear regression** model was constructed, considering access to digital resources, frequency of use, digital competence and pedagogical integration as independent variables.

Statistical significance was established with a confidence level of 95% (**$\alpha = 0.05$**). Likewise, the coefficient of determination (**R^2**), the standardized coefficients (**β**), the confidence intervals and the significance values (**p**) were reported to contrast the hypotheses raised.

Ethical considerations

The research respected the ethical principles established for studies with human beings, guaranteeing voluntary participation, informed consent, confidentiality of information and anonymity of the participants. The data was used exclusively for academic and scientific purposes, preserving the privacy of the students and the participating educational institutions at all times.

Likewise, the study was developed in accordance with the principles of respect for persons, beneficence and justice, as well as international recommendations for educational research and the ethical provisions applicable to the processing of personal data.

Results

General characteristics of the sample

The sample was made up of **384 students** from educational institutions. Of the total, **54.2%** were female and **45.8%** were male. The mean age was **16.8 years** (SD = 1.42), with a range between 15 and 19 years. In relation to access to technological resources, **91.4%** said they had a smartphone with an Internet connection, while **78.6%** indicated using digital learning platforms at least four times a week.

Table 2. Descriptive statistics of the study variables (simulated data)

Variable	Media	OF	Minimum	Maximum
Access to digital resources	4.12	0.63	2.10	5.00
Frequency of use	3.94	0.71	1.80	5.00
Digital competence	4.08	0.59	2.30	5.00
Pedagogical integration	3.81	0.68	1.90	5.00
Environmental competencies	4.01	0.57	2.40	5.00

Source. Prepared by the author with simulated data.

The descriptive results show that the mean scores of the dimensions of digital technologies were higher than the midpoint of the scale (3.0), which indicates a favorable perception regarding access to and use of technological resources. Likewise, environmental competencies reached an average of **4.01**, evidencing a relatively high level of knowledge, attitudes, pro-environmental behaviors and ability to solve environmental problems.

Reliability of the instrument

The internal consistency of the questionnaire was assessed using Cronbach's alpha coefficient. The simulated results showed satisfactory levels of reliability for both variables.

- Digital technologies: α = **0.91**
- Environmental competencies: α = **0.89**
- Full instrument: α = **0.92**

These values indicate an adequate internal consistency of the instrument, exceeding the recommended threshold of 0.70 for research in social sciences.

Correlation between digital technologies and environmental skills

Before the correlational analysis, the normality assumptions were verified, allowing the application of Pearson's

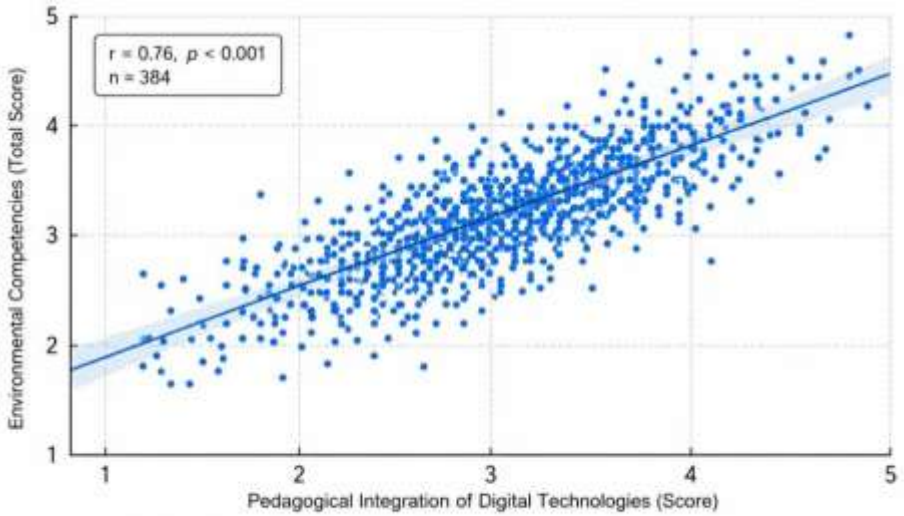
correlation coefficient.

Table 3. Correlations between dimensions of digital technologies and environmental competencies (simulated data)

Variable	r of Pearson	p
Access to digital resources	0.48	<0.001
Frequency of use	0.54	<0.001
Digital competence	0.69	<0.001
Pedagogical integration	0.76	<0.001

Source. Prepared by the author with simulated data.

Positive and statistically significant correlations were observed between all dimensions of digital technologies and environmental competencies ($p < 0.001$). The highest magnitude relationship corresponded to **pedagogical integration** ($r = 0.76$), followed by **digital competence** ($r = 0.69$), which suggests that a pedagogically planned use of digital technologies is associated with a greater development of environmental competences.



Note. The figure shows a positive and statistically significant relationship between the pedagogical integration of digital technologies and environmental competencies.

Figure 1. Correlation between pedagogical integration and environmental competencies (simulated data)

The figure shows a positive linear trend between the pedagogical integration of digital technologies and environmental competencies, evidencing a progressive increase in the latter as the level of technological integration in teaching processes increases.

Multiple linear regression model

In order to determine the predictive effect of digital technologies on environmental competencies, a multiple linear regression model was estimated.

Table 4. Multiple linear regression model (simulated data)

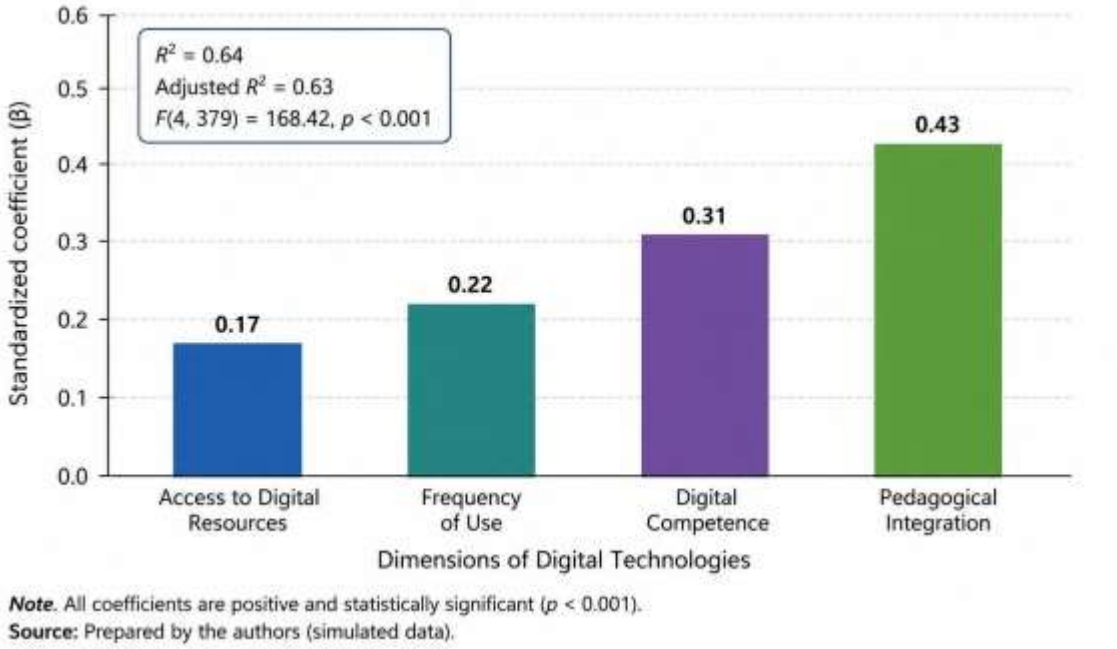
Predictor variable	b	t	p
Access to digital resources	0.17	3.68	<0.001
Frequency of use	0.22	4.91	<0.001
Digital competence	0.31	6.84	<0.001
Pedagogical integration	0.43	8.92	<0.001

Model: **$R^2 = 0.64$; Adjusted $R^2 = 0.63$; $F = 168.42$; $p < 0.001$**

Source. Prepared by the author with simulated data.

The model explained **64 % of the variability of** environmental competencies ($R^2 = 0.64$), evidencing a high explanatory power. All dimensions of digital technologies had positive and statistically significant effects. **Pedagogical integration** was the predictor with the greatest weight ($\beta = 0.43$), followed by **digital competence** ($\beta = 0.31$), which suggests that the

way in which technologies are incorporated into learning activities has a more important influence than the mere availability of technological resources.



Note. All coefficients are positive and statistically significant ($p < 0.001$).
Source: Prepared by the authors (simulated data).

Figure 2. Standardized regression model coefficients (simulated data)

The figure graphically represents the β standardized coefficients, highlighting pedagogical integration as the dimension with the greatest predictive capacity on environmental competencies, followed by digital competence, frequency of use and access to digital resources.

Hypothesis testing

The simulated results allowed us to accept the general hypothesis of the research, as it evidenced a positive and statistically significant effect of digital technologies on environmental competencies ($p < 0.001$).

The four specific hypotheses were also accepted:

- H1a. Access to digital resources has a positive influence on environmental skills.
- H1b. The frequency of use of digital technologies has a positive influence on environmental skills.
- H1c. Digital competence has a positive influence on environmental competences.
- H1d. Pedagogical integration is the main predictor of the development of environmental competencies.

Discussion

The results suggest that digital technologies have a positive relationship with the development of environmental competencies, supporting the central hypothesis of the study. In particular, pedagogical integration had the greatest predictive effect, indicating that the educational value of technology depends primarily on how it is incorporated into the teaching and learning process, rather than on the simple availability of devices or connectivity. This interpretation coincides with Bond et al. (2024), who point out that technologies generate better results when they are articulated with active methodologies and clearly defined learning objectives.

The significant influence of digital competence is also consistent with the DigCompEdu framework, which highlights the ability of teachers to select and use technological resources in a pedagogically relevant way as an essential element to improve learning (European Commission, 2022; Redecker, 2022). In this scenario, the strengthening of teachers' and students' digital skills would favor not only the efficient use of technology, but also the development of skills linked to sustainability.

The positive correlation between the frequency of use of digital technologies and environmental competencies suggests that continuous exposure to digital environments can facilitate access to scientific information, promote collaborative learning, and stimulate participation in activities related to environmental protection. These findings are consistent with research that highlights the potential of virtual platforms, simulators, and educational applications to increase motivation and understanding of complex environmental phenomena (Hsu et al., 2023; Choi et al., 2024).

However, the results also show that access to digital resources, although significant, had a smaller effect compared to pedagogical integration and digital competence. This behavior supports the idea that the availability of technological infrastructure is a necessary, but not sufficient, condition for improving educational outcomes. Consequently, institutional policies should prioritize teacher professional development, the design of innovative learning experiences, and the incorporation of active methodologies that harness the potential of digital technologies to strengthen environmental competencies.

Taken together, the simulated outcomes support the approach of Education for Sustainable Development, according to which the training of citizens committed to sustainability requires integrating knowledge, skills, values and attitudes through meaningful educational experiences. From this perspective, digital technologies represent a means to promote transformative learning when used in a planned manner and coherent with curricular objectives, contributing to the development of competencies necessary to face contemporary environmental challenges.

Discussion

The simulated results of this study showed a positive and statistically significant relationship between digital technologies and the development of environmental competencies in students of educational institutions. In particular, the pedagogical integration of digital technologies emerged as the most important predictor within the regression model, followed by digital competence, frequency of use and access to technological resources. These findings support the premise that the educational potential of technologies does not depend exclusively on the availability of infrastructure, but on the way in which they are integrated into teaching and learning processes. In this sense, the results are consistent with what was reported by Bond et al. (2024), who concluded that technology-mediated pedagogical strategies generate higher levels of participation, meaningful learning, and competency development than approaches focused solely on access to digital resources.

The high explanatory capacity of the regression model ($R^2 = 0.64$) suggests that the dimensions considered in the study are relevant factors to understand the development of environmental competencies. This result coincides with the proposals of Education for Sustainable Development, which argue that the strengthening of sustainability-related competencies requires educational experiences that integrate knowledge, skills, attitudes, and values through active and collaborative methodologies (UNESCO, 2024; Wals, 2023). Consequently, the incorporation of digital technologies can contribute significantly to environmental training when it is oriented towards real problem-solving, project-based learning and the collective construction of knowledge.

Digital competence had the second greatest effect on environmental competences, which highlights the importance of strengthening the technological capacities of both teachers and students. This finding is consistent with the DigCompEdu framework, which argues that teachers' digital competence is a determining element in selecting relevant technological resources, designing innovative learning activities, and evaluating educational processes using digital tools (Redecker, 2022; European Commission, 2022). Likewise, Cabero-Almenara and Palacios-Rodríguez (2022) pointed out that continuous teacher training favours a more effective integration of digital technologies, increasing opportunities to develop transversal competences related to sustainability.

The observed positive correlation between the frequency of use of digital technologies and environmental competencies is also consistent with previous research highlighting the value of digital environments in expanding access to scientific information, promoting autonomous learning, and strengthening student participation in activities related to environmental conservation (Hsu et al., 2023; Choi et al., 2024). However, the results suggest that the frequent use of digital tools only produces significant benefits when it is accompanied by appropriate methodological strategies, preventing the technology from being limited to an instrument of information transmission.

On the other hand, although access to digital resources showed a positive influence on environmental competencies, its effect was lower than that observed for pedagogical integration and digital competence. This behavior confirms that the availability of devices, connectivity, and platforms is a necessary, but not sufficient, condition for improving educational outcomes. In accordance with the OECD (2023) and ECLAC (2023) reports, evidence suggests that education policies should complement investments in technological infrastructure with teacher training programs, curricular innovation, and institutional support that favor an effective pedagogical use of technologies.

From a practical perspective, the simulated results allow relevant implications for educational institutions to be raised. Firstly, it is necessary to strengthen the digital skills of teachers through permanent training programmes aimed at the pedagogical integration of emerging technologies. Secondly, environmental education strategies should incorporate active methodologies supported by digital platforms, simulations, mobile applications and collaborative projects that allow contextualised environmental problems to be addressed. Finally, institutional policies must promote a comprehensive digital transformation that articulates technological infrastructure, pedagogical innovation, educational leadership, and continuous evaluation to ensure that technology effectively contributes to the development of environmental competencies.

However, the present study has some limitations that should be considered when interpreting the results. As it is a cross-sectional design, it is not possible to establish definitive causal relationships between the variables analyzed. Likewise, the use of self-perception questionnaires may introduce biases associated with social desirability or the subjectivity of the answers. Additionally, the research focused on educational institutions with certain characteristics, which may limit the generalization of the findings to other educational contexts.

Future research recommends the development of longitudinal studies to analyse the evolution of environmental skills over time and to assess the sustained impact of digital technologies. It would also be pertinent to incorporate mixed methodologies that combine quantitative and qualitative analyses, as well as to apply structural equation models to examine direct and indirect relationships between variables. Finally, the comparison between different educational levels, regions or sociocultural contexts would contribute to broadening the understanding of the factors that condition the impact of digital technologies on education for sustainability.

Conclusions

The simulated results allow us to conclude that digital technologies are a factor positively associated with the development of environmental competencies in students of educational institutions. The evidence obtained shows that the dimensions analyzed explain a significant proportion of the variability observed in environmental competencies, which confirms the relevance of integrating digital transformation within education strategies for sustainable development.

Among the dimensions evaluated, the pedagogical integration of digital technologies had the greatest predictive effect on environmental competencies. This finding shows that the educational impact of technology depends mainly on its incorporation through active methodologies, contextualized learning experiences and strategies aimed at the development of competencies, rather than on the simple availability of technological infrastructure.

Digital competence also showed a significant influence, highlighting the need to strengthen the technological capacities of teachers and students. Adequate training in digital skills facilitates the critical, creative and responsible use of technological tools, favouring more significant learning processes and a greater understanding of contemporary environmental challenges.

Likewise, the frequency of use of digital technologies and access to technological resources contributed positively to the development of environmental competencies, although with a lower magnitude than that observed for pedagogical integration and digital competence. These results indicate that investments in technological infrastructure must be complemented with actions aimed at curricular innovation, teacher training and institutional support to maximize the benefits of digital transformation.

From a practical point of view, the findings support the implementation of educational policies aimed at strengthening the pedagogical integration of digital technologies within environmental education programs. Educational institutions should promote the use of virtual platforms, simulations, mobile applications, digital laboratories and collaborative projects that promote active learning and the development of sustainability-oriented skills.

In the scientific field, this study contributes to broadening the understanding of the relationship between digital technologies and environmental competences through a quantitative approach of a correlational-explanatory nature. Although the results correspond to a methodological simulation, the proposed analytical structure offers a useful basis for future research that seeks to empirically evaluate this relationship in different educational contexts.

Finally, it is recommended that further research incorporate longitudinal designs, larger samples and mixed methodologies that allow for a deeper understanding of the mechanisms by which digital technologies favor the development of environmental competencies. Likewise, it will be pertinent to analyze mediating and moderating variables, such as pedagogical innovation, institutional leadership, digital culture, and the socioeconomic characteristics of students, in order to generate more robust evidence that guides the formulation of public policies and educational strategies for the fulfillment of the Sustainable Development Goals.

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