

Ecological Education and Digital Technologies: Pedagogical Convergences for Sustainable Citizenship

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Abstract

In an era defined by accelerating ecological crises and the pervasive presence of digital technologies, education stands at a crucial crossroads. This article explores the intersection between ecological education and digital innovation, analyzing how pedagogical frameworks can integrate technological tools to foster sustainable citizenship. Drawing on interdisciplinary perspectives, the paper investigates how digital environments can support ecological thinking, critical engagement, and collective responsibility among learners. It emphasizes the importance of pedagogical intentionality, teacher agency, and inclusive design in shaping educational practices that transcend instrumental uses of technology. Through a critical review of emerging approaches and case studies, the article highlights the need for education systems to cultivate not only digital competencies but also ecological awareness, ethical sensitivity, and democratic participation. Ultimately, it argues that the convergence of ecological and digital paradigms offers a unique opportunity to reimagine teaching and learning as transformative practices for a sustainable future.

Keywords: *Critical Consciousness; Systems Thinking; Teacher Agency; Democratic Education; Planetary Ethics; Transformative Learning.*

Introduction

In recent years, the convergence of ecological awareness and digital innovation has generated growing interest in educational theory and practice. As the climate crisis intensifies and digital technologies permeate nearly every aspect of human life, schools are increasingly called upon to cultivate forms of citizenship that are both environmentally responsible and digitally competent. The intersection of ecological education and digital learning thus emerges not only as a strategic opportunity but as a pedagogical imperative, one that challenges educators to imagine new ways of fostering sustainability-oriented values, behaviors, and knowledge in the digital age (Selby & Kagawa, 2015). This article situates itself within this critical intersection, aiming to explore how innovative pedagogical approaches can integrate environmental education and digital tools to support a transformative model of education for sustainable citizenship.

The urgency of rethinking education in light of planetary limits has been underscored by global frameworks such as UNESCO's Education for Sustainable Development (ESD), which

emphasizes the development of competencies necessary to address complex global challenges (UNESCO, 2020). At the same time, the widespread diffusion of digital technologies in schooling has reshaped pedagogical landscapes, offering both affordances and limitations in terms of engagement, critical thinking, and participation (Biesta, 2019). Despite this parallel evolution, ecological education and digital innovation have often been conceptualized as separate domains, rarely integrated into a coherent pedagogical vision. This article responds to this gap by proposing a theoretical and practical reflection on how digital technologies can be mobilized in service of ecological consciousness, and how environmental education can benefit from digital creativity, multimodality, and networked collaboration.

Ecopedagogy, a critical educational approach rooted in the work of Paulo Freire and expanded by thinkers such as Gadotti (2008), posits that education should empower learners to recognize and transform the socio-environmental injustices that underpin ecological degradation. This pedagogical stance emphasizes critical reflection, social action, and relational ethics, challenging technocratic and consumerist ideologies that frame both education and the environment. Within this framework, technology must be understood not simply as a neutral tool but as a cultural artifact embedded within systems of power and production (Postman, 1993). The introduction of digital tools in education, therefore, cannot be decoupled from ethical questions about their environmental footprint, ideological orientation, and pedagogical alignment. The integration of ecopedagogy with digital learning thus calls for an epistemological shift—from a utilitarian view of technology to a more critical, contextual, and values-driven engagement.

Recent studies have begun to explore how digital technologies can support environmental literacy and action. For instance, serious games, virtual simulations, and augmented reality experiences have been used to immerse students in complex ecological scenarios, fostering empathy, systems thinking, and problem-solving (Wu & Lee, 2015; de Freitas, 2014). Online platforms have enabled transnational collaboration on climate-related projects, while social media has facilitated youth activism and environmental awareness campaigns (Kahne, Hodgin, & Eidman-Aadahl, 2016). These developments suggest that when used critically and creatively, digital media can amplify the transformative potential of ecological education. However, they also raise questions about access, data ethics, and the digital divide—issues that intersect with broader concerns about sustainability and justice.

Moreover, the environmental costs of digitalization itself have prompted educators to adopt more reflexive stances. The material infrastructure of the digital world—server farms, energy consumption, e-waste, and rare-earth mining—contradicts the immaterial image often associated with online learning (Parikka, 2015). A truly sustainable education must therefore account for the ecological implications of its own technological tools. This requires developing digital literacies that are ecologically informed, encouraging students not only to use digital devices but also to question their lifecycle, ownership, and environmental impact (Maxwell & Miller, 2012). In this light, the intersection between digital and ecological education is not merely thematic but structural, involving a reassessment of how educational technologies are produced, distributed, and consumed.

Furthermore, integrating sustainability into digital pedagogies demands a shift from content delivery to participatory knowledge construction. Learners must be positioned as active agents capable of investigating real-world problems, engaging in community-based projects, and contributing to solutions through digital storytelling, mapping, and communication. This aligns with constructivist and experiential learning theories, which emphasize the role of context, collaboration, and authenticity in meaningful learning (Kolb, 1984; Lave & Wenger, 1991). The digital environment, if pedagogically designed, can function as a “third space” where formal curricula intersect with students’ lived experiences, enabling hybrid forms of engagement that foster both ecological insight and technological fluency.

In terms of teacher education, preparing educators for this eco-digital convergence is a key challenge. Many teachers report feeling underprepared to integrate environmental themes with digital tools, particularly in ways that are pedagogically sound and contextually relevant (Evans, Stevenson, Lasen, Ferreira, & Davis, 2017). Initial teacher education programs, as well as continuing professional development initiatives, must therefore include critical digital pedagogy and sustainability education as core components. These programs should not only impart technical skills but also support reflective practice, critical inquiry, and collaborative learning communities oriented toward ethical and ecological goals. The professional identity of teachers in the 21st century increasingly requires the capacity to navigate uncertainty, facilitate interdisciplinary learning, and model values of care, responsibility, and interdependence.

At the policy level, international agendas such as the European Green Deal and the Digital Education Action Plan (2021–2027) have begun to address the need for integrated approaches to green and digital transitions (European Commission, 2020, 2021). However, much remains to be done to translate these policy visions into classroom realities. Often, sustainability and digitalization are treated in parallel but disconnected silos, leading to fragmented initiatives and inconsistent implementation. What is needed is a systemic educational response that embraces the complexity of global interdependencies and equips learners with the skills, values, and dispositions necessary to act within them. This includes not only environmental knowledge or digital proficiency but also ethical judgment, emotional resilience, and civic engagement.

This article argues that the future of education lies in the ability to reimagine pedagogical spaces where ecological and digital imaginaries coalesce. Such a vision challenges technocratic narratives of innovation and calls for a relational pedagogy grounded in care for the planet, social justice, and the co-creation of knowledge. By bridging the conceptual and practical gaps between sustainability and digital education, it is possible to cultivate learning environments that are transformative, inclusive, and ecologically conscious. The subsequent sections of this article will further investigate the theoretical foundations, educational practices, and institutional strategies necessary to realize this integrated approach, drawing on diverse case studies, models, and frameworks from around the world.

1. Rethinking Environmental Literacy through Digital Mediation

As educational institutions navigate the growing imperatives of sustainability and digitalization, it becomes increasingly necessary to reconceptualize environmental literacy not as a static body of knowledge about ecological facts, but as a dynamic and mediated competence shaped through diverse digital interactions. The integration of digital media into ecological education offers not only new modalities for representing environmental data but also novel frameworks for interpreting ecological interdependence, agency, and action. Contemporary learners engage with environmental issues in an informational ecosystem that is saturated with multimodal, algorithmically-curated content. As such, environmental literacy in the digital age must encompass a broader spectrum of interpretive, critical, and communicative skills, enabling students to navigate complexity, ambiguity, and contested knowledge claims in technologically mediated contexts (van der Velden & Elgar, 2013).

Digital mediation has profoundly transformed the ways in which ecological problems are communicated, experienced, and understood. The ubiquity of climate change visualizations, infographics, satellite imagery, virtual simulations, and citizen science platforms enables learners to perceive environmental systems at varying scales, from the local to the planetary. For example, interactive climate dashboards, such as NASA's Climate Change Vital Signs or the Global Forest Watch platform, allow users to manipulate data sets, observe trends, and draw correlations between environmental and human systems. These tools not only democratize

access to scientific data but also foster data literacy, an essential component of ecological competence in the digital age (Gray, 2017). However, this access is not automatically transformative. Without pedagogical scaffolding, the abundance of digital information may overwhelm or mislead learners, resulting in passive consumption rather than critical engagement (Livingstone & Helsper, 2007). Consequently, educators must design learning experiences that frame digital tools within epistemologically robust and ethically grounded pedagogies.

An important aspect of this reconceptualization involves recognizing how digital storytelling and media production can act as powerful vectors of environmental awareness and action. Unlike traditional didactic models, which often position students as recipients of pre-structured knowledge, digital storytelling invites them to become authors, curators, and interpreters of environmental narratives. Research has shown that when students create their own media, be it videos, podcasts, blogs, or interactive websites, they engage more deeply with the content, develop personal connections to ecological issues, and build multimodal literacy skills (Guberman, 2018). Such practices also encourage learners to situate ecological concerns within their own communities and experiences, thereby fostering a more place-based and situated understanding of sustainability (Gruenewald, 2003).

Moreover, digital platforms facilitate translocal and intercultural exchanges that can enrich ecological education with diverse perspectives. Online collaborative projects between schools in different countries, for instance, allow students to compare environmental challenges, share solutions, and cultivate a sense of global ecological citizenship (Buckingham, 2010). Initiatives like eTwinning, Eco-Schools, and the GLOBE Program have demonstrated the potential of international digital partnerships to enhance environmental understanding and solidarity. In this regard, digital technologies can function as bridges across geographic, linguistic, and cultural divides, promoting a planetary consciousness that aligns with the ethos of the Anthropocene, a historical period in which human activity has become a geological force (Latour, 2017).

However, the digitization of environmental education also raises critical pedagogical and political questions. While digital tools can empower learners, they are also embedded in broader infrastructures of surveillance, commodification, and platform capitalism. Educational technologies often operate within commercial ecosystems that prioritize engagement metrics, data harvesting, and user manipulation over democratic values and pedagogical integrity (Zuboff, 2019). In the context of ecological education, this dynamic risks undermining the very goals of critical consciousness and systemic transformation. For instance, teaching sustainability through platforms that themselves contribute to environmental degradation or corporate monopolization may result in a form of cognitive dissonance that blunts students' moral engagement. Therefore, environmental literacy must also include a meta-critical dimension—one that interrogates the digital tools themselves, their materialities, their governance structures, and their socio-ecological footprints (Coulson & Woods, 2016).

One promising framework in this direction is that of post-digital education, which acknowledges the pervasiveness of digital technologies while seeking to move beyond techno-centric narratives. Post-digital pedagogies emphasize the entanglement of the digital with the social, ecological, and affective dimensions of learning, advocating for more situated, embodied, and relational approaches (Jandrić, 2020). Within this view, environmental literacy is not merely about acquiring knowledge but about cultivating ecological subjectivities that are attuned to the more-than-human world. It involves learning to perceive, feel, and act in ways that reflect ecological entanglements and ethical responsibilities, and digital media can serve as both a site of disruption and possibility in this process.

Another emerging area of interest lies in the integration of speculative and design-based approaches into ecological learning. Digital tools can be used to imagine alternative futures, simulate ecological scenarios, or prototype sustainable solutions. The use of design fiction,

virtual reality, and participatory modeling in environmental education allows students to experiment with complex systems thinking and to reflect on the social, ethical, and ecological consequences of different choices (Sterling, 2016). These practices do not merely reinforce existing knowledge but invite learners to co-create visions of sustainable futures, thereby shifting the pedagogical focus from adaptation to transformation.

Additionally, the potential of digital platforms to support ecojustice pedagogies must be foregrounded. Ecojustice education, which examines the intersections of environmental degradation, social inequality, and cultural oppression, demands a pedagogical stance that is both critical and emancipatory (Martusewicz, Edmundson, & Lupinacci, 2011). Digital media, with its capacities for narrative plurality, multimodal expression, and activist mobilization, can amplify marginalized voices and perspectives that are often excluded from mainstream environmental discourse. For example, Indigenous digital storytelling projects and community-mapping tools have enabled historically marginalized communities to assert their ecological knowledge, resist extractivist practices, and engage in policy advocacy (Corntassel & Hardbarger, 2019). Educators must be intentional in integrating such projects into curricula, not as add-ons but as central to the redefinition of environmental literacy in pluralistic and decolonial terms.

Ultimately, rethinking environmental literacy in digitally mediated contexts necessitates an integrated approach that balances technological innovation with ethical reflection, scientific understanding with cultural meaning-making, and individual empowerment with collective responsibility. Educators must navigate the tensions between the enabling and constraining aspects of digital media, crafting learning environments that are not only technologically rich but also pedagogically sound, ecologically conscious, and socially just. This entails curricular innovation, teacher training, institutional support, and critical engagement with both educational technology providers and policy frameworks. Only by embracing such complexity can environmental education in the digital age fulfill its transformative promise.

2. Pedagogical Pathways for Ecological Agency and Systems Thinking in the Digital Era

In an educational context increasingly shaped by the dual imperatives of ecological urgency and technological transformation, cultivating ecological agency and systems thinking among learners has become a central pedagogical challenge. Ecological agency refers to the capacity of individuals to understand, feel, and act responsibly within complex ecological systems, recognizing both their embeddedness in and impact on these systems. Systems thinking, meanwhile, entails the ability to perceive interconnections, feedback loops, and emergent properties within ecological and socio-technical environments. These competencies are not innate but must be cultivated through carefully designed pedagogical approaches that are responsive to the cognitive, affective, and ethical dimensions of learning. Digital technologies, when thoughtfully integrated, can serve as both catalysts and platforms for this pedagogical development, offering novel opportunities for modeling complexity, visualizing interdependence, and fostering participatory engagement.

At the core of this pedagogical shift lies the reconceptualization of knowledge not as a set of isolated facts to be memorized but as a dynamic, situated, and interconnected web of relations. This epistemological reorientation requires educators to move beyond linear instructional models toward constructivist and inquiry-based approaches that position students as co-creators of knowledge. Within such frameworks, digital tools can facilitate deep learning by enabling learners to simulate ecological systems, manipulate variables, and observe emergent behaviors over time. For example, educational platforms such as NetLogo or InsightMaker allow students to construct agent-based models that replicate complex ecological phenomena such as predator-prey dynamics, deforestation patterns, or climate feedback loops. By interacting with these simulations, learners begin to grasp the non-linearity and

unpredictability inherent in ecological systems, developing both cognitive flexibility and strategic foresight (Jacobson, Kapur, & Reimann, 2016).

In addition to fostering systems thinking, digital technologies can support the cultivation of ecological agency through immersive and affectively rich experiences. Virtual reality applications such as Stanford's Virtual Human Interaction Lab's "Tree" or the BBC's "Our World in VR" enable learners to experience environmental degradation and restoration from a first-person perspective. Such experiences have been shown to increase empathy toward non-human life forms, enhance emotional engagement, and stimulate pro-environmental behavior (Ahn, Bailenson, & Park, 2014). While caution must be exercised to avoid over-reliance on technological spectacle, these immersive media experiences can complement more traditional forms of ecological learning by making abstract concepts tangible and emotionally resonant.

Another critical dimension involves the use of participatory mapping and geospatial technologies to connect learners to their local environments. Through platforms like ArcGIS StoryMaps or OpenStreetMap, students can document ecological features, identify sustainability challenges, and propose interventions within their own communities. These activities promote place-based education, an approach that emphasizes learning grounded in the specificities of local ecosystems, cultures, and histories (Smith & Sobel, 2010). Moreover, when these tools are employed in collaborative and interdisciplinary projects, they encourage civic participation and collective problem-solving, aligning with broader goals of ecological citizenship and democratic education (Gruenewald & Smith, 2014).

Critical to these pedagogical transformations is the role of educators as facilitators of dialogue, reflection, and action. In digital contexts, this facilitative role becomes even more complex, requiring teachers to mediate between multiple knowledge systems, technological affordances, and ethical considerations. Educators must be adept at guiding students through information overload, curating reliable resources, and fostering critical digital literacy. This involves helping learners question dominant narratives, recognize power asymmetries in environmental discourse, and understand the ways in which digital infrastructures shape what is visible, sayable, and actionable (Pangrazio & Selwyn, 2019). For instance, an analysis of search engine results or social media algorithms related to climate change can reveal how certain perspectives are amplified while others are marginalized, thereby prompting students to critically reflect on issues of epistemic justice and digital ecology.

Collaborative pedagogies also play a key role in cultivating ecological agency. Approaches such as project-based learning, design thinking, and service learning encourage students to engage in meaningful problem-solving tasks that have real-world implications. When these projects are linked to sustainability goals, they provide opportunities for students to enact agency while applying systems thinking in authentic contexts. For example, students might work in interdisciplinary teams to design a school-wide waste reduction initiative, develop a mobile app to monitor local biodiversity, or create digital campaigns to raise awareness about water conservation. These activities not only deepen content understanding but also develop socio-emotional skills such as empathy, communication, and resilience, which are essential for navigating ecological crises (Barron & Darling-Hammond, 2010).

The integration of digital portfolios and reflective journaling further supports the development of ecological consciousness. Through multimedia journals, students can document their learning journeys, articulate evolving understandings, and explore tensions between personal values and systemic challenges. Reflection becomes a space for sense-making and identity formation, enabling learners to position themselves ethically within broader ecological networks. Platforms like Seesaw, Padlet, or Google Sites allow students to curate digital artifacts that demonstrate both their cognitive growth and their engagement with sustainability issues. When shared with peers, families, and community members, these

portfolios can also foster intergenerational dialogue and collective learning (Chatti, Jarke, & Specht, 2010).

Nevertheless, the promise of digital pedagogies for ecological education must be weighed against their potential limitations and unintended consequences. One concern involves the risk of technological solutionism, the belief that complex environmental problems can be solved primarily through technical means. This mindset can overshadow the need for cultural, political, and ethical transformation, reducing education to a tool for behavioral modification rather than a process of critical emancipation (Morozov, 2013). To counter this tendency, pedagogies must foreground not only technological fluency but also ecological humility, ethical reflection, and democratic deliberation. The goal is not to produce compliant eco-consumers but engaged citizens capable of questioning systems, imagining alternatives, and co-constructing sustainable futures.

Additionally, attention must be paid to the material and infrastructural dimensions of digital education. The energy consumption of data centers, the extractive practices underpinning device production, and the e-waste generated by obsolescence all have ecological impacts that are often invisible in classroom settings. Educators have a responsibility to address these contradictions and to integrate critical discussions of digital materiality into sustainability curricula. For instance, examining the life cycle of a smartphone or the carbon footprint of online streaming can provide entry points for analyzing the interdependencies between technology and ecology (Parikka, 2015). Such analyses can also foster systemic thinking by revealing how consumption patterns, global supply chains, and environmental degradation are interconnected.

Fostering ecological agency and systems thinking in the digital era requires an integrative pedagogical approach that combines cognitive complexity, emotional engagement, ethical deliberation, and participatory action. Digital technologies, when critically and creatively employed, can enhance these dimensions by providing new tools for modeling, storytelling, collaboration, and reflection. However, these technologies must be situated within pedagogical frameworks that prioritize ecological justice, epistemic diversity, and transformative learning. As educational systems seek to prepare students for the challenges of the Anthropocene, they must move beyond instrumental uses of technology toward a more holistic vision of digital ecological education—one that empowers learners to perceive interdependence, assume responsibility, and act collectively in pursuit of sustainable and just futures.

Conclusions

In the face of accelerating ecological crises and the pervasive influence of digital technologies, education must be reimagined as a transformative space that not only transmits knowledge but cultivates ecological consciousness, critical agency, and collective responsibility. The integration of digital technologies into educational practices offers both unprecedented opportunities and complex challenges. When guided by pedagogical intentionality, these tools can support learners in visualizing ecological complexity, engaging in meaningful inquiry, and enacting change within their communities. However, technology alone does not guarantee ecological awareness or sustainable behavior. What matters is the design of learning environments that prioritize ethical reflection, systems thinking, and democratic participation.

Ecological education in the digital age must therefore be grounded in pedagogical frameworks that emphasize connectivity, interdependence, and justice. This means fostering learning experiences that transcend disciplinary silos and technological instrumentalism, focusing instead on holistic development and contextual understanding. Teachers, as key agents of this transformation, must be equipped with the knowledge, skills, and dispositions necessary to guide learners through the uncertainties and contradictions of the Anthropocene. They must

also be supported in critically examining the material, political, and cultural dimensions of the digital tools they employ.

Moreover, the pursuit of sustainable citizenship calls for educational practices that are not only cognitively rigorous but also emotionally resonant and socially responsive. Learners need opportunities to explore the tensions between personal choices and systemic structures, to imagine alternative futures, and to engage in collaborative action. Digital technologies, if used creatively and critically, can enhance these possibilities by amplifying student voice, enabling real-time feedback, and facilitating global connections. Yet such benefits can only be realized through pedagogical practices that remain attentive to issues of equity, inclusion, and ecological integrity.

Ultimately, the convergence of ecological education and digital innovation invites a redefinition of what it means to learn, teach, and live together on a fragile planet. It challenges educators to design learning ecologies that honor complexity, nurture care, and inspire commitment. As we navigate an era of profound environmental and technological transformation, education must serve not as a mechanism for adaptation alone, but as a catalyst for systemic change and planetary stewardship. Only then can we hope to cultivate the forms of awareness, responsibility, and solidarity needed to co-create a more just and sustainable future.

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