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Developing Environmental Awareness and Stewardship by Multimodal Exploration of the Natural World with the Means of Digital Technologies

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ABSTRACT. Current and acute environmental problems highlight the need to develop educational approaches that can foster both environmental awareness and stewardship. Although environmental education has advanced in recent years and is increasingly supported by policy and legislation, the literature continues to point to a gap in terms of transferring knowledge into practice. Considering this gap, the purpose of this article is to propose a conceptual model for developing environmental awareness and stewardship in lower secondary education through the multimodal exploration of the natural world supported by digital technologies. The model, constructed through a systematic synthesis of literature, is based on raising environmental awareness and stewardship through the development of scientific, environmental, and digital competences, along with strengthening the connection with the environment through multimodal and digital exploration. To illustrate the model's applicability, the article presents an example of a practical activity combining multisensory field exploration with digital tools for documenting, identifying, and interpreting environmental phenomena. This example shows how multimodal experiences, supported by technology and structured classroom reflection, can create meaningful contexts for developing competences relevant to environmental responsibility. The article argues that such competence-based, experiential, and digitally enriched approaches offer promising directions for strengthening environmental awareness and stewardship in everyday-school practice.

Keywords: environmental awareness, environmental stewardship, multimodal exploration, digital technologies, environmental education

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1. INTRODUCTION

Climate change is one of the main environmental problems currently confronting both the Earth and human populations. According to the National Centers for Environmental Information' Annual Climate Report, 2024 was declared the warmest year on record. This situation has serious ecological, social, and educational consequences, highlighting the urgent need for action. Global warming reduces available drinking water due to the fast melting of glaciers, increases extreme weather events, and disrupts animal habitats (NCEI, 2025). It also impacts plant life cycles, with many species blooming earlier because of disturbed dormancy (NASA, 2022). Organizations such as the Intergovernmental Panel on Climate Change (IPCC) highlight that the next few decades will be crucial for determining the environmental future of our planet (IPCC, 2023).

In response to these urgent challenges, many countries have introduced environmental education and sustainability courses, alongside legislative measures (Hazel Mae, 2024). The European Union, for example, has implemented initiatives such as *GreenComp: The European Sustainability Competence Framework* (Bianchi et al., 2022) and the *Green Claims Directive* to promote sustainable practices and protect consumers from greenwashing (European Commission, 2023). However, while these measures are important and necessary, they are not enough. A stronger connection with the environment and a deeper understanding of both theoretical and practical aspects underlying climate change and its mitigation remain essential.

Environmental education (EE) plays a key role in addressing this gap. Scholars and policymakers believe that in addition to regulations, raising awareness, building knowledge, and encouraging pro-environmental behaviors are also crucial for mitigating environmental problems (Fos & Ko, 2019). Beyond knowledge acquisition, environmental education aims to develop the skills and attitudes necessary for learners to engage responsibly with the natural world (Hazel Mae, 2024; UNESCO, 1976). UNESCO's Education for Sustainable Development for 2030 framework aligns with the United Nations Sustainable Development Goals 4 (Quality Education) and 13 (Climate Action). It focuses on equipping learners with the knowledge, skills, and attitudes necessary to effectively respond to environmental challenges (UNESCO, 2020; United Nations, 2015).

Building on these perspectives, this article argues that without the development of *scientific and digital competences* – prerequisites and means for cultivating *environmental competences* – awareness remains at the level of mere knowledge and does not translate into concrete and informed action. Learners, especially adolescents, are a key group because their values, attitudes, and identities regarding nature and sustainability are formed during early adolescence. Therefore, bridging the gap between theoretical understanding and practical action is essential.

Environmental education provides a way to foster this kind of learning. According to UNESCO (1976, 1978), EE is a process where three elements – the cognitive, emotional, and behavioral – participate equally. Furthermore, it also aims to develop theoretical knowledge and introduce key concepts about environmental issues, such as:

- ***carbon footprint:*** the total amount of greenhouse gases emitted directly or indirectly by human activities, measured in CO_2 equivalents per year;
- ***ecological footprint***: the amount of land area needed to support human consumption and to absorb waste, providing a measure of lifestyle sustainability;
- ***handprint***: positive actions taken by individuals or organizations that help reduce negative environmental impact (Hazel Mae, 2024).

When learners internalize these concepts, it helps them move from awareness to responsibility and eventually to action through environmental stewardship. Environmental stewardship includes diverse sustainable practices such as: community engagement, protecting biodiversity, and using resources responsibly (Worrell & Appleby, 2000; UNESCO, 2020).

There is empirical evidence supporting the idea that environmental knowledge is likely to promote pro-environmental attitudes and behaviors. Previous research has identified several factors that affect students' environmental awareness and their willingness to engage in pro-environmental actions. For instance, McNeal et al. (2014) and Akrofi et al. (2019) observed that students who participate in interactive activities, such as debates or climate-focused clubs, show greater engagement and measurable learning outcomes. Specifically, participation in climate-related clubs and witnessing local effects of climate change increased students' knowledge and awareness. Similarly, Freije et al. (2017) showed that taking part in environmental education programs improves students' understanding of concepts like carbon and ecological footprints, leading to more sustainable behaviors. In addition, Barreda (2018) highlighted the fact that climate change and carbon footprint are better understood as grade level increases. Students' perceptions and beliefs, therefore, are essential components in promoting effective pro-environmental action.

Despite the increase in research, several gaps still remain. Most studies focus on knowledge construction, paying less attention to how different learning methods and digital tools can be combined to raise awareness and promote scientific and environmental competences in lower secondary environmental education. As students engage more with digital cultures, the use of new technologies, such as simulations, augmented reality, virtual reality, gamified environments, and collaborative digital platforms, could help bridge this gap and create more immersive, relevant, and impactful experiences.

Given the current environmental challenges, the goals of environmental education, and the gaps identified in existing research, this paper proposes a model designed to promote environmental awareness and foster environmental stewardship in lower secondary education. The model focuses on developing scientific, environmental and digital competences and strengthening students' connection with nature through both multimodal and digital exploration (Figure 1). The ultimate aim is to turn awareness into informed, responsible action.

2. CONCEPTUAL AND APPLIED FRAMEWORK

Figure 1 presents the proposed conceptual model, which illustrates the dynamic interplay among scientific, digital and environmental competences, connectedness with nature, multimodal and digital exploration, environmental awareness, and environmental stewardship. The model emphasizes how these aspects are linked and support each other.

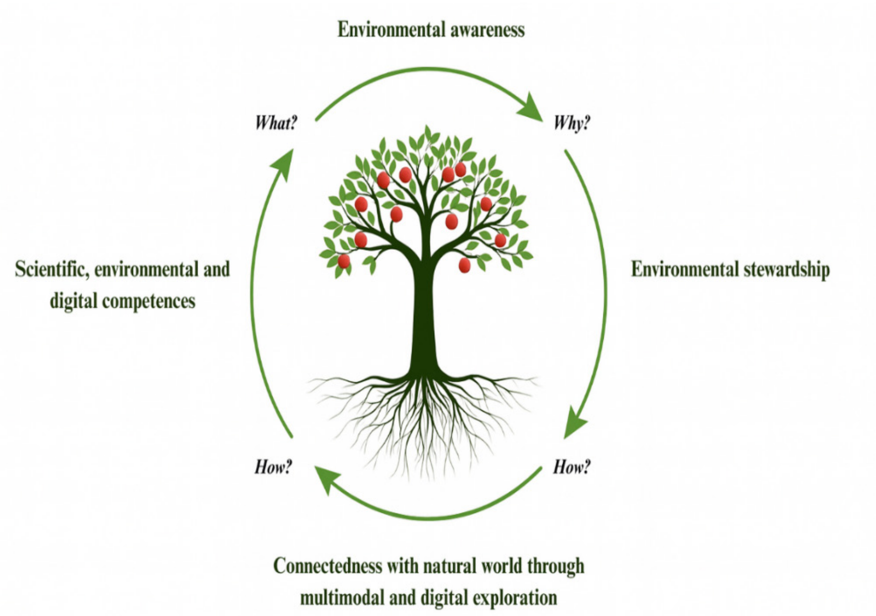

Figure 1. A conceptual model for developing environmental awareness and stewardship through multimodal and digital exploration

They shape students' understanding and involvement with the natural world. The following section elaborates on the conceptual foundations of the study, clarifying the definitions, dimensions, and pedagogical relevance of each construct within lower secondary education. Collectively, these concepts provide a framework for fostering scientifically grounded, digitally enhanced, and ethically responsible connections with the environment.

2.1. Environmental awareness – from knowledge to sensitivity

What is environmental awareness?

One meaning of the term *awareness* refers to the capacity "to be aware," that is, to recognize and engage with the surrounding reality. UNESCO (2017) defines environmental awareness as being conscious of the total environment and the impact of one's actions, combined with a desire to improve environmental conditions. Given the global phenomenon of climate change, environmental awareness means having clearly formed ideas about the origin and nature of environmental problems, including personal contributions to problems, such as carbon emissions (Hazel, 2024).

Scholars often regard environmental awareness as a multidimensional concept that includes three related dimensions (Roczen et al., 2014):

1. *Cognitive dimension* – refers to knowledge of ecological systems, environmental issues, and scientific processes. This would entail understanding cause and effect, for instance, linking the use of fossil fuels to the release of greenhouse gases.
2. *Affective dimension* – implies emotional involvement, sensitivity, and values in relation to environmental preservation. It highlights the internalization of environmental issues as personally significant and morally relevant.
3. *Behavioral-intentional dimension* – describes the willingness or intention to engage in environmentally friendly actions, which may not have yet materialized in concrete behavior, but serves as a significant predictor of such behavior.

Within this framework, two central questions arise: *Why is it important to address environmental awareness, and how can it be effectively cultivated?*

Why develop environmental awareness?

For a long time, environmental education has focused on knowledge acquisition about ecological processes, biodiversity, pollution, and climate change. However, research shows that knowledge alone does not encourage pro-environmental behavior (Jensen, 2002; Bamberg & Möser, 2007). Students may understand the causes of global warming or how the greenhouse effect works, but this understanding does not always lead to action or commitment.

What helps bridge this gap is *sensitivity*, understood as an emotional connection to environmental issues that fosters empathy, care, and personal relevance. Practical examples illustrate how knowledge can evolve into sensitivity. For instance, when students read about deforestation in a textbook, they acquire information at an intellectual level. However, when they explore local forests, observe signs of biodiversity loss, or engage with multimedia stories about communities affected by deforestation, their awareness deepens into sensitivity. This emotional connection creates the conditions for shifts in attitudes and behaviors.

How can environmental awareness be cultivated?

First, according to Roczen et al. (2014), environmental competences are multidimensional and include knowledge, skills, and attitudes related with the environment. Fostering environmental awareness requires the development of both scientific and environmental competences. Scientific competences enable students to investigate ecological systems, analyze data, and understand complex causal processes. Environmental competences guide this scientific knowledge towards making ethical decisions and adopting sustainable practices.

Second, an auspicious approach for cultivating awareness is strengthening *connectedness to nature*, defined as the perceived closeness of the human–nature relationship (Brügger et al., 2011). Studies suggest that a strong connection to nature can predict pro-environmental behaviors and contribute to psychological well-being (Capaldi et al., 2014; Pensini et al., 2016; Barbaro & Pickett, 2016). Direct experiences with nature, outdoor learning, and involvement in environmental projects often lead to higher levels of connectedness and greater commitment to ecological issues (Pensini et al., 2016). Additionally, Otto and Pensini (2017) argue that viewing oneself as part of the natural world predicts pro-environmental behavior more effectively than general environmental knowledge.

Therefore, cultivating awareness represents only the first step. For awareness to result in meaningful change, it must become a responsibility, which manifests through community involvement, sustainable actions, and a long-term commitment to environmental protection. This *responsibility*, expressed by the concept of environmental stewardship, will be discussed in the following section.

2.2. Environmental stewardship – from sensitivity to responsibility

Why environmental stewardship?

If environmental awareness provides the basis for *understanding* and *sensitivity*, environmental stewardship is where those feelings, attitudes, and forms of empathy translate into real *responsibility*. Environmental stewardship involves sustained care for ecosystems and natural resources, informed by sound decision-making, ethical behavior, and active participation (Bennett et al., 2018; Enqvist et al., 2018). It goes beyond one-time eco-friendly actions. It requires a continuous effort to keep ecological balance and sustainable livelihoods, both individually and collectively (Schlosberg et al., 2019).

The shift from sensitivity to responsibility can be seen as a developmental journey. Sensitivity fosters care and concern, while stewardship turns that care into action. In this sense, stewardship expresses itself through the use of three complementary dimensions:

1. *Individual responsibility* – performing actions to minimize environmental harm in everyday life, such as consuming less, using less energy, or protecting nature.
2. *Collective responsibility* – participating in community efforts, whether a school recycling program or a local habitat restoration project.
3. *Civic engagement* – supporting broader sustainability initiatives, from policy advocacy to youth engagement in climate action (Bennett et al., 2018).

Without this active layer, awareness risks remaining symbolic or superficial. This gap, frequently referred to as the *value–action gap*, has been identified in both early and recent research (Kollmuss & Agyeman, 2002; Gifford & Nilsson, 2014). Bridging it requires educational experiences in which students not only empathize with the natural world but also recognize their own agency and capacity to act. Several studies have highlighted that the perceptions of affective response, interdependence, and contributory value will positively impact learners' engagement in pro-environmental behaviors (Otto & Pensini, 2017; Stevenson et al., 2021).

For young people, stewardship closely relates to development of their identity. Early adolescence is a time when values, attitudes, and social identities are still forming, making it a crucial time to integrate sustainability into their self-concept (Stevenson et al., 2013). Engaging in real-world projects, such as citizen science, community conservation, or school-community partnerships, allows adolescents to move from passive learners to active participants. These experiences also build moral reasoning and an ethos of shared responsibility while reinforcing the idea that environmental stewardship is both an individual and a social effort.

Digital technologies add another layer to this process. Online collaboration platforms, simulations, gamified sustainability apps, or participatory mapping tools create exciting opportunities for students to act as stewards in both physical and digital environments (Kuo et al., 2019; Haji-Hassan et al., 2024). By measuring their ecological footprint using mobile phone applications, writing digital stories about their activities, or taking part in global online campaigns, for example, adolescents learn how environmental responsibility can be linked to their daily lives. In this sense, multimodal and digital approaches can make stewardship more relevant, accessible, and resonant with youth cultures.

In summary, environmental stewardship can be considered the responsibilization of sensitivity – a progression from empathic awareness to sustained action and civic engagement. By incorporating opportunities for personal responsibility, collective effort, and digital innovation, education can help shape students who are not only aware of environmental issues but also ready to serve as active stewards of the planet.

2.3. Connectedness with nature – multimodal and digital exploration

A key question in encouraging environmental awareness and responsibility is not just *what* learners should know or *why* these ideas are important, but *how to* cultivate them effectively. As mentioned before, recent educational research emphasizes that strengthening students' *connectedness with nature* – their sense of closeness and relationship with the natural world – is one of the most promising pathways toward lasting pro-environmental behavior (Whitburn et al., 2020; Martin et al., 2020). This connection goes beyond mere knowledge; it involves a relationship and an emotional bond that can inspire responsibility, empathy, and sustainable action. Because it reflects how close individuals feel to the natural environment, connectedness can be nurtured through direct contact with nature and through meaningful experiential activities (Pensini et al., 2016) mediated by digital technologies.

Multimodal exploration as a gateway to connection

Traditional classroom instruction often struggles to foster connectedness because it relies primarily on verbal and cognitive methods. In contrast, multimodal learning – which combines sensory, emotional, and physical experiences – provides a more complete approach. Louv (2008) introduced the idea of "nature deficit disorder, " highlighting the impact of modern lifestyles that keep young people away from direct contact with nature. To combat this, multimodal methods integrate visual, auditory, kinesthetic, and emotional experiences to enhance learner engagement and strengthen their relationship with nature.

Exploration of the natural world typically occurs through the senses and the integration of multiple natural stimuli (i.e., visual, audio, tactile, olfactory). The combination of the information derived from multiple sensory sources is called *multisensory integration,* a process that underpins the concept of "presence". In everyday experiences, the brain is constantly engaged in selecting relevant sensory stimuli over irrelevant ones. As a result, a stronger sense of presence emerges from a richer combination of sensory input (Marruci et al., 2021). In addition, from a psychological perspective, multimodal experiencing of the world stimulates the storage of sensory memory traces in long-term memory as episodic knowledge, although these traces tend to degrade quickly. Only when attention is directed to specific aspects of these sensory memories are they transferred into working memory. Within working memory, individuals can *consciously* retain the information and reflect on the experience in context (Fadel & Lemke, 2008).

Therefore, a multimodal exploration of the environment can be a way to increase connection with nature and, implicitly, eco-awareness and environmental stewardship. Studies show that combining various sensory inputs in education improves cognitive performance, sense of presence, and engagement in learning (Marucci et al., 2021, Luo, 2023). Additionally, this multimodal approach offers multiple access points for learners, particularly for those with different learning styles (Bezemer & Kress, 2016).

In the context of environmental education, a 2008 study conducted by Auer emphasizes the importance of using the senses to explore the environment as a complement to rational understanding. While helping to clarify the cause-and-effect relationships between humans and the environment, it also increases students' awareness of their own biological connections to nature. Through conscious involvement with what they see, hear, smell, taste, and touch, students begin to dissolve the boundaries between the observer and the observed, thereby creating an authentic relationship with the environment. Similarly, Beery and Jørgensen (2018) outline a learning progression that emphasizes children's sensory experiences as integral to developing environmental consciousness, blending imagination and knowledge.

A related pedagogical concept worth mentioning in connection with multimodal exploration is experiential learning. Experiential learning is defined as "the process whereby knowledge is created through the transformation of experience" (Kolb, 2014). Kolb describes this as a cyclical model with four phases: 1. concrete experience (experiencing), 2. reflective observation (reflecting), 3. abstract conceptualization (thinking), and 4. active experimentation (acting). The cycle begins with a concrete experience, followed by reflection. Learners then connect this experience with their prior and new knowledge, solidifying their understanding, which then leads to new behaviors.

Hence, multimodal exploration through concrete experiences enhances connection with the environment and implicitly strengthens eco-awareness, ultimately encouraging environmental stewardship. Outdoor explorations, eco-art projects, and reflective storytelling illustrate how sensory experience combined with emotional expression can foster a conscious attachment to nature (Beery, 2013). Activities such as noticing local ecosystems, conducting field-based investigations, visualizing and interpreting ecological data, and communicating findings through visual art, narrative, or digital media stimulate both the cognitive and affective dimensions of awareness (Somerville & Green, 2012).

Multimodal involvement allows learners not only to "learn about" the environment but also to experience it in layered, meaningful ways. Embodied and multisensory methods have been shown to deepen learners' relationships with nature and cultivate ecological sensitivity (Beames et al., 2012). For example, combining field observations with reflective writing and digital photography enables students to merge scientific inquiry with personal insight, fostering environmental responsibility through rich multimodal experiences supported by digital tools.

Digital exploration as a complement to direct experience

Deepening environmental education concepts and exploring the environment through the senses can be supported by integrating digital technologies into learning activities. Learners can use immersive tools such as augmented reality (AR) and virtual reality (VR) to witness ecosystems, engage with species, and model ecological processes that would otherwise be unavailable (Markowitz et al., 2018). Similarly, gamified platforms can engage learners in tasks such as monitoring biodiversity or reducing virtual ecological footprints, reinforcing both knowledge and affective engagement. Mobile applications for biodiversity monitoring, ecological footprint calculation, or citizen science projects also encourage active involvement and a sense of responsibility (Boncu et al., 2022).

Digital technologies also enhance the teaching and learning process. In a recent study, Greenwood and Hougham (2015) reported that digital tools – such as plant identification apps, simulators, and virtual hiking experiences – have become increasingly integrated into environmental education. According to the authors, these digital technologies provide essential means for gathering, tracking, and sharing relevant ecological information, and for involving students and the wider public in citizen science initiatives. Applications that facilitate the recognition of plants and animals, the measurement of noise pollution, or the documentation of natural elements also support the exploration and highlight the human-environment relationship. Several concrete examples of integrating digital technologies in environmental education are detailed in the practical suggestions subchapter.

The integration of multimodal and digital approaches is not intended to replace direct contact with the natural world but to complement and amplify it. When learners alternate between outdoor inquiry and digital enhancement their engagement deepens and becomes more personal. Research suggests that this hybrid model strengthens both the affective dimension (empathy and appreciation for nature) and the cognitive-behavioral dimension (knowledge application and action orientation) of connectedness (Markowitz et al., 2018).

In conclusion, multimodal exploration is an effective way to promote connectedness with nature and contributes to both the cognitive and affective dimensions of environmental awareness. However, its influence on sustainable behavior depends on the development of scientific and digital competences alongside environmental competences, which enable individuals to engage with, interpret, and act upon the natural world in meaningful ways. Multimodal exploration therefore reaches its full educational potential when embedded within a broader competence-based framework for action, as discussed in the next section.

2.4. Competences for action – scientific, environmental, and digital competences

Translating environmental awareness and stewardship into sustained behavior requires the development of competences for action. According to the Council of the European Union's recommendations, competences are understood as a combination of different types of knowledge, skills, values, and attitudes that a person acquires in various learning situations. Competences provide learners not only with knowledge but also with the cognitive, affective, and practical resources necessary to make informed decisions and engage in responsible practices (Council of the European Union, 2018). In environmental education, three types of competences are especially important: scientific, environmental, and digital. Together, they form the foundation that enables learners to move beyond awareness and toward meaningful environmental stewardship.

Scientific competences

The Romanian national education system, through the National Education Law no. 198/2023, has adopted the eight key competences recommended by the European Commission as overarching objectives for both compulsory and post-compulsory education (Parliament of Romania, 2023). However, because scientific subjects (Biology, Chemistry, and Physics) are taught separately in Romania, the present article frames scientific competences through the lens of Biology competences and the middle-school Biology syllabus.

The middle-school Biology syllabus focuses on developing four general competences – learning outcomes with a high level of generality, achieved at the end of a learning cycle (Șăitan, 2017; Kenyeres et al., 2022):

1. *Exploring biological systems, processes, and phenomena using scientific tools and methods;*
2. *Communicating appropriately in different scientific and social contexts;*
3. *Solving problem situations in the living world based on logical thinking and creativity;*
4. *Manifesting a healthy lifestyle within a natural environment conducive to life* (Ministry of National Education, 2017).

But why is it necessary to discuss scientific competences – specifically those developed through the study of Biology – in the context of environmental education and environmental competences?

First, in the proposed model, scientific competences are essential prerequisites for developing environmental awareness and environmental stewardship, which later converge toward the formation of environmental competences. Multiple researchers support this premise. For example, Popov (2006) argues that environmental competence manifests: “as a synthesis of intellectual and scientific components (cognitive and activity-based, including general knowledge and skills), personal characteristics (values, abilities, traits, willingness to engage in various activities), and experience that allows a person to use their potential to carry out complex tasks, and to adapt promptly and successfully to a constantly changing society and professional environment.” Furthermore, according to Berenyi (2016), developing scientific competences is essential for explaining the natural and mechanical processes underlying environmental issues.

A detailed analysis of general competences 1 and 3 shows that they support the development of exploratory knowledge and skills, critical and creative thinking, problem-solving abilities, as well as reflective attitudes – awareness of one’s place within the ecosystem – and decision-making skills aimed at protecting both the individual and the surrounding environment (Kenyeres et al., 2022). These objectives are closely connected to the meaning of environmental competences.

Environmental competences

The ultimate goal of environmental education is to foster a more ecological way of living. This can be attained by acquisition of environmental competences (EC). Specialists in this area define EC as abilities to make decisions that minimize environmental harm, to follow the principles of sustainable development, to apply environmental knowledge in real-life situations, and to take responsibility for addressing environmental issues arising from one's personal activities (Romaniuk et al., 2021). Other authors argue that EC are strongly related to environmental awareness, culture, ethics, behavior and values and consist of developing: "*cognitive skills* (understanding environmental processes and impacts), *practical skills* (ability to apply sustainable practices), *affective skills* (values, attitudes, and motivation to act), and *metacognitive skills* (reflection and critical thinking)" (Doychinova, 2024). Khrolenko (2021) defines EC as comprising several core components: "cognitive (knowledge-based), informational–experimental, motivational–value-oriented (axiological), and operational (practical–applied)". Considering the competence-based approach, EC can be understood as the application of this educational paradigm within the domains of ecology and sustainable development. Thus, environmental competence encompasses knowledge, skills, and attitudes that are applied in the background of environmental education.

Aligned with this paradigm, previous studies have proposed various models that describe what EC entail and how they can be developed, considering the interdependencies among factors that support its acquisition. Grasel (2001) described EC as a result of three interrelated aptitudes: application of knowledge, evaluation of behavioral alternatives (in terms of feasibility and consequences) and self-reflection. Corral-Verdugo (2002), however, described EC as a latent disposition that feed into different skills (knowing how to practice ecological behaviors) and aptitudes such as: personal motives, cultural beliefs, and awareness of environmental situations (environmental perception).

Kaiser and Fuhrer (2003) conceptually separated the types of knowledge associated with EC in:

a) ***environmental system knowledge*** (knowledge about how the natural environment functions),

b) ***action-related knowledge*** (knowledge about actions that reduce negative impact on the environment), and

c) ***effectiveness knowledge*** (knowledge about how effective are various behaviors in terms of reducing for example CO_2 emissions).

Subsequently, Frick et al. (2004) examined the relationship between environmental system knowledge and pro-environmental behavior. Their findings showed that although system knowledge did not directly trigger ecological behavior, it facilitated the acquisition of action-related and effectiveness knowledge. These latter two forms of knowledge, when combined, promoted pro-environmental behavior.

While environmental competences provide the cognitive, practical, and ethical grounding for responsible interaction with the natural world, they cannot be fully developed in isolation from today's digital landscape. As learners increasingly engage with information, communication, and problem-solving through digital tools, digital competences become essential for understanding, monitoring, and acting upon environmental issues.

Digital competences

A distinctive aspect of contemporary education is the increasing importance of digital competences in supporting environmental awareness and stewardship. Defined by the European Commission (2019) as the confident, critical, and responsible use of digital technologies for learning, work, and participation in society, digital competences extend environmental learning into interactive, multimodal contexts. Tools such as simulations, augmented and virtual reality, gamified environments, and collaborative online platforms allow students to explore complex ecological processes that are otherwise inaccessible. As previously mentioned, research indicates that integrating digital approaches enhances motivation, engagement, and long-term retention of pro-environmental attitudes (Markowitz et al., 2018).

Moreover, digital competences are central to fostering a sense of agency. When students monitor their ecological footprint through apps, share findings in collaborative digital platforms, or engage in online citizen science, they see their actions as part of a larger community of practice. Thus, digital competences complement scientific and environmental competences by situating knowledge and responsibility within the realities of learners' digital culture.

Together, these three types of competences provide the foundation for transforming awareness into action, a process illustrated in the following practical section through an applied example of fostering environmental awareness and stewardship.

3. PRACTICAL SUGGESTIONS

The next section presents an activity aligned with the proposed model outlined above. The activity is inspired by 4DX cinema experiences, where the design principle is to "use your senses" to engage actively and become fully immersed in the experience. In this way, a sensory and emotional connection with the surrounding environment is created. The activity is based on a multimodal exploration of the world, using four senses – visual, auditory, olfactory, and tactile – with the support of digital tools, and can be completed within a single school day. This method of exploring the environment through the senses, involves visiting locations that are impacted by human activity, such as industrial areas, and natural settings like forests. The purpose of the visit is to bring students into direct contact with nature, to observe the biophysical features, and to identify signs of human influence on habitats. Engaging the senses during the exploration helps strengthen students' connection to the natural world while fostering environmental awareness and stewardship.

4. METHODOLOGY

Participants and duration

- **Target group:** Lower secondary students
- **Group size:** 15–30 students
- **Duration:** One school day (3–6 hours depending on transport and site accessibility)

Targeted competences

a) Scientific competences (derived from the Biology syllabus)

a. Exploring biological systems, processes, and phenomena using scientific tools and methods.

b. Solving problem situations in the living world based on logical thinking and creativity.

b) Environmental competences

a. Developing awareness by perceiving, comparing, and reflecting on environmental conditions across contexts.

b. Assuming responsibility by identifying and proposing sustainable individual and collective actions.

c) Digital competences

a. Using digital tools to document, classify, and analyze environmental observations.

b. Monitoring environmental changes over time by using digital tools to track, compare, and interpret the effects of human activities.

Learning objectives

- Students will describe the concept of ecological and carbon footprint, based on their experience in the natural environment.
- Students will reason about the human impact on the environment based on the information gathered during the outdoor activity.

Students will propose solutions to reduce their carbon footprint based on the reflection exercise.

Materials

- Mobile devices, tablets or laptops;
- Flipchart sheets;
- Markers

Locations

1. Industrial area
2. Natural habitat (e.g. a forest)
3. Classroom

Procedure

Part I: Exploring an industrial area

The purpose of visiting an industrial area is to highlight the effect of human activities on the environment. This component of the activity guides students to explore cause–effect relationships between people and the environment through multimodal observation and digital tools.

The first exercise establishes an initial connection through the auditory sense. Students are invited to remain silent for one minute and attend closely to the surrounding soundscape. *What types of sounds do they identify?* In industrial zones, these may include traffic noise, mechanical tools, or industrial machinery. Afterward, students briefly reflect on their emotional and physical responses: *did the environment feel comfortable or safe?* Using a *decibel-meter application*, students then measure sound intensity to identify potential sources and levels of noise pollution.

Figure 2. Industrial area illustrating visible sources of emissions
Source: Public domain image

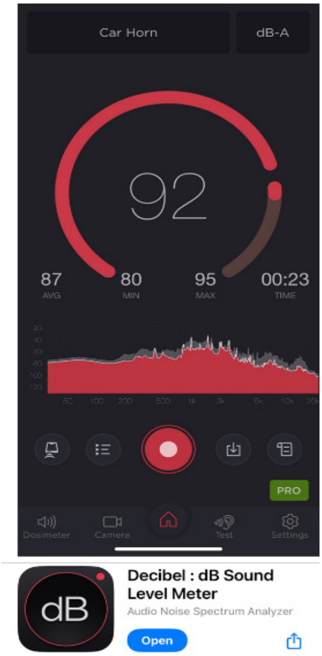

Figure 3. Example of sound level measurement
using the Decibel: dB Sound Level Meter app
Source: Screenshot from the Decibel: dB Sound Level Meter app

A second activity focuses on visual exploration and environmental recognition. Students observe natural and artificial elements in the area: *how many plant or animal species are visible? What built structures dominate the landscape, and what impacts might they have? How many vehicles circulate in the area?* By observing, students are also able to see the smoke rising from heavily producing factories, as well as the smoke from automobiles burning fuel. These are indicators of carbon footprint. Students record what they notice and reflect on how these features shape their feelings about the environment.

The final exercise in this section activates the sense of smell. Students focus on their breathing for one minute, inhaling and exhaling deliberately. *What scents do they perceive? What does the air feel like?* Industrial areas often contain odors associated with emissions, fuel combustion, or chemical processes, and students note their sensory impressions. This reflection supports awareness of air quality and its relationship to human activities.

Part II: Exploring a forest

Visiting a forest on the periphery of a city aims to provide students with a genuine connection to nature. Compared with industrial zones, this environment is minimally affected by human intervention, allowing students to engage with it in a more authentic way. As in the previous activity, at least four senses will be activated during the exploration.

Following the same methodology, students are invited to remain silent for one minute and attend closely to the sounds they can hear. *Which sounds will the students be able to identify*? Students may identify bird calls, insect vibrations, the rustling of leaves, or the cracking of dry twigs. This sensory investigation may stimulate curiosity about the sources of these sounds. Using apps such as *BirdNet Sound ID*, students can record and identify bird species based on audio input.

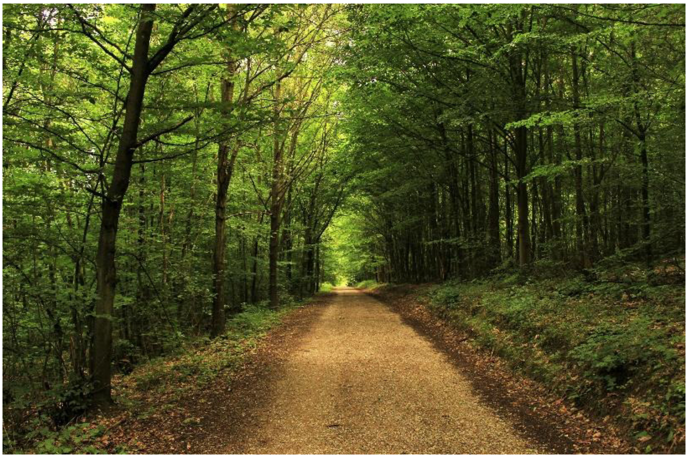

Figure 4. Forest environment used for multimodal exploration activities
Source: Public domain image

Figure 5. BirdNET Sound ID – digital tool for identifying bird species based on audio input
Source: BirdNET Project, Cornell Lab of Ornithology and Chemnitz University of Technology (https://birdnet.cornell.edu/)

Students will again measure sound intensity with the decibel app and compare the results with those collected in the industrial area, noting the significant differences between the two sites. Afterward, students reflect on their emotional responses to the soundscape.

The second activity focuses on visual and tactile exploration. Students observe natural and man-made elements present in the forest. Here, they may encounter the full biocenosis of the ecosystem: animals (birds, insects), plants, fungi, lichens, and other organisms. Some students may be drawn to particular trees, others to lichens growing on the bark, and others to the diversity of plants or fungi they notice. Applications such as *PictureThis* or *iNaturalist* can support this investigation by identifying species and providing information about their characteristics, habitat, and ecological requirements.

Figure 6. PictureThis application logo
Source: PictureThis – Plant Identifier App (https://www.picturethisai.com/)

Figure 7. iNaturalist application logo
Source: iNaturalist Platform, California Academy of Sciences & National Geographic Society (https://www.inaturalist.org/)

Direct contact with nature through touch deepens the sense of connection and, implicitly, nature awareness. Alongside the diversity and beauty of the biocenosis, students may also encounter traces of human intervention – improperly disposed plastics, waste, or areas affected by deforestation. These observations encourage students to reflect on human impact even in environments perceived as natural.

Finally, students activate the sense of smell to investigate the forest environment. *What scents can they identify?* Depending on the type of forest, they may perceive woody or resinous aromas, the scent of moss, lichens, insects, fungi, or soil. In some areas, they may also detect unpleasant odors resulting from improperly discarded waste. This multisensory engagement supports a deeper, embodied understanding of the ecosystem.

Part III: Classroom activity

Back in the classroom, students reflect on their field experiences by following Kolb's experiential learning cycle. They deepen their awareness by drawing inferences from what they saw, heard, smelled, and felt, and they further internalize the relationship between humans and the natural environment. To strengthen their environmental knowledge, students also engage in conceptual learning related to climate change, ecological and carbon footprints, and environmental stewardship. Discussions include the idea of a *handprint* and how individual and collective actions can mitigate environmental degradation.

Using a fishbone graphic organizer, students work in a whole-class activity to identify the causal factors observed during the field trip – such as deforestation, plastic waste, and carbon emissions from cars and factories – that contribute to accelerating global warming. This exercise provides an opportunity to explore and consolidate key concepts including *carbon footprint*, *ecological footprint*, *climate change*, and *global warming*.

Considering the fact that carbon emissions are the main factor contributing to the acceleration of global warming students can use the ecological footprint calculator to estimate their own environmental impact and better understand how carbon footprint metrics are determined.

Figure 8. Ecological Footprint Calculator interface
Source: Global Footprint Network – Ecological Footprint Calculator
(https://www.footprintcalculator.org/home/en)

To help students visualize the consequences of climate change, two digital simulations can be integrated into the activity. *See how your city's climate might change* (National Geographic simulator) uses scientific data to approximate changes in average regional temperatures by 2070. For example, projections for Cluj, Romania, indicate increases in both summer and winter averages by approximately 5-6°C.

Figure 9. Climate change projection interface from the National Geographic climate simulator

Source: National Geographic – "See how your city's climate might change by 2070" (https://www.nationalgeographic.com/magazine/graphics/see-how-your-citys-climate-might-change-by-2070-feature)

How concerning are these issues? They may seem abstract or distant to students, who often perceive climate change impacts as unlikely to occur in the near future. By using the following simulator, however, they can gain a more concrete understanding of these changes and their ecological implications. The *Climate Change Impact Filter* (Google Experiments) simulator illustrates, for example, how an ecosystem's fauna would respond to an average temperature increase of approximately five degrees, as projected for Cluj. Under such conditions, the model shows that many species would no longer survive. In contrast, what happens to improperly discarded waste – such as bottles or juice cans – under the same temperature increase? Unfortunately, the answer is very little: these materials remain largely unchanged, as they decompose only at much higher temperatures and over extremely long periods of time.

Figure 10. Interface of the Climate Change Impact Filter showing species survival projections under rising temperatures
Source: Google Arts & Culture – Climate Change Impact Filter (https://experiments.withgoogle.com/climate-impact-filter)

In the final classroom activity, using the Three-Step Interview technique, students reflect on their experience and on the possibility of changing certain behaviors. This activity requires working in groups of four, with each student taking on a different role in each interview round. They respond to several guiding questions: *what sensations or feelings did the two locations evoke for you? Which aspects of your daily behavior contribute to an increased carbon footprint? How can you contribute to reducing the carbon footprint?* The activity concludes with the creation of products such as posters, diagrams, or oral presentations through which students reflect on and propose solutions to various environmental problems.

Together, the set of activities presented above demonstrates how multimodal exploration, combined with digital tools and structured classroom reflection, can effectively transform environmental awareness into meaningful engagement. By activating multiple senses, field observations, and collaborative classroom work, students begin to develop the scientific, environmental, and digital competences needed to understand and respond to ecological challenges. These practical examples illustrate how environmental awareness and stewardship can be meaningfully initiated within everyday school practice.

5. CONCLUSIONS

Climate change and its negative consequences represent the most acute environmental problems requiring educational approaches to mitigate these challenges (IPCC, 2023; NCEI, 2025), therefore, raising awareness of these issues, along with enhancing active engagement, are important measures for combating these problems. The purpose of this article is to propose a model for developing eco-awareness and environmental stewardship based on the development of scientific, environmental, and digital competences and increasing connectedness to the environment through multimodal exploration supported by digital technologies.

The analysis presented in this article shows that environmental awareness and environmental stewardship are not isolated constructs but interconnected dimensions that evolve through cognitive understanding, emotional sensitivity, and action-oriented responsibility (Roczen et al., 2014). The conceptual model proposed here illustrates how environmental awareness requires establishing a connection with the environment, achieved through the development of scientific, environmental, and digital competences and mediated by the senses and technology (multimodal and digital exploration) and how this ultimately leads to the internalization of stewardship behaviors (Pensini et al., 2016). Multimodal exploration through the senses is the basis for establishing a connection with the environment, because daily interaction with the environment is achieved through the senses, which determine the feeling of awareness and presence (Marruci et al., 2021). Digital technologies such as AR/VR, 3D applications, observation tools, digital maps, etc. contribute to this connection by expanding access to and analysis of natural phenomena, processes, and elements (Markowitz et al., 2018).

The practical example provided – based on the multimodal and digital exploration of contrasting environments – demonstrates how the theoretical constructs discussed can be meaningfully operationalized in everyday school practice. Through sensory interaction, comparative analysis, experiential reflection, and the use of digital tools, students begin to develop the scientific, environmental, and digital competences needed to interpret environmental changes and propose sustainable solutions (Șăitan, 2017; Kenyeres et al., 2022). This approach effectively addresses the value–action gap identified in environmental education research (Kollmuss & Agyeman, 2002; Gifford & Nilsson, 2014) by enabling learners to translate awareness into responsibility and responsibility into informed action.

From this perspective, the article offers several contributions. From a conceptual standpoint, it describes and combines ideas from competence-based education, environmental awareness, stewardship, and connectedness to nature into a single model specifically designed for lower secondary education. From a pedagogical perspective, it transforms this model into a concrete activity sequence that integrates digital tools, multimodal, and outdoor exploration in order to support environmental awareness and stewardship. From an educational standpoint, it aligns with current national and European policy orientations that prioritize sustainability competences and the responsible use of digital technologies in education (Bianchi et al., 2022; Council of the European Union, 2018; Parliament of Romania, 2023). Together, these contributions position the article at the intersection of environmental education, science education, and digital education, making it relevant for curriculum designers, teacher educators, and practitioners interested in competence-based approaches to sustainability.

The article also presents a series of limitations that open up future directions for research. Firstly, the proposed model is predominantly conceptual and exemplified by a single activity applicable in lower secondary education. The article does not report empirical data on learning outcomes, changes in attitudes, or sustained behavioral effects. Second, the pedagogical design presupposes access to natural and anthropized sites, adequate time for fieldwork, and sufficient digital infrastructure and competences at the school level – conditions that may not be uniformly available across educational contexts.

In relation to future research directions, a first step would be the empirical validation of the proposed conceptual model. Studies should be conducted to investigate the impact of multimodal exploration and digital technologies on ecological behaviors. Other interventions or digital resources can also be developed to support the development of ecological awareness and stewardship. Last but not least, the professional development of teachers must be considered, preparing them for the design, implementation, and adaptation of activities aimed at developing ecological awareness and stewardship.

In conclusion, environmental stewardship is developed through a combination of awareness, knowledge, experience, and emotional involvement. This can be achieved by increasing connection with the environment through multimodal and digital exploration, based on the simultaneous development of scientific, digital, and environmental competences. Increasing environmental stewardship is a continuous process, that equips learners not only to understand the challenges of our time but also to participate actively in shaping a more sustainable future.

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