Chapter Four

Innovative Digital Tools and E-Learning for Green Skills Development

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The E-Learning Classroom and MOOCs: Pedagogical Approaches to Circular Economy and Plastic Waste Management

The transition towards a circular economy (CE) and sustainable plastic waste management is a critical global challenge, increasingly addressed through education and capacity building. As digital transformation reshapes the educational landscape, the 'e-learning classroom' and Massive Open Online Courses (MOOCS) have emerged as pivotal tools for disseminating knowledge and fostering 'green skills' among diverse learners, from students to industry professionals (Školnik Škrabe et al., 2025). This review examines current pedagogical approaches in online education for circularity, with a particular focus on the EDU4PlastiCircular project and its contribution to the field.

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Massive open online courses (MOOCS) emerged in the early 2010s as a disruptive innovation within higher education institutions, promising to democratize access to quality learning resources on an unprecedented scale. MOOCS are characterized by their openness (often free or low-cost), scalability (allowing thousands of simultaneous learners), and flexibility (allowing self-paced or cohort-based learning) (Arıker, 2021). Major platforms such as Coursera, edX, FutureLearn, as well as other local, regional initiatives have proliferated globally, offering courses in various disciplines. The COVID-19 pandemic has accelerated the adoption of MOOCS as educational institutions around the world have faced sudden closures and the imperative to move to distance learning (Agrawal & Ting, 2022). This crisis has revealed both the potential and the limitations of online education, catalysing innovations in pedagogical design, technological infrastructure, and learner support systems (Borowska & Kołodziej, 2022). In addition, MOOCS have been recognized as a fundamental tool for the delivery of entrepreneurial education, offering methods to reach large volumes of students in culturally rich virtual workspaces.

Recent developments have introduced hybrid models, including SPOCS (Small Private Online Courses) that combine MOOC technologies with limited enrolment and institutional integration, as well as blended learning approaches that blend online and face-to-face instruction. Thus, MOOC platforms have evolved from simple content repositories to sophisticated learning ecosystems that incorporate adaptive learning technologies, social learning features, and accreditation mechanisms (Arıker, 2021; Konecki, 2025).

The Role of E-Learning and MOOCS in Circular Economy Education

Online education offers a scalable and accessible platform for teaching the complex, interdisciplinary nature of the circular economy. Research indicates that MOOCS are particularly effective for lifelong learning and professional development in environmental management (Pérez & Spalletti, 2021). Modern e-learning for CE has moved beyond traditional didactic teaching towards more interactive and student-centred methodologies. Literature highlights key strategies such as:

- *Interdisciplinary integration.* Effective CE education must bridge the gap between technical, economic, social, and managerial perspectives (Wageningen University & Research, 2023).

- *Inquiry-based and simulation learning.* Studies comparing different teaching methods for plastic waste management found that 'guided inquiry' and 'gaming simulations' significantly outperform direct teaching in enhancing students' problem-solving capacities and recycling intentions (Yeung et al., 2017).
- *Visual didactic regulators.* The use of visual tools and digital libraries helps in structuring complex information about the plastic lifecycle, from design to end-of-life (Steinberg et al., 2025).

Content analysis of existing online courses reveals a shift from simple waste management (downstream solutions) to a holistic 'lifecycle approach' (upstream and downstream). Courses are increasingly emphasizing sustainable design, circular business models, and the reduction of microplastics (Dermol & Dermol, 2024). For instance, the 'Sustainable Packaging in a Circular Economy' MOOC by Delft University of Technology focuses on design strategies to eliminate waste before it is created.[1]

Circular Economy and Plastic Waste Management in Higher Education

Plastic systems involve interconnected processes of production, consumption, waste management, and environmental leakage, thus the plastic waste management as a complex, multi-scalar system problem. The implementation of the circular economy (CE) framework proposing the close of the material loops through reuse, recycling, and redesign of products and systems is constrained by behavioral, institutional, and knowledge-related barriers (Kirchherr et al., 2017). Consequently, education in this domain must address not only technical processes but also decision-making, responsibility, and systemic interactions.

The framework for Education for Sustainable Development developed by UNESCO emphasizes competencies such as critical thinking, collaboration, and strategic action (UNESCO, 2017). Research indicates that effective ESD requires participatory and action-oriented learning (Lozano et al., 2017). Thus, learning is extended beyond knowledge acquisition toward competence development and action.

[1] See https://www.edx.org/learn/circular-economy/delft-university-of-technology-sustainable-packaging-in-a-circular-economy

In this context, Higher Education Institutions (HEIS) serve as 'microcosms' for the circular transition. Integrating CE principles into university curricula involves not only theoretical knowledge but also practical 'campus-as-a-living-lab' initiatives where students manage plastic waste on-site (Vergani, 2024). The concept of 'green skills' is central to modern sustainability pedagogy. These skills encompass technical expertise (e.g., polymer recycling), cognitive skills (e.g., systems thinking), and values/attitudes necessary for a climate-neutral economy (United Nations Environment Programme, 2025). The EDU4 PlastiCircular project specifically targets these skills to bridge the educational gap in plastic circularity (Školnik Škrabe et al., 2025).

The EDU4 PlastiCircular Project: A Case Study in Innovative Pedagogy

The Erasmus+ project EDU4 PlastiCircular (Education for Plastic in a Circular and Climate Neutral Economy) represents a significant advancement in e-learning for plastic management.

- *Targeted training.* The project develops open-access training materials and an e-learning platform specifically designed for HEI staff, students, and industry managers (Školnik Škrabe et al., 2025).
- *Innovative methods.* By employing MOOCS and a digital library, the project promotes equitable access to high-quality education regardless of geographic limitations, as mentioned in the *Handbook for Trainers.*[2]
- *Curriculum structure.* The project's handbook for trainers outlines a structured approach with five chapters, covering the entire plastic value chain and emphasizing the transition to a circular and climate-neutral model (Giurea et al., 2025).

The EDU4 PlastiCircular Learning Ecosystem

The EDU4 PlastiCircular initiative can be analyzed as a learning ecosystem rather than as a single online course because its instructional architecture combines multiple actors, learning environments, resources, and activity types into an integrated system organized around a shared sustainability problem: plastic circularity and plastic waste management.

[2] See https://dermol.si/wp-content/uploads/2025/05/D2.3-Handbook-for-Trainers.pdf

In ecosystem terms, the relevant analytical units are not limited to content modules, but include the relationships among digital infrastructure, pedagogical design, learners, educators, project partners, and real-world contexts of application. This interpretation is consistent with design-based views of higher education, according to which technology-mediated learning environments become educationally effective when tools, tasks, and feedback processes are intentionally aligned with learning goals and participation structures (Laurillard, 2012). It is also consistent with the literature on Education for Sustainable Development, which emphasizes that sustainability competencies are best developed in settings that connect knowledge, action, and stakeholder interaction rather than in isolated disciplinary instruction (UNESCO, 2017; Wiek et al., 2011).

At structural level, the EDU4 PlastiCircular learning ecosystem consists at least of five components, described in Figure 4.1: content, pedagogical frameworks, social interaction, experiential environment.

The content is organized into thematic modules covering plastic materials, waste management, circular economy, organizational responsibility, and awareness and responsible behavior. Each module contains topics structured in lessons. The EDU4 PlastiCircular Handbook[3] provides the topics structured in Learning Activities and Assessment (LAA) as the fundamental instructional units that operationalize the course design. They are not single tasks, but structured methodological sequences that integrate learning objectives, instructional input, learner activity, and assessment.

The pedagogical design of EDU4 PlastiCircular reflects an integrated approach, combining experiential learning (experiments, internships), problem-based learning (case studies, design challenges), project-based learning (such as 3D printing), systems thinking (LCA, pathway mapping), collaborative learning (role-play, group projects), transformative learning (thorough reflection, ethical analysis). This integration supports the sustainability education which requires multi-method pedagogical frameworks to address complex, interdisciplinary problems and to support behavioral change. Importantly, these approaches are not applied independently but are embedded within the LAA structure, ensuring that each learning sequence combines conceptual understanding (through lectures, interactive lectures, e-learning platform

[3] See https://dermol.si/wp-content/uploads/2025/05/D2.3-Handbook-for-Trainers.pdf

readings, etc), active engagement of learners in activities in different learning environments, reflection on the new understanding, application in new contexts. This approach enables learners to move from knowledge acquisition to applied competence and action in the context of circular economy and plastic waste management.

The digital component is centered on an e-learning platform and digital resources that support access to materials, case studies, open educational resources, and online assessment. Among the multiple facilities and advantages of digitalization in the EDU4PlastiCircular learning ecosystem we mention in this context the access to the learning content, the opportunity for multiple interactions, the opportunities of learning analytics.

The social component is based on different types of interactions provided by the ecosystem: among learners, since many LAA propose collaborative activities (peer discussions, group production, or stakeholder simulations engaging methods like role-play, group projects, jigsaw), among authors (since the EDU4PlastiCircular learning ecosystem is the result of the collaboration of project members).

The ecosystem includes the experiential component, because learning sequences explicitly extend beyond the digital classroom to laboratory experimentation, field-like problem contexts, or workplace-based internship learning. In EDU4PlastiCircular, real-world integration is evident across modules, as for example: Plastic pollution pathway analysis (requires learners to map real environmental processes disturbed by plastics); Lifecycle assessment tasks (require evaluation of actual production and waste scenarios); Behavioral intervention design (requires learners to propose actionable strategies to reduce plastic use). These activities are not abstract exercises; they are structured to simulate or directly engage with real systems, enabling learners to connect knowledge with decision-making and intervention design.

The EDU4PlastiCircular learning ecosystem is addressed at different levels of educational activity (micro – individual, mezzo – course/classroom, macro – institutional), since it provides tools for a holistic design to link knowledge, skills and actions. The structure supports progression from cognitive to transformative outcomes, starting with knowledge and awareness, and analytical and systems thinking, going through ethical and systemic reasoning, and application and problem-solving, and envisaging behavioral and transformative outcomes. The transformative learning outcomes can be systematically developed

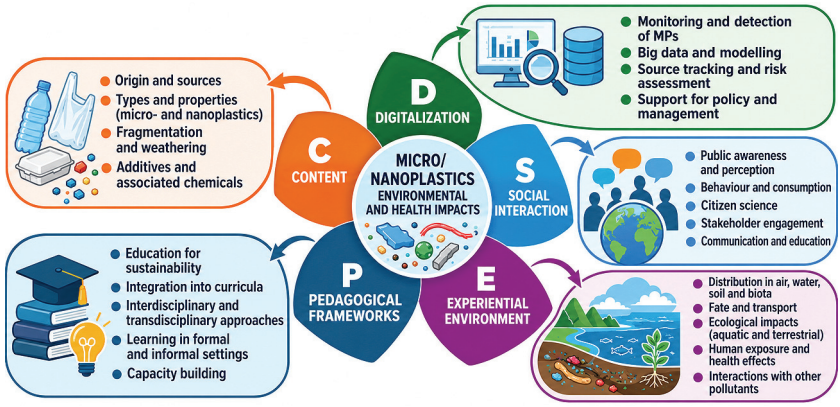


FIGURE 4.1 Components of the EDU4 PlastiCircular Learning Ecosystem

NOTES Created using ChatGPT.

through integration of cognitive, practical, and reflective activities, alignment of pedagogical approaches with competence frameworks, incorporation of real-world and behavioral dimensions. The combination of these elements enables learners to move from knowledge acquisition to systems understanding, competence development, behavioral change, perspective transformation. At the level of implementation, this concept can operate in various contexts, thus one can distinguish (design/implement) between different learning environments:

- *Digital learning ecosystem* – fully mediated by digital platform;
- *Blended ecosystem* – combines physical and digital environment;
- *Work-integrated ecosystem* – links academia with industry and practice;
- *Sustainable learning ecosystem* – focusing on complex, transdisciplinary challenges.

The EDU4 PlastiCircular learning ecosystem extends beyond the e-learning classroom by establishing a distributed learning ecosystem in which:

- Learning occurs across multiple contexts (digital, experiential, social);
- Stakeholders are integrated into the learning process;
- Real-world problems structure learning activities;

- Feedback supports iterative development;
- Behavioral and societal dimensions are explicitly addressed.

This configuration aligns with contemporary research in sustainability education, which identifies ecosystem-based approaches as necessary for developing competencies and enabling meaningful engagement with complex environmental challenges.

Challenges and Future Directions

Implementing sustainable, digital learning ecosystems faces structural, pedagogical, and technological challenges. Research in higher education indicates that sustainability education initiatives often encounter barriers related to institutional capacity, pedagogical integration, and digital transformation (Abo-Khalil, 2024). These challenges are not incidental but reflect the complexity of integrating interdisciplinary content, innovative pedagogies, and digital infrastructures within existing educational systems.

The EDU4PlastiCircular initiative provides a relevant case for examining these challenges, as it combines:

- Sustainability content (circular economy, plastic waste);
- Complex pedagogical approaches (experiential, problem-based, transformative learning);
- Digital mediation (e-learning platforms, learning analytics).

The *complexity of sustainability as a learning domain* is evident in:

- The need to connect material science with environmental systems;
- The integration of policy and responsibility with engineering design;
- The inclusion of behavioral and societal dimensions.

The challenge comes from the learners who may struggle to integrate interdisciplinary knowledge, to understand system-level interactions, to transfer knowledge across contexts.

To overcome these challenges, the EDU4PlastiCircular offers a modular structure with progressive complexity (from materials → systems → solutions → behavior) is necessary to scaffold learning.

The *pedagogical complexity* and instructional design demands due to the fact that each topic includes multiple LAAS combining lecture, activity, and assessment and activities vary from experiments to role-play, to design tasks requires high design effort for educators, need for pedagogical expertise to manage diverse methods, and difficulty in maintaining coherence across activities. To overcome the challenges due to pedagogical complexity, the use of a standardized LAA structure (learning objectives → activity → assessment) supports consistency and replicability. This reflects design-based approaches to teaching, where structured activity sequences improve alignment and clarity.

Digital transformation in higher education is associated with multiple barriers, including lack of infrastructure, insufficient digital competencies, and institutional constraints. Studies also highlight disparities in access to technology and digital skills as significant obstacles (Adhikari & Rana, 2024).

Although EDU4PlastiCircular is designed as an e-learning ecosystem, such challenges remain relevant: variability in learners' digital skills, dependence on stable digital infrastructure, need for educator training in digital pedagogy. To overcome this challenge, digital tools are usually accompanied by: clear guidance and scaffolding, support for digital skill development, alternative formats when necessary.

Despite the potential of e-learning, challenges remain in ensuring the 'circularity of learning environments' themselves, reducing the digital footprint of education and ensuring that online tools are as sustainable as the topics they teach (Morales et al., 2022). Future research should focus on the long-term impact of MOOCS on behavioural change and the integration of advanced technologies like AI in personalizing CE education.

Building a Knowledge Repository: The Digital Library of Relevant Materials

Purpose and Concept of the Digital Library

A digital library is a system that provides organised access to digital objects (texts, images, audio, video, datasets) through networked environments, enabling discovery, retrieval, preservation, and reuse. Its core purpose is to support learning, research, and scholarship by making cultural, scientific, and educational resources Findable, Accessible, Interoperable, and Reusable (FAIR) within and across institutions. This

concept encompasses metadata creation and management, information organisation, user-centred design, and interoperable technologies that allow diverse users to locate and use digital materials efficiently. Multiple sources converge on these points, emphasising metadata as a primary enabler of findability and interoperability, and the digital library as both a repository and an access/learning platform that evolves with user needs and technological change (Fox & Urs, 2002; Cool & Ng, 2013; Zeng, 2019; Nikolaidou et al., 2005).

In addition to conceptual definitions, research on digital library systems also emphasises the importance of evaluation frameworks and software infrastructures that ensure functionality, usability, and scalability. For example, checklists and evaluation models for digital library software highlight criteria such as accessibility, metadata quality, interoperability, and user experience as essential components of effective digital repositories (Goh et al., 2006; Foo & Theng, 2004). These perspectives further reinforce the understanding of digital libraries as complex socio-technical systems rather than merely collections of digital content.

Digital libraries serve multiple interrelated purposes that support access, preservation, and use of digital knowledge. First, they enhance discoverability and access by enabling diverse user groups (such as scholars, students, and the general public) to efficiently locate digital resources through structured metadata, advanced search interfaces, and interoperable systems (Cool & Ng, 2013; Zeng, 2019; Nikolaidou et al., 2005). Second, they play a crucial role in preservation and stewardship, ensuring long-term access to cultural heritage, scientific data, and scholarly outputs. This is achieved through the use of standardised metadata frameworks and archival practices that support sustainability and interoperability (Cool & Ng, 2013; Ferro & Silvello, 2013; Neugebauer et al., 2012). Third, digital libraries promote interoperability and reuse by enabling integration across heterogeneous systems such as libraries, archives, and museums. Through shared metadata standards and linked data approaches, they facilitate cross-platform discovery, data reuse, and new research opportunities (Fox & Urs, 2002; Zeng, 2019; Chi et al., 2006; Nikolaidou et al., 2005). Furthermore, there is a growing emphasis on user-centred design and contextual relevance, where metadata, interfaces, and content organisation are adapted to user needs. This includes incorporating user-generated input, such as tagging and feedback, to enhance findability and usability (Matu-

siak, 2006; Therrell, 2019; Hu et al., 2018; Cairns, 2013; Klavans et al., 2013). Finally, digital libraries increasingly support digital humanities and data science, providing infrastructures for semantic enrichment, linked data, and advanced analytical workflows. These capabilities enable new forms of knowledge creation and interdisciplinary research (Hyvönen, 2023; Zeng, 2019; Chi et al., 2006; Saumure & Shiri, 2008).

In the case of the EDU4PlastiCircular project, the Digital Library serves as a strategic and pedagogical response to the growing need for structured, accessible, and high-quality knowledge on environmental sustainability, particularly plastics and the circular economy. As highlighted in the analysed study, awareness-raising and capacity-building are essential for enabling systemic transitions toward sustainable and circular models (Dermol & Dermol, 2024). In this context, the Digital Library is conceptualised not merely as a repository of materials but as a comprehensive digital learning ecosystem. It supports the dissemination of interdisciplinary knowledge, combining environmental science, technological innovation, and behavioural change. Its purpose aligns closely with the broader objectives of contemporary sustainability education: promoting informed decision-making, fostering environmental responsibility, and developing the competencies needed to address complex ecological challenges. The Digital Library hosted on microplastics.today exemplifies this approach and serves as a central platform for accessing project outputs, educational materials, and sustainability-related knowledge resources. It is embedded within the Erasmus+ project framework and contributes to the development of green skills, awareness, and sustainable practices related to plastics and the circular economy. By integrating educational materials with digital accessibility, it supports both formal and informal learning environments.

Comparing the Digital Library hosted on microplastics.today with the theoretical definition of a digital library, the analysis shows that the Digital Library largely fulfils key functions of a digital library, particularly in terms of accessibility, content organisation, and support for education. It is important to emphasise that this Digital Library was developed within an Erasmus+ project, with the primary aim of disseminating educational materials and sharing the knowledge generated in the field of plastics and the circular economy. Its strengths are reflected in its well-structured thematic content, multilingual accessibility, and clear focus on learning and awareness-raising. However,

from a technical and infrastructural perspective, it only partially aligns with the characteristics of advanced digital library systems. However, there is limited use of structured metadata, an absence of standardised schemas and interoperability protocols, and a lack of advanced functionalities such as enhanced search capabilities or user-generated metadata. Therefore, it can best be described as a structured, content-rich digital repository with strong dissemination and educational functions, rather than as a fully developed interoperable digital library infrastructure in the strict technical sense (Nikolaidou et al., 2005; Neugebauer et al., 2012; Zeng, 2019).

Development Process

The development of the Digital Library is grounded in both pedagogical principles and empirical insights derived from the analysis of online courses in circular economy education. These findings indicate that effective digital learning environments must be user-centred, modular, and adaptable to diverse audiences, including students, educators, professionals, and policymakers (Dermol & Dermol, 2024). In this context, the Digital Library hosted on the microplastics.today platform was not developed as an isolated output but as part of a structured and iterative project process embedded within the Erasmus+ project EDU4PlastiCircular.

The materials in the Digital Library represent a comprehensive, systematically developed collection of texts, videos, presentations, and other educational resources created during the elaboration of project deliverables. The development process followed a logical progression of activities, including:

- Identification of knowledge gaps and collection of best practices (D2.1);
- Development of curriculum and training methodology (D2.2);
- Creation of open-access digital content and e-learning modules;
- Integration with broader e-learning platforms and training programmes.

More specifically, the Digital Library builds on key outputs, including the analysis and synthesis of existing training programmes, the definition of training personas, the development of learning objectives, curricula, and course structures, and the design of learning paths and

assessment tools (e.g., quizzes and exam questions). Additional components include guidelines for implementing training at higher education institutions, definitions of pedagogical approaches for both online and face-to-face learning, and the conduct of train-the-trainers activities, including presentations and webinars. These outputs were progressively transformed into digital learning materials and curated within the Digital Library, ensuring coherence, pedagogical consistency, and practical applicability. Similar challenges in curriculum design and implementation have been identified in sustainability-focused education initiatives, where the adoption of new content often depends on institutional support, teacher readiness, and alignment with existing curricula (Goodale, 2020).

Content selection within the Digital Library follows clearly defined criteria:

- Scientific reliability and alignment with current research;
- Relevance to circular economy and plastic waste management;
- Applicability to real-world contexts;
- Accessibility and usability for diverse user groups.

Importantly, the development process reflects the need identified in the literature for combining theoretical knowledge with applied learning approaches, such as case studies, practical tools, and real-world examples (Whiter, 2022). This ensures that the Digital Library is not only informative but also actionable, enabling users to translate knowledge into practice.

In this sense, the Digital Library functions as a centralised platform for integrating, disseminating, and reusing knowledge, where project-generated content is systematically organised and made accessible. It also embodies the project's broader objective of developing open training materials, e-learning content, and digital resources to build green skills and promote sustainable practices.

The benefits of this development approach extend across multiple stakeholder groups. For higher education institutions, the Digital Library provides structured curricula, teaching materials, and methodological guidelines that support curriculum innovation and the integration of sustainability topics into formal education. For teachers and trainers, it offers pedagogically grounded resources and training tools to enhance teaching effectiveness and facilitate the delivery of engag-

ing, up-to-date content. For students and learners, it enables flexible, self-directed learning through access to diverse and multimedia-rich materials, supporting the development of knowledge and competencies in the circular economy and environmental sustainability.

Furthermore, professionals and industry stakeholders benefit from practical insights, case-based knowledge, and tools that can be applied in organisational contexts, supporting the implementation of sustainable practices. Policymakers and public sector stakeholders can use the Digital Library as a source of consolidated knowledge and best practices to inform decision-making. Finally, for the broader public, the Digital Library raises awareness and promotes environmentally responsible behaviour by making complex sustainability topics accessible and understandable.

Overall, the Digital Library enhances the transferability, scalability, and long-term impact of project results by ensuring that the knowledge generated within the Erasmus+ project is not only preserved but also actively disseminated, reused, and further developed across different educational and professional contexts.

Structure and Content of the Digital Library

A key strength of the Digital Library lies in its structured, multi-layered content organisation, which reflects both pedagogical logic and the thematic coverage of circular economy education.

The Digital Library is available on microplastics.today platform includes a wide range of content types, such as:

- Presentations;
- Readings and theoretical materials;
- Terminology resources;
- Worksheet templates;
- Videos and multimedia content;
- Project deliverables and reports;
- Newsletters and awareness materials.

These materials are systematically categorised into thematic areas, including:

- Plastics in everyday life and environmental impact;
- Plastic materials and manufacturing technologies;

- Circular economy principles and applications;
- Plastic waste management and recycling;
- Innovation in plastics and sustainable materials.

For example, introductory modules such as 'Plastics in Our Daily Lives' provide foundational knowledge on the use, impact, and sustainability implications of plastics, while more advanced materials address manufacturing technologies and circular economy integration.

An important feature of the Digital Library is its multilingual accessibility, with materials available in several languages (e.g., Slovenian, Spanish, Romanian, Italian), which significantly enhances inclusivity and dissemination potential.

The thematic structure of the Digital Library strongly aligns with the key content areas identified in the analysed online courses, including circular design, waste management, business models, and policy frameworks (Dermol & Dermol, 2024). This alignment confirms that the Digital Library reflects current trends and priorities in sustainability education.

The materials developed within the EDU4PlastiCircular project can be understood as Open Educational Resources (OER), which strongly reinforces the conceptual and functional role of the Digital Library. OER are part of a broader movement of open education that encompasses Open Educational Practices (OEP), open pedagogy, open access, and open licensing frameworks. This broader ecosystem reflects a shift from simply providing access to content toward enabling collaborative, participatory, and flexible learning environments (Shareefa et al., 2023; Benlamri et al., 2016).

From a structural perspective, the Digital Library aligns with established OER taxonomies, as it includes a wide range of resource types, such as course modules, learning objects, video materials, training presentations, and supporting documents. These correspond to commonly recognised forms of OER, including open courseware, multimedia learning materials, and supplementary resources that support diverse learning pathways (Cirulli et al., 2016; Shareefa et al., 2023; Wiley, 2020; Benlamri et al., 2016). In addition, such resources are typically designed to be reusable and adaptable, often supported by open licensing frameworks such as Creative Commons, which operationalise the principles of openness through the well-known 5RS (retain, reuse, revise, remix, redistribute) (Pineda & Guerrieri, 2021; Shareefa et al., 2023). The

development and use of OER are also closely linked to broader discussions on openness in education, which emphasise not only access to resources but also the transformation of educational practices toward more collaborative and participatory models (Peters & Brítez, 2008). In this context, digital repositories play a crucial role in supporting open knowledge infrastructures and facilitating the sharing and adaptation of educational content across institutions.

The integration of OER within a Digital Library also reflects the development of open learning ecosystems, where repositories, metadata practices, and interoperable infrastructures support discoverability and reuse across platforms. Such ecosystems are increasingly connected with learning management systems (LMS), analytics tools, and broader educational networks, enabling scalable and sustainable knowledge dissemination (Otto & Kerres, 2022; Otto et al., 2021; Benlamri et al., 2016; Wiley, 2020). In this sense, the Digital Library functions as a key node within a wider ecosystem of digital learning and knowledge sharing. Furthermore, the integration of repositories with other digital systems, such as learning management systems and institutional platforms, is increasingly recognised as a key factor for enhancing usability and supporting seamless access to learning resources (Penello Temporao & Pavani, 2018).

The educational value of OER further strengthens the rationale for developing and maintaining Digital Libraries. One of the primary purposes of OER is to enhance access, affordability, and equity in education by reducing financial barriers and increasing the availability of high-quality learning materials (Geith & Vignare, 2008; Haughery et al., 2021; Otto & Kerres, 2022; Otto et al., 2021; Shareefa et al., 2023; Wiley, 2020). By making project outputs openly accessible, the Digital Library contributes to more inclusive educational opportunities and supports learners who may otherwise lack access to specialised knowledge.

Beyond access, OER also offer significant pedagogical potential, enabling open pedagogy and innovative teaching practices. They support collaborative learning, co-creation of knowledge, and flexible learning pathways, allowing both educators and learners to adapt materials to specific contexts and needs (Peters & Brítez, 2008; Shareefa et al., 2023). This flexibility is particularly relevant in sustainability education, where interdisciplinary approaches and contextual adaptation are essential.

At the same time, research highlights the importance of systematic

development, evaluation, and curation of OER. Institutions developing digital repositories must address challenges related to discoverability, licensing clarity, quality assurance, and long-term sustainability (Geith & Vignare, 2008; Otto & Kerres, 2022; Wiley, 2020). The effectiveness of OER-based systems also depends on their ability to support diverse learners through accessible design and inclusive practices, including alignment with principles such as Universal Design for Learning (UDL) (Moon & Park, 2021; Shareefa et al., 2023). Issues related to metadata quality, standardisation, and consistency remain central challenges in digital repositories, as poorly structured metadata can significantly reduce discoverability and usability of resources (Stvilia et al., 2006).

From a practical perspective, the implementation of OER within a Digital Library requires a clear strategic approach, including the definition of openness principles, the use of interoperable repository infrastructures, and continuous evaluation of impact and usability (Wiley, 2020; Shareefa et al., 2023; Otto & Kerres, 2022). While openness facilitates reuse and scalability, it must be balanced with considerations of quality, contextual relevance, and pedagogical effectiveness.

Finally, the relationship between OER and digital libraries is particularly significant. OER dissemination relies on digital library-like infrastructures, including metadata, repositories, and interoperability standards, which support access, reuse, and long-term preservation. This convergence highlights the role of Digital Libraries as essential components of modern learning ecosystems, bridging information management practices with educational innovation (Saumure & Shiri, 2008; Krahmer et al., 2021; Shareefa et al., 2023; Wiley, 2020).

In this context, the Digital Library developed within the Erasmus+ project can be seen not only as a repository of materials but as an open, scalable, and pedagogically grounded knowledge infrastructure, supporting both the dissemination of project results and the broader goals of open and inclusive education.

Digital Accessibility and User Experience

The Digital Library demonstrates a strong commitment to accessibility and user-centred design, positioning it as an inclusive digital environment that supports a wide range of users. Digital accessibility refers to the design and delivery of digital content in ways that enable people with diverse abilities-including those with visual, auditory, motor, cognitive, or situational limitations-to perceive, understand, navigate, and

interact effectively with digital systems (Putra et al., 2024; Halbach & Haugstvedt, 2021; Gould et al., 2021). In this sense, accessibility is not a separate feature but an integral component of overall user experience (UX), ensuring that digital platforms are usable, equitable, and effective for all users (Bertot et al., 2006; Snead et al., 2005).

The Digital Library integrates several key features that enhance usability and inclusiveness. These include intuitive navigation and thematic categorisation, which support efficient information retrieval; responsive design, enabling access across different devices and contexts; and accessibility tools, such as text size adjustment and contrast settings, which improve readability and accommodate users with visual impairments. In addition, the platform provides open access to educational materials, reducing barriers to entry and supporting equitable participation in learning. Together, these features contribute to a positive, inclusive user experience, aligning with established accessibility and usability principles in digital environments.

These design choices are particularly important in addressing well-documented barriers in online education, such as the digital divide and varying levels of digital literacy (Jeruszka, 2023). By incorporating accessibility features and offering multilingual content, the Digital Library expands its reach and ensures that a broader and more diverse audience can engage with sustainability-related knowledge. This reflects a user-centred design approach, where content organisation, interface design, and functionality are aligned with the needs and capabilities of different user groups (Putra et al., 2024; Halbach & Haugstvedt, 2021).

From a technical and standards perspective, digital accessibility is commonly guided by frameworks such as the Web Content Accessibility Guidelines (WCAG), which define principles of perceivability, operability, understandability, and robustness. While not all technical compliance details are explicitly visible, the Digital Library reflects several of these principles through its emphasis on readable formats, structured content, and accessible interface design. Moreover, accessibility extends beyond web pages to include diverse content formats such as documents, videos, and interactive materials, all of which should be designed to support assistive technologies and enhance comprehension (Putra et al., 2024; Gould et al., 2021).

Importantly, accessibility is closely linked to user experience and evaluation practices. Integrating accessibility into UX design-through user-centred approaches and iterative testing-ensures that potential

barriers are identified and addressed early in the development process. In digital library contexts, this often involves combining usability testing with accessibility evaluation, including the participation of users with diverse needs (Putra et al., 2024; Bertot et al., 2006; Snead et al., 2005). Although such processes may not always be fully formalised in project-based platforms, the presence of user-friendly features suggests an awareness of these principles. Previous studies also highlight the importance of integrating accessibility evaluation with usability testing to ensure that digital platforms effectively meet the needs of diverse user groups, including those with disabilities (Snead et al., 2005; Bertot et al., 2006).

From a practical perspective, ensuring accessibility requires proactive planning and continuous improvement. Best practices include adopting inclusive design principles, providing alternative text for images, ensuring sufficient colour contrast, enabling keyboard navigation, and offering captions or transcripts for multimedia content (Putra et al., 2024; Halbach & Haugstvedt, 2021; Gould et al., 2021). In addition, the use of accessibility metadata in digital repositories can further enhance discoverability and support users who rely on assistive technologies.

At the same time, the literature highlights ongoing challenges and debates. These include potential trade-offs between visual design and accessibility, the need to ensure that open educational resources are also accessible, and the recognition that accessibility is not a one-time achievement but a continuous process of monitoring, testing, and adaptation (Putra et al., 2024; Snead et al., 2005; Alić, 2025). This perspective is particularly relevant for digital libraries, where content and technologies evolve over time.

In conclusion, the Digital Library reflects key principles of digital accessibility and user-centred design, contributing to an inclusive and effective learning environment. By combining accessible design features with structured content and open access, it supports a positive user experience and aligns with broader goals of equity and inclusion in digital education. At the same time, continued development and evaluation are necessary to ensure that accessibility remains an ongoing priority and that the platform adapts to the evolving needs of its users.

Contribution to Environmental Education

The Digital Library represents an important contribution to environmental education by supporting both knowledge dissemination and

capacity building, thereby enabling the development of competencies necessary for a transition toward a circular and climate-neutral economy. Environmental education (EE) is widely understood as a multidisciplinary and transformative process that equips learners with knowledge, skills, values, and attitudes required to understand and address environmental challenges (Parry & Metzger, 2023; Rahmawati et al., 2022; Abidin et al., 2024). Within this broader framework, the Digital Library functions as a practical tool that operationalises these principles through accessible and structured learning resources.

Environmental education extends beyond raising awareness and aims to foster critical thinking, problem-solving abilities, and action-oriented competences that support sustainable behaviour and decision-making. As emphasised in the literature, effective EE must move beyond theoretical understanding and enable learners to apply knowledge in real-world contexts (Dragomir et al., 2019). The Digital Library responds to this need by integrating multiple forms of learning content, including theoretical materials, practical tools, and case-based learning resources, thereby supporting both conceptual understanding and practical application.

This combination reflects contemporary approaches to EE, which emphasise experiential, place-based, and applied learning. By incorporating real-world examples, project deliverables, and context-specific materials, the Digital Library enables learners to connect abstract concepts with concrete practices. Such an approach aligns with broader educational trends that promote interdisciplinary and action-oriented learning, often situated within the framework of Education for Sustainable Development (ESD) (Parry & Metzger, 2023; Stewart et al., 2021; Bounnite, 2025). Through this integration, learners are encouraged not only to understand environmental issues but also to actively engage in addressing them.

Furthermore, the Digital Library supports key objectives of environmental education, including the development of environmental knowledge, pro-environmental attitudes, and sustainability-related skills. These include critical and systems thinking, collaboration, and the ability to design and implement solutions to environmental challenges (Rahmawati et al., 2022; Bounnite, 2025). By offering diverse, multimedia-rich resources, the platform accommodates different learning styles and supports inclusive, flexible learning pathways.

From a pedagogical perspective, the Digital Library also facilitates

the integration of environmental education into various educational contexts. It can support formal education through curriculum integration, as well as non-formal and informal learning, enabling lifelong learning and broader public engagement. This is particularly important given that effective environmental education often requires cross-curricular approaches, teacher training, and institutional support to ensure meaningful implementation (Abidin et al., 2024; Stewart et al., 2021).

At the same time, the Digital Library addresses some of the practical challenges in environmental education, such as limited access to high-quality materials, a lack of teaching resources, and the need for adaptable, context-relevant content. By providing openly accessible, structured, and reusable materials, it helps reduce these barriers and supports educators and learners in implementing sustainability-oriented learning practices.

In conclusion, the Digital Library can be understood as a key enabler of contemporary environmental education, bridging the gap between knowledge and action. By combining theoretical foundations with applied learning resources and aligning with the principles of EE and ESD, it supports the development of environmentally responsible individuals and contributes to broader societal transitions toward sustainability.

Challenges and Lessons Learned

Despite its conceptual strengths and pedagogical value, the development and implementation of the Digital Library reveal a number of structural, technological, and educational challenges that are characteristic of digital learning environments and repository-based systems.

One of the primary challenges is maintaining up-to-date and relevant content. As sustainability, circular economy practices, and technological solutions evolve rapidly, digital repositories risk becoming outdated if continuous content revision and curation are not ensured. This challenge is particularly pronounced in project-based digital libraries, where content is often developed within a fixed timeframe and requires post-project sustainability mechanisms to remain current and impactful.

Closely related is the issue of ensuring consistent quality across diverse materials. The Digital Library integrates a wide range of resources – including reports, videos, presentations, and training materials – de-

veloped by multiple partners. While this diversity enriches the repository, it also introduces variability in format, depth, pedagogical design, and scientific rigour. Maintaining coherence and quality standards across such heterogeneous content requires clear editorial guidelines, quality assurance procedures, and ongoing review processes.

Another critical challenge concerns user engagement and learning effectiveness. As highlighted in the analysis of online courses in circular economy education, there is a strong tendency toward traditional, lecture-based teaching formats, even within digital environments (Dermol & Dermol, 2024). This tendency is also reflected in digital repositories, which may primarily function as content storage systems rather than interactive learning environments. Without integrating participatory elements, digital libraries risk promoting passive consumption of information rather than active knowledge construction and skill development.

In addition, technological and cognitive barriers continue to affect the accessibility and usability of digital learning resources. These include differences in digital literacy, varying levels of familiarity with online learning platforms, and limitations related to access to devices or stable internet connections. Even when accessibility features are implemented, users may still face challenges in navigating large volumes of content or efficiently identifying relevant materials. This highlights the importance of intuitive design, structured categorisation, and user guidance within digital libraries.

The development process also reveals limitations in relation to technical infrastructure and interoperability. As noted in earlier sections, the Digital Library functions effectively as a structured repository but lacks some of the advanced features of fully developed digital library systems, such as sophisticated metadata schemas, interoperability protocols, and enhanced search functionalities. This limits its integration with broader knowledge ecosystems and reduces opportunities for automated data exchange, reuse, and scalability.

These challenges provide several important lessons for the future development of digital libraries in educational and sustainability contexts. First, there is a clear need to move beyond static repositories toward dynamic, continuously updated knowledge platforms, supported by long-term maintenance strategies and institutional commitment. Second, quality assurance and standardisation mechanisms should be embedded throughout the content development process to ensure

consistency and reliability across materials. Third, and perhaps most importantly, digital libraries should increasingly incorporate interactive and participatory learning features, such as quizzes, discussion forums, collaborative tools, and problem-based learning scenarios. Such elements can transform digital libraries from passive information repositories into active learning environments that support deeper engagement and knowledge application.

Finally, addressing technological and cognitive barriers requires a continued emphasis on user-centred design, accessibility, and guidance, ensuring that diverse user groups can effectively navigate and benefit from the available resources. This includes not only technical accessibility but also pedagogical clarity and support for different learning pathways.

In conclusion, while the Digital Library represents a valuable and impactful educational resource, its development highlights the importance of continuous improvement, integration of interactive elements, and alignment with evolving digital learning practices. These lessons are essential for enhancing the long-term effectiveness, usability, and sustainability of digital knowledge repositories in environmental education and beyond.

Future Development and Sustainability

The future development of the Digital Library should move beyond its current role as a structured repository toward a more interactive, adaptive, and sustainable digital learning ecosystem. While the existing platform successfully supports knowledge dissemination and access to educational materials, further enhancements are necessary to maximise its pedagogical impact, user engagement, and long-term relevance.

One of the key directions for future development is integrating interactive learning tools and virtual environments. The current structure, which is largely based on static resources such as documents and videos, could be complemented by simulations, virtual labs, and scenario-based learning tools. Such features would enable users to experiment with real-world sustainability challenges, such as plastic lifecycle analysis or circular economy decision-making processes. This shift from passive content consumption to active engagement is essential for supporting deeper learning and skill development.

Closely related is the incorporation of gamification elements, which

can significantly enhance motivation and user participation. Features such as progress tracking, badges, interactive challenges, and achievement systems can encourage continuous learning and increase user retention. Gamification has been widely recognised as an effective strategy for improving engagement in digital education environments, particularly when addressing complex and interdisciplinary topics such as environmental sustainability.

Another important direction is the development of personalised learning pathways. Given the diversity of target users-including students, educators, professionals, and policymakers-the Digital Library should support adaptive learning experiences tailored to different needs, prior knowledge levels, and learning goals. This could involve guided learning journeys, modular course structures, and recommendation systems that suggest relevant materials based on user profiles and behaviour. Such personalisation would enhance both usability and learning effectiveness, making the platform more responsive to individual learning contexts.

Furthermore, there is significant potential for stronger integration with online courses, learning management systems (LMS), and MOOCS. While the Digital Library already contains a wealth of structured educational materials, linking these resources with formalised courses, certification pathways, and assessment tools would increase their practical value. This integration would also support blended learning models and facilitate the incorporation of Digital Library content into formal education programmes and professional training.

In terms of content development, the analysis highlights the need to expand and continually update thematic coverage, particularly in emerging areas of sustainability and circular-economy education. As suggested by the analysed study (Dermol & Dermol, 2024), future content should include advanced and forward-looking topics such as innovative and bio-based materials, digital monitoring and tracking tools (e.g., IOT and data-driven systems), and policy frameworks for implementing the circular economy. Including such topics would ensure that the Digital Library remains aligned with current research, industry developments, and policy priorities.

Equally important is the establishment of sustainable governance and maintenance mechanisms. Long-term sustainability of the Digital Library requires clear ownership, regular content updates, and dedicated resources for technical maintenance and development. Without

such structures, the platform risks gradually losing relevance and usability after the project's completion. Sustainable models may include institutional embedding, partnerships with educational organisations, or integration into broader European or international knowledge platforms.

In addition, future development should strengthen the Digital Library's technical infrastructure, particularly in metadata standardisation, interoperability, and advanced search functionality. Enhancing these aspects would improve discoverability, enable integration with other repositories, and support the reuse of materials across different platforms and contexts.

Finally, continuous attention should be given to user engagement, accessibility, and evaluation. This includes incorporating user feedback mechanisms, conducting usability and accessibility testing, and monitoring usage patterns and learning outcomes. Such evaluation processes are essential for ensuring that the Digital Library evolves in line with user needs and technological developments.

In conclusion, the long-term sustainability and impact of the Digital Library depend on its ability to evolve from a static repository into a dynamic, user-centred, and interoperable learning environment. By integrating interactive features, expanding content, enhancing technical capabilities, and ensuring sustainable governance, the Digital Library can become a robust and scalable platform that supports environmental education and contributes to broader sustainability transitions.

Digital Tools for Sustainable Engagement

The Digital Frontier in Environmental Education

Digital technologies are fundamentally transforming how environmental education (EE) is designed, delivered, and experienced. They enable more flexible, scalable, and interactive learning environments, supporting new forms of knowledge construction, collaboration, and dissemination. At the same time, the effectiveness of these technologies depends on their capacity to foster meaningful engagement, interaction, and accessibility, rather than merely digitising traditional teaching practices (Guzmán et al., 2022). Within this evolving landscape, digital platforms-such as the Digital Library and associated online environments-represent key components of a broader 'digital frontier' in environmental education, opening new possibilities for learning, communication, and participation.

From a functional perspective, digital technologies in EE encompass a wide range of tools and platforms. These include digital content repositories, such as e-books, multimedia resources, and online learning materials, which serve as structured sources of environmental knowledge and support multimodal learning. In this context, the Digital Library can be understood as part of a wider ecosystem of digital knowledge infrastructures that facilitate access to curated educational resources and support cross-disciplinary learning. The effectiveness of such repositories depends not only on the availability of content but also on the organisation, accessibility, and integration of knowledge resources within broader digital ecosystems (Li et al., 2022; Mejabi et al., 2016).

In addition, interactive visualisation and geospatial technologies, including GIS tools, GPS applications, and platforms such as StoryMaps, are increasingly important in environmental education. These tools enable learners to explore environmental issues through data analysis, spatial representation, and place-based investigation, thereby strengthening connections between local contexts and global sustainability challenges (Cisneros et al., 2023). Such approaches contribute to the development of eco-digital storytelling practices in which learners actively engage in interpreting and communicating environmental data.

A further important dimension is the use of digital storytelling and media-rich learning environments, which combine text, images, audio, and video to communicate environmental concepts. These approaches enhance learners' ability to articulate complex issues, develop critical thinking, and engage in science communication, while also fostering global citizenship and sustainability literacy. By enabling learners to connect personal experiences with broader environmental narratives, digital storytelling supports both cognitive and affective dimensions of learning.

Digital technologies also play a crucial role in supporting collaborative and participatory pedagogies. Information and communication technologies (ICT), including learning management systems (LMS), online collaboration tools, blogs, and social media platforms, facilitate interaction among learners, educators, and communities. These tools support inquiry-based learning, reflection, and co-creation of knowledge, and they enable the implementation of blended and remote learning models (Sadieda & Sutini, 2023). In this regard, platforms such

as Digital Libraries not only provide access to content but also function as hubs for knowledge exchange and collaborative learning.

Another significant contribution of digital technologies lies in assessment and learning analytics. Digital platforms enable the implementation of online assessments, performance-based tasks, and real-time feedback mechanisms, and support data-driven evaluation of learning outcomes. These tools can be used to monitor the development of environmental literacy, digital competencies, and sustainability-related skills, and to inform the continuous improvement of educational programmes (Rohmanurmeta & Dewi, 2020).

From a pedagogical perspective, the integration of digital technologies in environmental education must be carefully aligned with established principles of experiential, place-based, and interdisciplinary learning. Rather than replacing hands-on experiences, digital tools should complement and enhance them by enabling data collection, documentation, and sharing of environmental observations (Borisenoka, 2024; Rahmawati et al., 2022; Sadieda & Sutini, 2023). This is particularly important in sustainability education, where real-world engagement and contextual understanding are essential.

Moreover, digital technologies support the integration of environmental education with STEAM (science, technology, engineering, arts, and mathematics) approaches, enabling learners to address complex sustainability challenges from multiple perspectives. By combining technological tools with ethical, social, and environmental considerations, such approaches foster holistic and systems-oriented thinking (Rahmawati et al., 2022; Bounnite, 2025; Cisneros et al., 2023).

However, the successful implementation of digital technologies in environmental education also depends on several enabling conditions. These include digital literacy among learners and educators, access to appropriate infrastructure, and the availability of pedagogically meaningful resources (Sadieda & Sutini, 2023). Without these conditions, digital tools risk reinforcing existing inequalities, particularly in contexts where access to technology and digital skills is uneven.

In practical terms, digital technologies are already being applied in a variety of educational contexts. These include the use of digital content libraries and repositories to support structured learning pathways, the implementation of GIS-based projects and environmental storytelling, and the integration of citizen science initiatives that encourage public participation and environmental engagement (Cisneros et al., 2023). In

addition, digital platforms play a key role in teacher professional development, providing opportunities for continuous learning, collaboration, and exchange of best practices (Sadieda & Sutini, 2023).

Despite these opportunities, several challenges remain. These include issues related to the digital divide, the need for pedagogical alignment and curriculum integration, and the importance of teacher readiness and professional development. Furthermore, the empirical evidence on the impact of digital technologies in environmental education remains context-dependent, highlighting the need for more rigorous and longitudinal research.

In conclusion, digital technologies represent powerful enablers of innovation in environmental education, offering new opportunities for engagement, collaboration, and knowledge creation. However, their effectiveness depends on thoughtful integration with pedagogical principles, attention to accessibility and equity, and continuous evaluation of their impact. Within this context, Digital Libraries and similar platforms play a crucial role as bridging infrastructures, connecting knowledge resources, learning environments, and communities in support of sustainable development.

Project Website as a Learning Hub

The microplastics.today platform functions as a central digital learning hub that integrates the Digital Library, project outputs and deliverables, and training materials and e-learning resources into a unified environment. Rather than serving merely as a repository of information, the platform operates as a connecting infrastructure that links knowledge creation, organisation, and dissemination with user engagement and learning processes. In this sense, it reflects the broader role of digital platforms within the evolving 'digital frontier' of environmental education, where technology supports not only access to content but also interaction, participation, and knowledge exchange (Guzmán et al., 2022).

Building on the principles outlined above, the platform embodies key characteristics of effective digital learning environments. It provides structured, thematic access to interdisciplinary knowledge on plastics, sustainability, and the circular economy, while supporting open access and flexible learning pathways. The integration of diverse content types (ranging from reports and presentations to multimedia materials) enables users to engage with knowledge in multiple

ways, thereby supporting different learning preferences and contexts.

Importantly, the platform is designed to address a wide range of users, including educators, students, professionals, and the general public. This aligns with findings from the analysed study, which emphasise that digital learning environments in circular economy education should be user-centred, modular, and adaptable to diverse audiences (Dermol & Dermol, 2024). As such, the website functions as a dynamic learning ecosystem that facilitates knowledge transfer across institutional and societal boundaries, contributing to the broader goals of environmental education and sustainable development.

Social Media and Communication Channels

Social media platforms and communication channels, such as Facebook and project newsletters, extend the reach and impact of digital learning environments by enabling continuous interaction and engagement with diverse audiences. In contrast to static digital repositories, these tools provide dynamic and responsive communication spaces in which information can be shared, discussed, and co-created. This ongoing interaction is essential for maintaining engagement in online learning contexts, as highlighted by Mucundanyi (2021), who emphasises the importance of sustained communication in supporting learner participation and motivation. Sustained engagement in digital learning environments also depends on the design of interactive communication strategies and continuous learner support, which are essential for maintaining motivation and participation (Robertson, 2021).

From a pedagogical perspective, social media can be understood as part of a broader ecosystem of informal and networked learning environments. These platforms facilitate peer-to-peer interaction, collaborative knowledge construction, and the dissemination of ideas beyond formal educational settings. In the context of environmental education, they also support awareness-raising and public engagement by enabling the communication of sustainability-related topics in accessible and engaging formats.

Furthermore, social media contributes to the development of eco-digital storytelling practices, where environmental issues are communicated through visual, narrative, and multimedia content. This not only enhances understanding but also fosters emotional engagement and a sense of connection to environmental challenges. In this way,

social media and communication channels complement the Digital Library by transforming it into an interactive and socially embedded learning ecosystem.

Local Campaigns for Community Engagement

Local campaigns play a crucial role in bridging the gap between digital knowledge and real-world action. While digital platforms provide access to information and learning resources, local initiatives enable individuals and communities to apply this knowledge in practice. This connection is particularly important in environmental education, where the ultimate goal is not only to increase awareness but also to promote behavioural change and active participation in sustainability initiatives.

Such campaigns align with the principles of experiential and place-based learning, which emphasise the importance of engaging learners in real-life contexts and local environments (Rahmawati et al., 2022; Borisenoka, 2024). By addressing locally relevant environmental issues, they enhance the contextual relevance of knowledge and encourage community involvement. This, in turn, strengthens the impact of educational interventions and supports the development of environmentally responsible behaviours.

The integration of digital and local approaches represents a hybrid model of learning in which online resources provide the theoretical foundation, while offline activities enable practical application. This synergy ensures that knowledge is not only disseminated but also internalised and translated into action. As a result, local campaigns function as an essential component of a comprehensive environmental education strategy, linking digital learning ecosystems with societal transformation.

Digital Tools Enhancing Learning and Participation

The Digital Library incorporates a wide range of digital tools that support learning and participation, including textual materials, multimedia content, and various supporting resources such as worksheets and templates. This diversity of formats enables multimodal learning, which is particularly important in digital environments where users engage with content in different ways and contexts. By combining visual, textual, and interactive elements, the platform enhances comprehension, retention, and engagement.

However, despite these advantages, the analysis of online courses in circular economy education reveals a continued reliance on traditional, content-centred approaches, with limited integration of interactive and collaborative learning methods (Dermol & Dermol, 2024). This reflects a broader challenge in digital education, where technological tools are often used to replicate conventional teaching practices rather than to transform them (Guzmán et al., 2022).

To address this limitation, there is a need to further develop participatory and learner-centred approaches, including collaborative learning environments, problem-based learning, and interactive simulations. Such approaches would enable learners to actively engage with content, apply knowledge in practical contexts, and develop higher-order skills such as critical thinking and problem-solving. In this sense, the future development of digital tools should focus on enhancing interactivity and participation, thereby transforming the Digital Library into a more dynamic and engaging learning environment.

Impact on Learning and Behaviour Change

Digital tools play a significant role in enhancing learning outcomes and supporting behavioural change in environmental education. By increasing accessibility to knowledge, they enable learners from diverse backgrounds to engage with sustainability-related topics, regardless of geographical or institutional constraints. At the same time, the use of multimedia and interactive elements contributes to higher levels of engagement and supports more effective knowledge acquisition.

Beyond cognitive learning, digital tools also contribute to the development of practical skills and competencies that are essential for addressing environmental challenges. By integrating theoretical knowledge with real-world examples and applied learning materials, digital platforms support a deeper understanding of complex issues such as plastic waste management and circular economy practices. This aligns with the broader objectives of environmental education, which emphasise not only knowledge acquisition but also the development of attitudes and behaviours that support sustainability (Dragomir et al., 2019).

Importantly, the combination of structured content and interactive learning opportunities creates conditions that can foster behavioural change. When learners are actively engaged and able to relate knowledge to their own experiences and contexts, they are more likely to

adopt sustainable practices. In this way, digital tools serve as important enablers of both individual and collective transformation toward more sustainable ways of living.

Challenges and Opportunities

While digital tools offer immense potential for environmental education, their integration introduces several critical challenges that warrant careful consideration and strategic management. Chief among these concerns is the digital divide—a disparity characterized by unequal access to technology, reliable infrastructure, and digital literacy skills. This gap risks excluding marginalized learners and further widening existing socioeconomic inequalities, particularly within under-resourced communities. Furthermore, the sheer volume of available digital content frequently results in information overload, complicating the user's ability to filter relevant data, critically evaluate sources, and navigate learning materials effectively.

Another important challenge concerns the level of interactivity and the pedagogical effectiveness of digital tools. As noted earlier, many digital learning environments remain largely content-driven, with limited opportunities for active engagement and collaboration. This highlights the need for stronger alignment between technological solutions and pedagogical principles to ensure that digital tools effectively support learning objectives (Sadieda & Sutini, 2023).

At the same time, these challenges open up significant opportunities for innovation. Advances in digital technologies, such as gamification, adaptive learning systems, and simulation-based environments, offer new possibilities for enhancing engagement and learning outcomes. These approaches can support personalised learning experiences, increase motivation, and enable learners to explore complex environmental systems interactively (Sashank et al., 2023).

Looking ahead, the key opportunity lies in transforming digital platforms from static repositories into dynamic, user-centred learning ecosystems. This requires continuous development, integration of interactive features, and ongoing evaluation of user needs and learning outcomes. By addressing existing challenges and leveraging emerging technologies, digital tools can play a central role in advancing environmental education and supporting the transition toward sustainability. In addition, improving metadata practices and repository design remains a critical area for future development, as these elements directly

influence the usability, discoverability, and long-term sustainability of digital knowledge systems (Krahmer et al., 2021).

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