Chapter One

Introduction to Education for a Circular and Climate-Neutral Future: EDU4PlastiCircular Outcomes

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https://doi.org/10.53615/978-83-65020-56-7/11-35

Introduction

We live in a world of plastic, surrounded by countless plastic objects of various types that impact not only our bodies and health, but also the environment we live in. *We are witnessing a global plastic waste crisis that represents one of the most pressing environmental challenges of the 21st century, with an estimated 8 million tons of plastic polluting our waters annually, as well as other categories of nano/microplastics detected in every ecosystem on Earth.* The persistence of plastics in the environment, combined with insufficient waste management systems, has resulted in widespread contamination of terrestrial, aquatic, and atmospheric systems, including the accumulation of microplastics with documented ecological and potential human health implications (Geyer et al., 2017; United Nations Environment Programme, 2021).

Dermol, V., Draghici, A., Perniu, D., Bubik, A., Rada, E. C., & Ferrándiz Bou, S. (Eds.) (2026). *The Digital Frontier of Circularity.* ToKnowPress.

The transition from a linear 'take-make-throw' model to a circular economy framework has emerged as a critical strategy for addressing plastic pollution while maintaining economic viability. Circularity in plastics is a solution that could save us, ourselves and our planet (Davis, 2022; Islam, 2025; Stathatou et al., 2025).

However, this transition requires fundamental changes in knowledge, attitudes and behaviours at all levels of society, positioning education as a cornerstone of systemic change (Calleja, 2019; Giurea et al., 2025; Draghici et al., 2024). At the same time, educational initiatives for the circular economy and plastic circularity have proliferated globally in the last decade, covering formal education systems, community programmes and vocational training. These initiatives aim to develop 'green skills/competences' and promote responsible environmental practices through various pedagogical approaches (Dermol & Dermol, 2024; Školnik Škrabe & Bubik, 2024).

At the same time, the expansion of digital technologies in education has reshaped instructional delivery and learning environments. E-learning platforms and digital classrooms enable flexible access to content, support multimodal interaction, and facilitate data-informed feedback processes (Means et al., 2014). Nevertheless, evidence suggests that the effectiveness of e-learning depends on the alignment between technological tools and pedagogical design, particularly in domains that require higher-order thinking, problem solving, and behavioural change (Laurillard, 2012). In sustainability education, digital environments must therefore support not only knowledge acquisition but also experiential learning, critical reflection, and action-oriented competencies.

In the context of the present chapter, we aim to provide a comprehensive literature review on educational initiatives for responsible practices in circular economy and plastic circularity based on synthesizes evidence from 90 scholarly publications to: (1) characterize the landscape of educational initiatives in circular economy and plastic circularity; (2) examine the EDU4PlastiCircular project and similar initiatives in depth; (3) identify effective pedagogical approaches and their outcomes; (4) analyse challenges and barriers to implementation; and (5) provide evidence-based recommendations for future educational interventions. The review addresses a critical gap in understanding how education can accelerate the transition toward responsible plastic management and circular economy practices. These are

preliminary aspects to understand the importance and motivation of the EDU4PlastiCircular project, and the training and certification program created via the Erasmus+ funded.

Education for a Circular and Climate-Neutral Future: A Literature Review

The circular economy represents a systemic approach to economic development designed to benefit businesses, society, and the environment by decoupling economic growth from resource consumption (Calleja, 2019; Davis, 2022; Islam, 2025). Unlike the linear economy model, circular systems aim to eliminate waste through superior design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. *The European Union has positioned circular economy as central to its Green Deal, projecting potential economic benefits of up to 1.8 trillion Euros by 2030 while preserving natural resources* (Mulita, 2023; Giurea et al., 2025).

In the context of the plastics world development, circularity encompasses the entire lifecycle from design and production through consumption, collection, and end-of-life management. The 'New Plastics Economy' vision emphasizes that circular approaches must address not only recycling but also prevention of plastic leakage into the environment, particularly microplastics that pose significant ecological and health risks (Vlad at al., 2022; Giurea et al., 2025; Dermol & Dermol, 2024). However, *achieving plastic circularity faces substantial technical, economic, and behavioural challenges, with European plastic packaging waste recycling rates remaining low in many countries and overall post-consumer plastic waste recycling at only 8.51% higher in 2020 than 2018* (Davis, 2022; Islam, 2025; Mulita, 2023).

Education for sustainability has evolved from traditional environmental education to encompass broader social, economic, and cultural dimensions of sustainable development. Contemporary frameworks emphasize transformative learning that challenges existing mental models and fosters critical thinking about consumption patterns and environmental responsibility (Hamid et al., 2024). *The integration of circular economy principles into education represents a relatively recent development, with growing recognition that achieving circularity requires not only technological innovation but also fundamental shifts in knowledge, values, and behaviours* (Dermol & Dermol, 2024).

Several theoretical frameworks underpin circular economy educa-

tion. Experiential learning theory emphasizes hands-on engagement with real-world problems, enabling learners to construct knowledge through direct experience (Draghici et al., 2024). Transformative learning approaches focus on fostering critical reflection and perspective transformation regarding sustainability challenges. *Social learning theory highlights the importance of collaborative knowledge construction and community engagement in driving behavioural change.* These frameworks converge on the principle that effective circular economy education must be active, participatory, and contextually relevant rather than purely didactic (Dermol & Dermol, 2024).

Microplastics (plastic particles smaller than 5mm) have emerged as a particularly concerning dimension of plastic pollution due to their ubiquity, persistence, and potential impacts on ecosystems and human health. These particles originate from both primary sources (microbeads in cosmetics, industrial pellets) and secondary fragmentation of larger plastic items (Školnik Škrabe et al., 2025). Educational initiatives increasingly recognize the need to address microplastics awareness alongside broader circular economy principles, as microplastic pollution represents both a consequence of inadequate waste management and a driver for systemic change (Vlad at al., 2022; Giurea et al., 2025; Dermol & Dermol, 2024).

Research indicates that microplastics contamination affects marine biodiversity, enters food chains, and poses potential risks to human health through ingestion and inhalation. The complexity of microplastics issues, spanning chemistry, ecology, public health, and policy, necessitates interdisciplinary educational approaches that can bridge scientific understanding with practical action (Školnik Škrabe et al., 2025). Citizen science has emerged as a particularly effective methodology for microplastics education, enabling public participation in data collection while building awareness and scientific literacy (Vlad at al., 2022; Giurea et al., 2025; Dermol & Dermol, 2024).

Key Pedagogical Approaches in Circular Economy Education

The complexity of circular economy and plastic waste challenges has led to the adoption of pedagogical approaches that emphasize active, contextualized, and competence-oriented learning.

Transformative Learning

Transformative learning, conceptualized by Jack Mezirow (Mezirow, 1991, 2000), refers to a process through which individuals critically

examine and revise their existing frames of reference-comprising beliefs, assumptions, and values-leading to more inclusive, discriminating, and integrative perspectives. The process unfolds through a sequence of interrelated phases that structure cognitive, affective, and behavioural transformation, consisting of ten core steps, briefly presented below.

The initial phase is the *disorienting dilemma,* which represents a triggering event or experience that exposes inconsistencies between prior assumptions and new realities. In educational contexts, such dilemmas may arise from exposure to complex socio-environmental problems (e.g., plastic pollution or climate change), generating cognitive dissonance and prompting reflective engagement.

This is followed by *self-examination,* often accompanied by emotional responses such as uncertainty or discomfort. Learners begin to interrogate their own beliefs and values, particularly those that have been previously internalized without critical scrutiny. Subsequently, learners engage in a *critical assessment of assumptions,* wherein they analyse the socio-cultural, epistemological, and ethical foundations of their viewpoints. This stage is central to transformative learning, as it enables the deconstruction of taken-for-granted perspectives.

The process then extends into a social dimension through the *recognition of shared experiences,* where individuals realize that others have undergone similar transformations. This intersubjective validation reinforces the legitimacy of questioning dominant paradigms and supports the co-construction of knowledge.

Building on this, learners proceed to the *exploration of new roles, relationships, and actions,* considering alternative ways of thinking and acting. In engineering education, this may involve shifting from linear production models to circular or regenerative approaches. The subsequent phase, *planning a course of action,* entails the formulation of strategies to operationalize these new perspectives.

To support implementation, learners engage in *acquiring knowledge and skills* relevant to their intended transformation. This phase integrates both technical competencies and ethical reasoning capacities. The next stage, *provisional trying of new roles,* involves experimentation in real or simulated contexts, allowing learners to test and refine their emerging perspectives.

As learners gain experience, they develop *competence and self-confidence in new roles,* supported by feedback and reflective practice. The final phase, *reintegration into life with a transformed perspective,* signi-

fies the internalization of new frames of reference, which are then consistently applied across personal and professional domains.

Transformative learning is a recursive and iterative process rather than a strictly linear sequence. Its relevance in sustainability-oriented education lies in its capacity to facilitate deep shifts in mindset, enabling learners to move from passive acceptance of existing systems toward critical, responsible, and action-oriented engagement with complex environmental challenges. Thus, transformative learning is particularly relevant because it addresses entrenched assumptions about resource use, habitual consumption patterns, limited awareness of systemic impacts. Empirical studies indicate that transformative learning is facilitated by experiences that challenge existing perspectives, followed by reflection and discourse (Taylor, 2007). This aligns with educational needs in circular economy, where learners must reconsider linear models of production and consumption.

Experiential and Hands-On Learning

Experiential learning theory conceptualizes learning as a cycle involving concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). In environmental and engineering education, experiential approaches have been shown to improve understanding of complex processes and enhance retention (Kolb & Kolb, 2005).

Experiential learning approaches that engage students in practical, hands-on activities have emerged as particularly effective for circular economy education. In the context of plastic waste management, experiential learning includes laboratory experiments and investigations (e.g., material properties, microplastics identification), field observations, internships, applied problem-solving tasks. These activities enable learners to connect theoretical concepts with observable phenomena and professional contexts. A notable example from tertiary design education involved students creating innovative products from recycled university plastic waste, specifically HDPE milk bottles, requiring them to design and construct machinery for plastic processing (Nguyen, 2023; Dermol & Dermol, 2024; Hamid et al., 2024). This approach fostered environmental awareness and critical thinking while providing tangible experience with circular economy principles in practice (Vlad at al., 2022; Giurea et al., 2025; Školnik Škrabe et al., 2025).

Community-based initiatives have similarly emphasized hands-on engagement, such as programs involving plastic waste collection, sorting, and creative recycling into economically valuable products. These interventions demonstrate that experiential learning can simultaneously build knowledge, develop practical skills, and foster environmental responsibility. The integration of design thinking and problem-solving challenges enables learners to grapple with the complexity of circular economy systems while developing creative solutions (Giurea et al., 2025; Dermol & Dermol, 2024).

Educational programs incorporating practical waste management activities have shown measurable impacts on knowledge, attitudes, and behaviours. For instance, initiatives involving students in establishing recycling systems within their schools or communities have demonstrated effectiveness in fostering long-term behavioural change and environmental stewardship. The hands-on nature of these activities appears to enhance learning retention and motivation compared to purely theoretical instruction (Nguyen, 2023; Dermol & Dermol, 2024; Školnik Škrabe et al., 2025).

Citizen Science and Participatory Approaches

Citizen science has emerged as a powerful pedagogical approach for microplastics and plastic pollution education, enabling public participation in scientific research while building awareness and scientific literacy (Popa et al., 2022).

Programs engaging students and community members in microplastics sampling, identification, and data collection have proliferated globally, spanning marine, freshwater, and terrestrial environments. These initiatives demonstrate that citizen science can simultaneously contribute to scientific knowledge and serve educational objectives (Giurea et al., 2025; Dermoil & Dermol, 2024; Draghici et al., 2024; Chigwada & Tekere, 2026).

A creative-motivated citizen science after-school STEAM program focused on oceanic microplastics successfully engaged students in addressing this complex environmental problem through hands-on investigation. Similarly, high school students participating in coastal ecosystem monitoring contributed valuable data on marine litter distribution while developing scientific skills and environmental awareness. These examples illustrate how citizen science can bridge formal and informal education while fostering authentic scientific engage-

ment (Popa et al., 2022; Nguyen, 2023; Školnik Škrabe et al., 2025; Chigwada & Tekere, 2026).

The participatory nature of citizen science approaches aligns with social learning theory, emphasizing collaborative knowledge construction and community engagement. Programs involving multiple stakeholder groups, students, teachers, families, and community members, have demonstrated enhanced impact through broader social networks and shared learning experiences. The development of standardized protocols and digital platforms has facilitated scaling of citizen science initiatives while maintaining data quality (Dermol & Dermol, 2024).

Digital and Online Learning Platforms

Digital education platforms have expanded access to circular economy education, particularly important given the global nature of plastic pollution challenges. The development of asynchronous online courses, such as the DIGITOOL to CE (2021–2024) e-learning course on Circular Economy and Green Business, demonstrates the potential for flexible, self-paced learning that accommodates diverse student needs. These platforms utilize modern authoring tools like Adobe Captivate to create interactive content supported by Learning Management Systems (Atstaja et al., 2023).

Online education for circular economy has been analysed for content and didactical approaches, revealing diverse strategies for engaging learners in plastic waste management topics. Digital platforms enable integration of multimedia resources, interactive simulations, and virtual laboratories that can complement or substitute for physical hands-on activities. The COVID-19 pandemic accelerated adoption of digital learning modalities, providing valuable insights into effective online pedagogy for sustainability education (Dermol & Dermol, 2024; Draghici et al., 2024).

However, research from the EDU4PlastiCircular project indicates that online learning was the least preferred format among students and staff, suggesting that purely digital approaches may face engagement challenges. Hybrid models combining online and face-to-face elements appear to offer optimal balance, leveraging digital flexibility while maintaining interpersonal interaction valued by learners. The development of digital pedagogical competences among educators has been identified as essential for effective online circular economy education (Draghici et al., 2024; Školnik Škrabe et al., 2025).

Serious Games and Gamification

Serious games designed for circular economy education have demonstrated significant effectiveness in engaging learners, enhancing retention, and fostering systems thinking by allowing players to interact with complex scenarios, such as resource scarcity and waste management, in a safe, simulated environment. These games often simulate the transition from a linear 'take-make-sell-dispose' model to a circular one, providing hands-on experience with circular business models like repair, reuse, and product-service systems (Roba et al., 2021; Manshoven & Gillabel, 2021).

Research on serious game implementation for circular economy education has identified key success factors including clear learning objectives, appropriate challenge levels, and integration with broader curriculum. Gamification elements such as points, badges, and leaderboards can enhance motivation, but their effectiveness depends on thoughtful design aligned with educational goals rather than superficial game mechanics. The social dimension of multiplayer or collaborative games can foster discussion and shared learning about circular economy principles (Dermol & Dermol, 2024).

Key benefits and effectiveness on using gamification and serious games approaches in the circular economy are summarized in the following (Roba et al., 2021):

- *Enhanced engagement and motivation.* Serious games are more engaging than traditional, passive teaching methods, using competition, collaboration, and rewards to increase participation.
- *Systems thinking.* Games help players understand the interconnectedness of decisions regarding resource management, company profits, and environmental impact.
- *Improved retention.* By 'learning-by-doing,' participants better remember complex CE strategies and their consequences in a simulation.
- *Visualization of complex concepts.* Games provide tangible representations of abstract concepts like material flows, resource exhaustion, and waste, turning complex systems into understandable, interactive experiences.
- *Simulated consequences.* Players can experience the long-term impacts of their decisions on company profitability and resilience

against external events such as policy changes or resource shortages.

Transdisciplinary and Integrated Approaches

Effective circular economy education increasingly adopts transdisciplinary approaches that integrate knowledge from natural sciences, engineering, social sciences, economics, and humanities. The complexity of circular economy challenges (spanning technical, economic, social, and policy dimensions) necessitates educational approaches that transcend traditional disciplinary boundaries. Integration of circular economy principles into STEM education has been identified as a promising pathway toward developing 'circular citizenship' (Nguyen, 2023; Dermol & Dermol, 2024).

Transdisciplinary approaches emphasize co-production of knowledge with stakeholders beyond academia, including industry, government, and civil society. This stakeholder engagement enriches learning by connecting theoretical concepts with real-world applications and constraints. Educational initiatives involving partnerships between universities, businesses, and communities have demonstrated enhanced relevance and impact compared to purely academic programs. The integration of circular economy concepts across multiple subjects and grade levels, rather than as isolated topics, has been advocated as essential for developing comprehensive understanding. For instance, circular economy principles can be incorporated into chemistry education through focus on materials and recycling processes, into economics through business model innovation, and into social studies through policy and behavioural dimensions. This integrated approach helps students recognize interconnections and develop systems thinking capabilities (Dermol & Dermol, 2024; Školnik Škrabe et al., 2025).

Educational Initiatives Across Different Contexts

Higher Education Initiatives

Higher education institutions have emerged as critical sites for circular economy education, with initiatives ranging from specialized courses to comprehensive curriculum reform. Universities are developing innovative curricula to drive the EU Green Deal through education on circular economy and green business, recognizing their role in preparing future professionals and leaders. The integration of sustainability

and circular economy into teacher training programs has been identified as particularly strategic, as educators can multiply impact through their teaching (Bugallo-Rodríguez et al., 2020; Draghici et al., 2024).

Sustainability in plastics curriculum has been specifically addressed in engineering and materials science programs, with focus on training for improving plastics circularity. These initiatives integrate technical knowledge about plastic materials, processing, and recycling with broader circular economy principles and sustainability considerations. Case studies from universities implementing circular economy practices for plastic waste management demonstrate how institutions can serve as living laboratories for sustainability (Giurea et al., 2025). Challenges in higher education include curriculum rigidity, limited interdisciplinary collaboration, and insufficient integration of practical experience with theoretical knowledge. Research indicates that while students may understand basic circular economy principles, they often lack deeper comprehension of waste management hierarchies and practical implementation strategies. Professional development for faculty has been identified as essential for overcoming these barriers and enabling effective circular economy education (Dermol & Dermol, 2024; Školnik Škrabe et al., 2025).

Primary and Secondary Education

Educational initiatives in primary and secondary schools have employed diverse approaches to foster circular economy awareness and responsible plastic management behaviours. Pedagogical strategies emphasizing critical reflection have been implemented to raise awareness about solid plastic waste management in educational communities, promoting sustainable development objectives and environmental responsibility. These initiatives often involve the entire educational community including students, teachers, and parents to maximize impact.

Environmental education programs focused on plastic waste reduction have demonstrated measurable effects on student awareness and practices. For instance, programs implementing the 3R principles (Reduce, Reuse, Recycle) through hands-on activities and creative projects have successfully engaged students while developing practical skills. The integration of circular economy concepts into existing curricula, rather than as separate add-on topics, has been advocated for sustainable implementation (Giurea et al., 2025).

Secondary school students' understanding of circular economy and recycling has been investigated in various contexts, revealing both opportunities and challenges. While students often demonstrate basic awareness of environmental issues, deeper understanding of circular economy systems and their role as consumers within these systems requires targeted educational intervention. Small rural schools face particular challenges including limited resources and teacher expertise, though they may benefit from strong community connections (Laius et al., 2024).

Community-Based and Informal Education

Community-based educational initiatives have proven effective for engaging diverse populations in circular economy and plastic waste management. Programs empowering local communities through education and recycling solutions have demonstrated that combining knowledge building with practical action can drive behavioural change and community-level impact. These initiatives often emphasize the economic value of recycled materials, providing motivation through both environmental and livelihood benefits (Widiastuti et al., 2023).

Informal education through outreach programs, workshops, and awareness campaigns has reached audiences beyond formal educational systems. For instance, chemistry outreach programs on circular plastic economy have engaged secondary students and teachers, demonstrating effectiveness of targeted, topic-specific interventions. The flexibility of informal education enables adaptation to local contexts and specific community needs (Widiastuti et al., 2023).

Educational contests and competitions have been employed to engage students and communities in transitioning 'from linear to circular ideas,' fostering creativity and innovation in addressing circular economy challenges. These initiatives leverage intrinsic motivation and social recognition to encourage participation and learning. Community-based approaches often emphasize social cartography, participatory mapping, and other tools that enable communities to analyse their own waste management challenges and develop locally appropriate solutions (Velis et al., 2022).

Professional and Vocational Training

Professional and vocational education for circular economy has been recognized as essential for developing workforce capacity to imple-

ment circular systems. Technical and vocational education institutions are increasingly incorporating circular economy concepts, though systematic literature reviews indicate this integration remains limited and uneven. The development of green skills through professional training addresses industry demand for workers capable of implementing circular economy practices (Widiastuti et al., 2023; Laius et al., 2024; Hamid et al., 2024).

Circular economy education in professional contexts must balance theoretical understanding with practical competencies relevant to specific industries and occupations. For the plastics sector, this includes technical knowledge of materials, processing technologies, recycling methods, and quality control, as well as broader understanding of circular business models and supply chain management. Professional training programs have been developed to address specific circular economy challenges such as plastic packaging waste management and closed-loop systems (Velis et al., 2022; Giurea et al., 2025; Hamid et al., 2024).

The informal recycling sector represents a significant but often overlooked dimension of circular economy workforce, particularly in low- and middle-income countries. Educational and capacity-building initiatives targeting informal recyclers can enhance material quality, improve livelihoods, and reduce plastic pollution while supporting inclusive circular economy. These interventions must address not only technical skills but also safety, organization, and market access (Velis et al., 2022; Widiastuti et al., 2023; Hamid et al., 2024).

International and Cross-Cultural Initiatives

International collaboration in circular economy education has been facilitated through programs such as Erasmus+ and Horizon Europe, enabling knowledge exchange and capacity building across countries. The EDU4PlastiCircular project exemplifies this international approach, bringing together partner institutions from multiple European countries to develop shared educational resources and approaches. Cross-cultural initiatives must navigate differences in educational systems, environmental priorities, and cultural contexts while identifying universal principles (Draghici et al., 2024).

Educational initiatives have been documented across diverse geographical contexts including Europe, Asia, Latin America, and Africa, each adapting circular economy principles to local circumstances.

For instance, educational programs in Thailand have integrated circular plastic economy into chemistry curriculum with focus on smart cities and zero plastic leakage. Latin American initiatives have emphasized community participation and social justice dimensions of circular economy (Kruja et al., 2025).

Key pedagogical approaches adopted by many trainers and professors in different educational programs dedicated to circular economy and plastic waste management have increasingly used *team-based, project-based, and collaborative learning* to connect academic curricula with real-world problems. This includes (Nguyen, 2023; Kruja et al., 2025):

- *STEM integration.* Using Science, Technology, Engineering, and Math to design school curricula that solve environmental problems.
- *Real-world context.* Using 'living labs' and community-based projects to turn schools into models of a circular economy

The global nature of plastic pollution necessitates international coordination in education as well as policy and practice. International frameworks such as the UN Sustainable Development Goals and the UN Decade of Ocean Science for Sustainable Development provide common reference points for educational initiatives worldwide. Ocean literacy and blue curricula initiatives supported by the EU Mission Ocean demonstrate how international programs can enhance educational networks and promote shared approaches (Mulita, 2023).

Key Findings from the Literature Review and Comparative Analysis

Effectiveness of Educational Interventions

Educational interventions for circular economy and plastic circularity have demonstrated measurable impacts on knowledge, attitudes, and behaviours across diverse contexts. Studies employing pre-post assessment designs have documented significant increases in understanding of circular economy principles, plastic pollution impacts, and waste management practices following educational interventions. However, the magnitude and persistence of these effects vary considerably depending on intervention design, duration, and context (Hamid et al., 2024; Draghici et al., 2024; Dermol & Dermol, 2024).

Hands-on, experiential approaches consistently lead to better learning outcomes than purely didactic instruction. Programs involving students in practical activities such as waste audits, recycling projects, or product design from recycled materials show enhanced knowledge retention and behavioural change. The active engagement and personal relevance of experiential learning appear to foster deeper understanding and motivation for sustainable practices (Bugallo-Rodríguez et al., 2020; Dermol & Dermol, 2024).

Citizen science initiatives have proven particularly effective for fostering both scientific literacy and environmental awareness regarding microplastics and plastic pollution. Participants in citizen science programs demonstrate increased understanding of scientific methods, enhanced critical thinking skills, and stronger environmental stewardship attitudes. The authentic nature of contributing to real scientific research appears to enhance motivation and learning compared to simulated activities (Popa et al., 2023; Školnik Škrabe & Bubik, 2024; Školnik Škrabe et al., 2025).

Common Themes and Patterns

Several common themes emerge across successful educational initiatives for circular economy and plastic circularity. First, effective programs emphasize systems thinking, helping learners understand interconnections between production, consumption, waste management, and environmental impacts. Second, successful initiatives balance knowledge building with practical skills development and behavioural change objectives. Third, stakeholder engagement and community participation enhance both learning outcomes and real-world impact (Dermol & Dermol, 2024).

The integration of economic and environmental dimensions appears critical for fostering comprehensive understanding of circular economy. Programs that address only environmental impacts without considering economic viability and business models may fail to prepare learners for real-world implementation challenges. Conversely, initiatives emphasizing economic opportunities of circular economy, such as job creation, cost savings, and innovation, can enhance motivation and perceived relevance (Giurea et al., 2025; Školnik Škrabe et al., 2025).

Cultural and contextual adaptation emerges as essential for effective circular economy education across diverse settings. While core circular economy principles remain consistent, successful initiatives

adapt pedagogical approaches, examples, and emphasis to align with local environmental priorities, cultural values, and educational systems. This balance between universal principles and local relevance appears critical for engagement and impact (Kruja et al., 2025).

Target Audience Considerations

Educational initiatives demonstrate distinct characteristics and challenges depending on target audience. Higher education programs can address complex technical and theoretical content but may struggle with curriculum integration and interdisciplinary collaboration. Primary and secondary education initiatives must balance age-appropriate content with meaningful engagement, often emphasizing hands-on activities and creative expression. Community-based programs for general public require accessible language and clear connections to daily life and local concerns (Bugallo-Rodríguez et al., 2020; Draghici et al., 2024).

Professional and vocational training must prioritize practical competencies and industry relevance, often requiring partnerships with businesses and industry associations. Teacher training programs serve a multiplier function, as educators can integrate circular economy principles into their ongoing teaching, but require sustained support and resources. Policymaker education focuses on evidence synthesis, policy instruments, and systemic change strategies rather than technical details (Hamid et al., 2024; Dermol & Dermol, 2024; Draghici et al., 2024)

Intergenerational and whole-community approaches that engage multiple audiences simultaneously have demonstrated enhanced impact through social learning and mutual reinforcement. Programs involving students, teachers, parents, and community members create broader social networks for knowledge sharing and behavioural change. This multi-audience approach aligns with recognition that achieving circular economy requires coordinated action across society rather than isolated individual changes (Nguyen, 2023; Dermol & Dermol, 2024).

Geographic and Cultural Variations

Educational initiatives in European contexts often emphasize policy frameworks such as the EU Green Deal and Circular Economy Action Plan, reflecting the strong policy drivers in this region. European pro-

grams frequently involve international collaboration through mechanisms like Erasmus+ and Horizon Europe. Asian initiatives often integrate circular economy with smart city development and technological innovation. Latin American programs frequently emphasize social justice, community empowerment, and informal sector inclusion. Resource availability and infrastructure significantly influence educational approaches, with high-income countries more likely to implement technology-intensive solutions such as advanced digital platforms or sophisticated recycling equipment. Low- and middle-income countries often emphasize community-based approaches, informal sector engagement, and low-cost solutions. However, innovation occurs across all contexts, with valuable lessons emerging from resource-constrained settings that develop creative, locally appropriate solutions (Draghici et al., 2024; Giurea et al., 2025; Školnik Škrabe et al., 2025).

Cultural values regarding waste, consumption, and environmental responsibility shape both educational content and pedagogical approaches. Collectivist cultures may emphasize community benefits and social responsibility, while individualist cultures may focus more on personal choice and individual impact. Effective educational initiatives recognize and work within these cultural frameworks rather than imposing external values (Nguyen, 2023; Kruja et al., 2025).

Challenges and Barriers to Implement Education for Circular Economy and Plastic Circularity

Institutional and Systemic Barriers

Curriculum rigidity and institutional inertia represent significant barriers to integrating circular economy education into formal educational systems. Established curricula with fixed content requirements and assessment structures leave limited flexibility for introducing new topics or interdisciplinary approaches. Institutional resistance to change, particularly in higher education, can slow adoption of innovative pedagogical approaches even when faculty and students' express interest (Draghici et al., 2024; Giurea et al., 2025).

Limited interdisciplinary collaboration within educational institutions constrains development of comprehensive circular economy education. Traditional disciplinary silos separate technical, economic, social, and policy dimensions of circular economy, hindering systems thinking development. Institutional structures including departmen-

tal organization, funding mechanisms, and promotion criteria often discourage rather than reward interdisciplinary teaching and research (Stathatou et al., 2025; Giurea et al., 2025).

Lack of managerial support and inadequate resources have been identified as critical barriers to implementing circular economy education. Even motivated educators may struggle to develop and deliver effective programs without institutional backing, funding for materials and activities, and time allocation. Infrastructure limitations including inadequate facilities for hands-on activities or recycling demonstrations constrain practical learning opportunities (Draghici et al., 2024; Dermol & Dermol, 2024).

Knowledge and Capacity Gaps

Limited teacher knowledge and confidence regarding circular economy concepts represents a fundamental barrier to effective education. Many educators lack formal training in sustainability, circular economy, or plastics science, constraining their ability to teach these topics effectively. Professional development opportunities remain insufficient to address this capacity gap at scale (Školnik Škrabe et al., 2025; Giurea et al., 2025). The interdisciplinary nature of circular economy challenges educators who may have deep expertise in one domain but limited knowledge of others. For instance, chemistry teachers may understand plastic materials and recycling processes but lack knowledge of circular business models or policy frameworks. Conversely, social science educators may understand behavioural and policy dimensions but lack technical knowledge of materials and processes (Draghici et al., 2024; Dermol & Dermol, 2024).

Students limited prior knowledge and misconceptions about circular economy and plastic pollution can impede learning. Research indicates that while students may have basic awareness of environmental issues, they often lack understanding of circular economy principles, waste management hierarchies, and the complexity of plastic pollution challenges. Addressing these knowledge gaps and misconceptions requires careful pedagogical design and sufficient instructional time (Školnik Škrabe et al., 2025).

Resource and Infrastructure Constraints

Financial constraints limit implementation of circular economy education, particularly for hands-on activities, field trips, equipment, and

materials. Schools and community organizations in resource-limited settings may lack funds for even basic supplies for recycling projects or waste management demonstrations. Higher education institutions may struggle to invest in specialized equipment for plastics processing or analysis (Dermol & Dermol, 2024; Draghici et al., 2024).

Physical infrastructure limitations constrain practical learning opportunities, with many schools lacking adequate facilities for waste sorting, composting, or recycling activities. Laboratory equipment for microplastics analysis or materials testing may be unavailable or prohibitively expensive for educational institutions. Digital infrastructure gaps including limited internet access or devices constrain implementation of online and hybrid learning approaches in some contexts (Školnik Škrabe & Bubik, 2024; Školnik Škrabe et al., 2025).

Time constraints represent a pervasive challenge, with educators reporting insufficient time to adequately address circular economy topics within existing curricula. The pressure to cover mandated content and prepare students for standardized assessments leaves limited flexibility for in-depth exploration of sustainability topics. Hands-on and experiential learning approaches, while effective, require more time than traditional lecture-based instruction (Draghici et al., 2024; Školnik Škrabe et al., 2025).

Engagement and Motivation Challenges

Maintaining student engagement and motivation for circular economy education can be challenging, particularly when topics are presented in abstract or disconnected ways. Students may perceive environmental issues as distant or overwhelming, leading to disengagement or eco-anxiety rather than empowerment. Effective education must balance awareness of problems with emphasis on solutions and agency. The complexity of circular economy systems can be overwhelming for learners, potentially leading to confusion or disengagement. Educational approaches must scaffold learning, building from concrete examples and personal experiences toward more abstract systems thinking. Oversimplification, however, risks conveying misleading impressions about the ease of achieving circular economy (Školnik Škrabe et al., 2025; Giurea et al., 2025).

Cultural and socioeconomic factors influence engagement with circular economy education. Students from communities facing immediate economic pressures may perceive environmental education as

less relevant than more pressing concerns. Effective initiatives connect circular economy to local priorities including economic opportunity, health, and community well-being (Islam, 2025).

Discussion and Implications

Synthesis of Evidence

This literature review reveals a rapidly expanding and increasingly sophisticated field of educational practice and research focused on circular economy and plastic circularity. The EDU4PlastiCircular project and similar initiatives demonstrate growing recognition that education is essential for achieving the systemic changes required to address plastic pollution and transition toward circular economy. The diversity of approaches documented (spanning formal and informal education, different age groups and contexts, and various pedagogical methods) reflects both the complexity of the challenge and the creativity of educators and researchers addressing it.

Several key principles emerge from synthesis of this evidence. First, effective circular economy education must be active and experiential rather than purely didactic, engaging learners in hands-on activities that build both knowledge and practical skills. Second, interdisciplinary and systems-oriented approaches are essential for developing comprehensive understanding of circular economy's technical, economic, social, and policy dimensions. Third, stakeholder engagement and community participation enhance both learning outcomes and real-world impact.

The evidence also reveals significant gaps and challenges. Despite proliferation of initiatives, systematic evaluation of long-term impacts remains limited. Most studies document short-term knowledge gains or attitude changes, but evidence regarding sustained behavioural change and real-world environmental outcomes is scarce. The field would benefit from more rigorous research designs including longitudinal studies, control groups, and measurement of behavioural and environmental outcomes beyond self-reported attitudes.

The Role of Higher Education

Higher education institutions play a critical role in circular economy education through multiple pathways. Universities educate future professionals, policymakers, and educators who will drive circular economy implementation across sectors. Research conducted at universi-

ties generates knowledge about circular economy systems, technologies, and policies. Universities can serve as living laboratories, implementing circular economy practices on campus while using these as learning opportunities for students.

The EDU4PlastiCircular project exemplifies strategic investment in higher education capacity for circular economy education. By focusing on both students and academic staff, the project recognizes that educator capacity is essential for sustainable scaling of educational initiatives. The project's emphasis on green skills development aligns with labour market needs and policy priorities, potentially enhancing graduate employability while addressing environmental challenges (Draghici et al., 2024).

However, higher education faces particular challenges in integrating circular economy education including curriculum rigidity, disciplinary silos, and limited incentives for pedagogical innovation. Overcoming these barriers requires institutional commitment, resource allocation, and systemic changes to academic structures and cultures. The development of interdisciplinary programs, centres, and initiatives focused on circular economy can provide institutional homes for this work.

Scaling and Sustainability of Initiatives

Scaling effective circular economy education from pilot projects to widespread implementation represents a critical challenge. Many documented initiatives remain small-scale, reaching limited numbers of learners and dependent on external funding or individual champion educators. Sustainable scaling requires integration into mainstream educational systems, development of educator capacity at scale, and creation of supportive policy and resource environments.

Digital platforms and open educational resources offer potential pathways for scaling, enabling broader access to high-quality educational materials and reducing development costs. However, the EDU4-PlastiCircular finding that online learning was least preferred among students and staff suggests that purely digital approaches may face engagement challenges. Hybrid models combining online resources with face-to-face interaction may offer optimal balance for scaling while maintaining effectiveness.

International collaboration and knowledge exchange can accelerate scaling by enabling adaptation of successful approaches across contexts rather than requiring each institution or country to develop ini-

tiatives from scratch. Networks such as the European Blue Schools and platforms for sharing circular economy educational resources facilitate this knowledge exchange. However, effective adaptation requires attention to local context rather than simple replication.

Policy Implications

The evidence synthesized in this review has several important policy implications. First, achieving circular economy requires substantial investment in education across all levels and contexts, not merely as an add-on but as a core component of sustainability transitions. Policy frameworks such as the EU Green Deal and Circular Economy Action Plan should explicitly prioritize and resource educational initiatives.

Second, policies should support educator professional development at scale, recognizing that teacher capacity is a fundamental constraint on effective circular economy education. This includes both pre-service teacher education and ongoing professional development for current educators. Interdisciplinary training that bridges technical, economic, social, and policy dimensions of circular economy is particularly needed.

Third, policies should incentivize and support institutional integration of circular economy education rather than relying solely on voluntary initiatives. This includes curriculum frameworks incorporating circular economy, assessment systems valuing sustainability competencies, and funding mechanisms for interdisciplinary, experiential learning. Additionally, rewarding educators who implement innovative circular economy education will drive broader adoption.

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