Sustainability in Education Technology Design: Bridging Green Design and Education for Sustainability

In "Promoting Multi-Sector Sustainability With Policy and Innovation"

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Abstract

This chapter introduces a distinctive perspective at the confluence of sustainability, education, and technology, serving as a crucial bridge between sustainability innovations technology, design and education. Education stands as a potential catalyst for change by promoting holistic understandings of sustainable systems that have potential to support sustainable behaviors beyond the classroom. With continued advances in modern technology that teachers might exploit for learning in the classroom (e.g., artificial intelligence, augmented/virtual reality, video conferencing), well-designed educational technology (EdTech) can provide meaningful learning opportunities in this domain. Yet, much EdTech designed to-date does not take sustainability-relevant theory into account, and—crucially—may in fact contribute to the climate crisis through its use of material resources and energy. The central contribution of this chapter lies in the creation of a novel conceptual framework, offering essential and practical guidance to EdTech designers/developers and researchers as they embark on crafting Sustainable EdTech for Sustainability (SETS).

1 Introduction: Why is this chapter needed?

The stakes are exceptionally high as the world grapples with pressing sustainability challenges. The future of our global community hinges upon our capacity to take meaningful steps toward sustainability. Education stands as a potential catalyst for change, yet the absence of a sustainable focus within education and technology jeopardizes the readiness of future generations to address urgent global issues. Scholars posit that digital technology can play a pivotal role in advancing sustainable development, especially within the field of education. Kioupi and Voulvoulis (2019, p. 13) underscore this point by stating, “Education is the pathway to sustainability, and without adequate investment in it, reaching sustainable goals may remain elusive”. In light of the extensive integration of digital technologies in the creation and dissemination of knowledge in our society, numerous policymakers, industry leaders, and education experts champion the idea of the ‘digital transformation of education’ as a core element of sustainable development in the 2020s and beyond (OECD, 2021, p. 5).

This chapter argues that discussions around sustainable development should move away from the automatic assumption that ongoing digitalization of education is inherently positive. Selwyn (2021) contends that a continued emphasis on intensive digital education methods could make the environmental problems associated with producing, using, and disposing of digital technology even worse. So, if we're excited about using more digital technology in education, we need to be aware of how it affects our planet. We should think of computer resources as something valuable and limited. We should only use them when we really need to and use them efficiently. And, when we do create new ones, they should be durable, energy-efficient technology that follow a circular, cradle-to-cradle design approach. This entails creating modular components that are easily repairable or replaceable, ideally by users themselves, and employing sustainable materials, such as alternatives to plastics.

This approach of using less digital technology can make us rethink how we use technology in education. We should think about technology that's good for the environment. The field of sustainable human-computer interaction (SHCI), which deals with this issue, posits that technology should aim to (i) "limit environmental consequences related to computing technology", i.e., be designed sustainable, and (ii) "help effect pro-environmental behaviors", which, if considering the field of education, might be accomplished through technologies that supporting learning and engagement in sustainability (Bremer et al., 2022).

The global EdTech market is anticipated to witness substantial growth from 2024 to 2030, building on the steady progress observed in 2022-2023, with prominent industry leaders implementing new strategies. Given this ongoing growth, it is evident that EdTech not a passing trend. Rather than outrightly rejecting the idea of digital education because of its environmental impact, a new approach is needed: one that focuses on exploiting green technology design and development strategies while promoting sustainable development through its content and pedagogy, following trends in SHCI. It's been many years since Elshof (2008) argued that, to address the problem of sustainability, we need more than just ideas; we need a shared commitment. And, to achieve that in EdTech, we need to make sustainability a central theme.

However, guidance on how to design and integrate sustainability content and pedagogy into interactive tools—that are themselves designed sustainably—are unconsolidated, requiring those interested in this domain to access many different sources and to know where to look. In an effort to address this gap, we have crafted a conceptual framework. The framework comprises a central core of three interconnected components and an outer encompassing layer. The central core represents the design of EdTech that promotes sustainability learning (e.g., awareness, attitudes, and behaviors), while the outer layer represents the sustainable design of EdTech itself.

The rest of this chapter is structured as follows. Section 2 presents literature informing the design of EdTech for sustainability learning, touching on pedagogy (2.1), content (2.2), and human-computer interaction design (2.3). This is followed by Section 3, which presents literature informing environmentally sustainable design (or eco-design) of EdTech, including how technology contributes to the environmental degradation and climate change (3.1), the eco-design of EdTech hardware (3.2) and software (3.3), and multi-stakeholder nature of eco-design. Finally, Section 4 breaks down the components of our framework and provides practical checklists and sets of questions for those seeking to design or implement Sustainable EdTech for Sustainability.

2 Designing EdTech for sustainability learning and action

With technological innovations delivering new capabilities to the EdTech sector, coupled with the current state of environmental crisis, we call for a radical change in the way we design EdTech to integrate and promote sustainability and environmental learning and engagement. Sustainability is simply no longer a nice-to-have addition to the curriculums but an imperative need for a future generation that is environmentally aware.

> *"There is ... a growing demand from business, for graduates to be sustainability literate, with company leaders increasingly seeing sustainability as one of the top 3 priorities (McKinsey, 2014)."*

Winner (1980) argues that design is a value-laden process. We argue by instilling early sustainable views in EdTech designs, we might help transform the EdTech industry and reshape the beliefs of students or EdTech users toward more sustainable thinking and practices. Designers can act as a link between the designed products or services and the people. In many cases, design has the power to influence people's behaviors and sway them in certain directions.

By inviting designers to design for sustainability, we might achieve milestones in moving towards a more sustainable planet.

A great example of how education is crucial to the new era that we are living in is a quote from Irina Bokova, Former Director-General of UNESCO.

> *"A fundamental change is needed in the way we think about education's role in global development because it has a catalytic impact on the well-being of individuals and the future of our planet ... Now, more than ever, education has a responsibility to be in gear with 21st-century challenges and aspirations and foster the right types of values and skills that will lead to sustainable and inclusive growth, and peaceful living together."* (UNESCO, 2017, p.7)

In this quote, there is an emphasis on the shift in the way we traditionally look at education and education's role in facing future challenges when it comes to building a sustainable life. As argued by different scholars, there is a fundamental mismatch between what we say is important for environmental education (transformative, situated, interdisciplinary learning) what we typically do in schools (explicit, subject-based teaching) (Stevenson et al., 2007; Bedi & Germein, 2016). This trend tends to be reflected in our designs of EdTech, too.

In this section we will explore different sustainability pedagogies, how sustainability knowledge can be integrated into current subject-based curricula, and how EdTech might be designed to facilitate this.

2.1 Pedagogical approaches to learning about sustainability

Pedagogy plays an important role in shaping educational experiences. It goes hand-in-hand with designing curricular content, as it serves as a catalyst, shaping how students learn, perceive, and actively engage with the world around them. The design of learning activities under effective pedagogy encourages students to embark on a transformative journey, fostering sustainability as a core element. In essence, sustainability pedagogies should align with principles of good pedagogy more generally. The emphasis on transformative and learner-centered approaches, coupled with the cultivation of higher-order thinking skills, enriching the overall teaching and learning experience (Bedi & Germein, 2016).

Bedi and Germein (2016) provide an example of an Australian initiative in applying Education for Sustainability (EfS) to competency-based vocational training, where educators received scholarships to attend Trainings for Sustainability. These initiatives aimed to equip educators with the necessary skills and knowledge to effectively apply EfS approaches into their teaching. The goal was to encourage and upskill educators to embrace transformative, constructivist, and social learning approaches. EfS pedagogies aim to foster higher-order thinking, incorporate reflective, critical, relational, whole-of-systems, and ecological thinking. The learning activities within this framework encourage students to assess their experiences, beliefs, values, and worldviews (Bedi & Germein, 2016). But, as highlighted by Stevenson et al. back in 2007, these principles of good EfS pedagogy are in contradiction to what actually happens in classrooms—and if we examine the types of learning that occur in schools today, can we say that the educational landscape is much different? Monroe et al. (2008) present a framework of four environmental education strategies requiring increasingly transformative teaching approaches:

- **Conveying information**: a one-way transmission of knowledge or facts to raise awareness of environmental issues.
    - **Examples include**: Textbooks, lectures, videos, and internet resources
- **Building understanding**: a two-way transmission of information, aimed at helping the learner build their own mental models of the issues, exchange ideas, and develop a sense of place in nature.
    - **Examples include**: Discussions, role play, simulations, case studies, experiments, games, constructivist activities, experiential learning, field studies
- **Improving skills**: goes beyond knowledge acquisition, by enabling learners to engage directly with pro-environmental behaviors and to practice active citizenship, critical thinking, group communication, and collaboration.
    - **Examples include**: Cooperative learning, issue investigations, inquiry-based learning, citizen science programs, volunteer service, some types of project-based education

- **Enabling sustainable actions**: "[builds] capacity for effective citizenship in a complex world" (Monroe et al., 2008) and tends to include more systemic thinking by connecting environmental issues to real-world causes by and consequences for the economy and society. Sustainable action is enabled beyond the classroom.
    - **Examples include**: Inquiry-based learning, co-curricular learning, and other opportunities for learners to define problems, design, and select action projects, identify facts, and build skills in problem solving. Activities that "build transformative capacity for leadership, creative problem solving, monitoring" (Monroe et al., 2008).

Bedi & Germain (2016) emphasize the importance of EfS to focus on promoting skills and enabling sustainable action. However, is this what we see in schools and universities today? In 2017, Stevenson et al. postulated that this may not be the case, partially due to disciplinary or subject-based nature of education, and that efforts could be made to integrate sustainability in an interdisciplinary way, in the context of real-world problems that extend beyond the classroom, to overcome this issue.

While such an approach may be difficult depending on institutional regulations (Stevenson et al., 2017), one possible way to accomplish this is by leveraging the Sustainable Development Goals (SDGs) and implementing Education for Sustainable Development (ESD) strategies. The Sustainable Development Goals (SDGs), that introduce 17 of global challenges (https://sdgs.un.org/goals), encourages people to think about the interdependence of the environment, society, and economy (the three pillars of sustainability) in a systematic and interdisciplinary way. In addition to raising awareness of SDGs in the education system, ESD focuses on creating a transformative educational system that addresses content, outcomes, pedagogy, and learning environment as well. It integrates interactive, learner-centered teaching, and it advocates for action-oriented and transformative pedagogy, similar to EfS. According to UNESCO (2017), ESD focuses on developing the competencies that both enable and empower learners to reflect on their actions and behaviors towards society, culture, and environment, to enable individuals to act in complex situations sustainably. The report encourages all institutions (including formal and informal educational institutions) to consider ESD as an integral part of education. ESD for 2030's goal is "to build a more just and sustainable world through strengthening ESD and contributing to the achievement of the 17 SDGs." and its objective is "to fully integrate ESD and the 17 SDGs into policies, learning environments, capacity-building of educators, the empowerment and mobilization of young people, and local level action" (UNESCO,2020, p.20).

While we recognize the SDGs as a valuable framework for structuring sustainability goals and mapping these to curricula, we also acknowledge existing discrepancies. The SDGs have been subject to criticism regarding their effectiveness and potential negative consequences. For example, one prominent critique raised by Kopnina (2015) is that the SDGs, while advocating for a holistic sustainable framework, might inadvertently have a detrimental impact on non-human life. The prioritization of human benefits is seen as a core issue within the SDGs, potentially neglecting the well-being of non-human species. Crist (2012) echoes this concern, emphasizing the ongoing environmental crisis, loss of biodiversity, and the necessity for critical scrutiny of human activities' impact on the planet. The SDGs, according to this perspective, lean heavily on sustaining *human* life, raising the call for environmental justice to encompass all inhabitants of the planet, both human and non-human.

Kopnina (2015) further argues that some SDGs contradict each other. For instance, a focus on economic development may neglect social inequality aspects. Economic growth might be prioritized over environmental preservation, highlighting a hierarchy that places economic interests above ecological benefits. Additionally, Kopnina points out that while the SDGs have positively impacted health and development, they have not adequately addressed interconnected challenges such as population growth, natural resource limitations, and economic complexities. A more comprehensive approach is necessary, considering all these contradictions.

In addressing the shortcomings of the SDGs, Kopnina proposes several recommendations. Firstly, there is a need for a reorientation towards holistic sustainability that considers the benefits for both human and non-human life. She advocates for transformative actions, endorsing concepts like "cradle to cradle design" (see Section 3.2), which propose designing human industries to nourish the entire ecosystem rather than contribute to ecological degradation, breaking away from a solely human-centric perspective (Kopnina, 2015).

While it is imperative to acknowledge the limitations and shortcomings of the UN SDGs, emphasizing the necessity for a more cohesive framework that encompasses all sustainability elements for both humans and non-human species, we still see value in using the SDGs provide an accessible mechanism for integrating sustainability knowledge, skills, and actions into mainstream education in meaningful ways. The next section provides several strategies with which to achieve this.

2.2 Mapping sustainability to subject-based curricula

As previously mentioned, the SDGs offer one approach for introducing global issues across various domains of sustainability in a systematic and interdisciplinary way. SDG integration into the curriculum can either focus narrowly on one or a few SDGs or adopt a broader perspective, viewing the SDGs as interconnected global goals. Furthermore, these goals can be integrated into existing content and curricula or pave the way for new curricula built with the SDGs in mind.

Wersun et al. (2020) explore three methods for incorporating SDGs into curricula. The Simplest method is "Mapping by SDG Icon". This method means that the instructional designer chooses to link general themes found in syllabi to specific SDGs. For example, SDG7 Affordable and Clean Energy might be linked to physics curricula; SDG5 Gender Equality to history; or SDG6 Clean Water and Sanitation to geography. However, it's important to recognize the limitations of this method. It does not consider SDG sub-targets and relies on the subjective judgment of the designer. SDG sub-targets and indicators provide a more measurable breakdown and milestones for achieving the overarching target. An illustrative example is "Sub-Target 6.1.1: Proportion of the population using safely managed drinking water services" (United Nations, 2016). This method offers a straightforward approach to incorporating SDGs into curricula, it is crucial for instructional designers to be mindful of its limitations.

A more comprehensive mapping technique is the use of the "SDG Key Words Search" (Wersun et al., 2020). After compiling relevant keywords, instructional designers proceed to analyze course materials to identify activities aligned with Sustainable Development Goals. This content analysis aims to gauge the materials' relevance to sustainable development objectives. Once these activities are pinpointed, designers explore ways to enhance them in relation to SDGs. This may involve incorporating real-world examples, fostering systems thinking, and addressing sustainability issues. The goal is to create engaging learning experiences that contribute to broader sustainability goals outlined in the SDGs. However, Wersun et al. (2020) indicate that there is no universally agreed-upon set of keywords, and institutions often create their own lists based on perceived relevance of each of the 17 SDGs.

The third and most complex mapping methodology is to align educational activities with specific SDG sub-targets, totaling 169 sub-targets. While this method is resource-intensive, it ensures a robust assessment of SDG integration. To illustrate, when aligning a curriculum or educational program not just with the overarching SDG, such as "Clean Water and Sanitation" (SDG6), but with its specific sub-targets, such as *"Sub-Target 6.1.1: Proportion of population using safely managed drinking water services"* (United Nations, 2016). An instructional designer crafting a geography curriculum would design learning objectives and activities that directly contribute to students' understandings of how geography (e.g., topology, resources, infrastructure, policies) relates to populations' access to clean water. For instance, they might incorporate activities requiring students to collect, critically analyse, and communicate data collected through field work in a range of local neighbourhoods' water supplies/rivers, and relate these to the infrastructure (e.g., waste management plants) and governmental policies in place in these regions. This alignment ensures a comprehensive and measurable approach toward meeting the Sustainable Development Goals in the educational context.

The Sustainable Development Solutions Network (SDSN, 2020) has introduced a framework designed for evaluating the implementation of SDGs into education. This framework explores principles to assist universities in comparing and prioritizing various options for integrating SDGs into higher education programs. Although SDSN primarily discusses these principles in the context of university-wide implementation, the model could extend to curriculum design more broadly. The principles outlined in this framework include Priority, Suitability, Depth, and Reach:

1. **Priority**: This refers to that Universities ability to prioritize the comprehensive implementation of SDGs for specific groups of learners (SDSN, 2020). This could also extend to prioritizing goals within curricula based on their global urgency and relevance, taking into account local and regional priorities to enhance contextual significance.

1. **Suitability**: According to SDSN (2020), this refers to the suitability of certain pedagogical methods and avenues to certain elements of SDGs. It also distinguishes between general knowledge (basic understanding of sustainable development issues), profession-specific knowledge, and transformative learning approaches (SDSN, 2020). This pillar can also extend to selecting SDGs that naturally align with each course's subject matter, assessing interdisciplinary potential, and considering the developmental stage of learners.

2. **Depth**: SDGs vary in terms of the depth of knowledge, skills, and mindsets they can help learners develop, which should be determined based on the nature of the course and the target audience (SDSN, 2020). Here we could also consider the three level of integration by Wersun et al. (2020) whether we would align with a simple SDG icon, Keywords or Mapping via SDGs target.

3. **Reach**: Discusses the pathways capacity to reach potential learners (SDSN, 2020). This could also extend to how educational activities might need to be more accessible, adaptable, and applicable to a wide range of learners. This might involve simplifying complicated concepts, using general themes, and employing methods that cater to diverse learning styles.

This approach encourages instructional designers to systematically address integrating and mapping SDGs into their curricula design through considering the multiple layers involved in curricula designs while thinking of the macro and micro scale of sustainability. This ensures a balanced design approach that fosters impactful and relevant educational experience that promotes sustainable development goals.

2.3 Interaction design for sustainability learning

Building on the second objective of SHCI—to affect pro-environmental behaviors, in our case, through EdTech—how do these pedagogical and content considerations translate into a transformative, technology-enhanced learning experience?

A recent literature review on digital transformation in higher education toward sustainability suggests that a key affordance of technology is to diversify pedagogies, stimulate pro-environmental action, and enable virtual transnational collaborations (Trevisan et al., 2023). Vasalou & Gauthier's review (2023) provide more detail to inform these ideas by exploring how human-computer interaction design can support learning about climate change and engagement in sustainability. While Vasalou & Gauthier's review focused on technology *for children*, these techniques might reasonably extend to adult learning. Their analysis identified four overarching interaction design themes that shape the development of digital technologies for children's engagement in sustainability:

The first theme, 'Making the hidden visible mobilises action', employs technology to reveal unseen aspects of the natural world (such as energy flows/consumption, biodegradation) with the intention of impacting learners' situated sustainable interactions. For instance, augmented reality might be used to superimpose information on learners' surroundings, to build understanding of climate concepts in the real-world (e.g., Dobal et al., 2021). Or learners might use internet-of-things gadgets and sensors to monitor their otherwise hidden resource-consumption and visualize these through eco-feedback, to reflect upon their environmental impact and adjust their behaviors (e.g., Mylonas et al., 2021).

The second theme, 'Supporting the exploration of cause-effect relations', leverages the capabilities of technology to simulate relationships with various levels of complexity, allowing learners to exercise systems-thinking. For example, game-based learning interventions can allow learners to test hypotheses about how economically driven decisions impact the environment and society (e.g., Alves-Oliveira et al., 2019).

The third theme, 'Making as a way of expressing and negotiating environmental sustainability', utilizes authoring technology and tangible objects as creative tools that learners can employ to represent and express their understandings and values related to environmental sustainability, often building research, communication, and collaboration skills through the process. To illustrate, Brady et al. (2022) invited teenagers to participate in collaborative game-authoring workshops themed around marine plastic, where they produced a range of provocative games reflecting their concerns, targeted toward for younger children.

The fourth theme, ‘Creating attachments and affective connections’, utilizes technology to facilitate children’s emotional comprehension of environmental sustainability, strengthening their ties to the physical world through technology enhanced hands-on interactions. This frequently seeks to nurture ecological identities that encourage future stewardship. For instance, mobile applications can be used on nature trails to enhance learners’ place-based appreciation (e.g., Goralnik et al., 2020), or in gardens to enhance the caretaking of plant-life (e.g., Valguarnera et al., 2020).

Ultimately, the integration of EfS into EdTech requires thoughtful pedagogical, content, and technological interaction design. This multifaceted approach aims to cultivate a mindset that aligns with the goals of a more just and sustainable world. However, we must practice what we preach… EdTech for sustainability learning must also be designed sustainably, which we look at next.

3 Designing EdTech Sustainably

In this section, we will examine some of the unsustainable impacts of technology, which served as a catalyst for our framework’s development. Additionally, we will explore concepts that informed the creation of the outer layer of the framework (green design considerations) that encompasses the central core components on EdTech for sustainability learning.

3.1 The unsustainable impact of EdTech

Selwyn (2021) postulates that Edtech is broadly driven by the assumptions that technology will continue to evolve in its capabilities, and that these evolved technologies will be leveraged in education to improve teaching and learning. These assumptions give us hope that EdTech will improve the lives of children and young people through quality education the world over (SDG4). Yet, this positive framing does not account for the environmental cost of EdTech and the consideration that such technologies may actually propel the world into environmental collapse at even greater speeds. We’ve known for a long time that we must account for the eco-friendliness of new technological developments, lest we build a world no longer suited for living (Elshof, 2008). Thus, it’s high time we put this into practice.

When designing an EdTech tool, the ecological impact of two distinct aspects of EdTech should be considered: (1) the material hardware through which users consume the EdTech (e.g., computers, tablets, mobile phones, smartboards, educational robots, internet-of-things gadgets/sensors, AR and VR headsets) and (2) the digital EdTech software itself (e.g., learning management systems, e-learning platforms, mobile applications, games, large language models and other AI interfaces, or more generalist software, to name a few). The sustainability impact of both hardware and software should be considered when designing new EdTech.

While EdTech can bring positive societal changes, its negative environmental impacts require attention. For example, when EdTech hardware is tossed away, it produces electronic waste (e-waste), which is a rapidly growing global issue, constituting 70% of toxic waste in US landfills. Despite high-tech advancements, the US exhibits a low rate of recycling e-waste, with only 17.4% recycled according to the United Nations Institute of Training and Research. By 2030, the projected total e-waste volume is 74 million tons, further underscoring the urgency of the problem (Arribas Cámara, 2023). E-waste, rich in valuable metals like copper, silver, gold, and platinum, presents an opportunity for resource recovery. Millar (2015) highlights that we should pay closer attention to recycling e-waste when manufacturing new devices. However, the challenge lies in the high cost and inefficiency of current technologies for recycling and scrapping, which must be addressed to avoid exacerbating environmental impacts through technology production (Arribas Cámara, 2023).

Additionally, if we examine digitization (i.e., the software aspect), we will find that it’s often seen as a friend of sustainability, due to its benefits such as dematerialization, decarbonization, and the shift from a product to a service culture. For example, telecommunication and video conferencing reduces carbon emissions from travel (Tomlinson, 2012). However, digitization also comes at a cost, accounting for 3% of global primary energy, 7% of electricity, and 2 to 4% of global greenhouse gas emissions, as per the International Energy Agency. Furthermore, the rise of large language models (e.g., ChatGPT) and other AI interfaces in education (and life in general) poses a further environmental threat. These models are extremely resource-intensive in every phase of their life cycle, from its production and algorithmic training to its usage and disposal (Delort et al., 2023). For example, Patterson (2021) estimated that training a GPT3 model produces as much carbon as three round-trip flights from San Fransisco to New York.

However, it is generally recognised that we don't have yet a good idea of the environmental costs of AI as a field, as reporting of impacts is uncommon (Delort et al., 2023).

These are just few of the examples of the impacts of technology. EdTech has a very limited achievement when thinking about practices for designing towards sustainability. We believe that this is due to the lack of guidelines or strategies that can assist designers in adhering and moving toward more environmentally sustainable EdTech (Turner, 2008). Additionally, where guidelines are available, these are dispersed across different domains (e.g., ICT, AI, Education), making it difficult for designers pull together all available knowledge. As such, designers generally make their own intuitive decisions in terms of what's sustainable and what's not, and most of the time will make trade-offs and choose between cost and sustainability. Turner argues that "designing for sustainability was about optimizing, not compromising" (Turner, p.2, 2008).

As previously mentioned, EdTech can pose environmental harm through both its hardware and software. Correspondingly, designers should consider (1) the eco-design of the hardware's materials and the reusability of its constituent parts, as well as (2) the environmental impact of the software (e.g., energy use), as well as user's interactions with the software that may exacerbate these impacts. In this way, we aim to develop "appropriate" technologies (Beder, 1994), ones that work in harmony with the environment.

In the subsequent subsections, we will delve into relevant literature that has shaped the formulation of considerations for green design and sustainable user behavior within the framework.

3.2 Strategies for the eco-design of EdTech hardware

Goggin & Lawler (2003) state that designing for sustainability needs to refocus on achieving "more for less" by focusing on macro views of the social, economical, and environmental aspects. A first strategy is to consider whether there is a no-technology or low-technology alternative and, if not, whether the benefit of the innovation truly outweighs the environmental cost (Baumer & Silberman, 2011). If a new technology is warranted, then we must consider eco-design strategies to reduce the environmental impact. The World Business Council for

Sustainable Development (WBCSD) outlined seven important goals for eco-friendly hardware design in a commercial context:

1. Reduce material intensity of goods and services.
2. Reduce the energy intensity of goods and services.
3. Reduce toxic dispersion.
4. Enhance material recyclability.
5. Maximize sustainable use of renewable resources.
6. Reduce material durability.
7. Increase service intensity of goods and services.

If we consider applying eco-design principles in developing new EdTech hardware, we need to incorporate sustainability consideration throughout the process. For example, when thinking about the materials, the designers would select materials that have the lowest environmental cost through choosing lightweight materials to reduce material intensity. Alternatively, designers might opt for choosing recycled or renewable materials and those produced using renewable energy sources.

It is also highly recommended that the constituent parts of the hardware be modular or recyclable. Elshof (2008, p.6) explains that our current system of consumption/use is linear and revolves around the notion of "design → manufacture → use → dispose". Most of our designs are made to be disposed of eventually, turning raw materials into waste, a concept that McDonough & Braungart (2009) describe as "Cradle to Grave" design. By making EdTech hardware modular, it can be easily repaired and/or upcycled—that is, reused for other purposes beyond the lifetime of the EdTech tool. This is the circular concept of "Cradle to Cradle" design, where, after disposal, the technology is broken down into its constituent parts or raw materials in a way that can be used again and do not end up as waste. (McDonough & Braungart, 2009)

3.3 Strategies for the eco-design of EdTech's software

We also need to think of the impact of the EdTech's *software*, namely its energy consumption, by optimizing the program to run efficiently, e.g., limiting input/output (I/O) requests. Particularly, those EdTech tools that embed AI should follow guidelines propose by Ligozat et al. (2021), such as reducing redundant computation and data storage, choosing a low-carbon data centre, building upon existing trained models to reduce unnecessary waste of resources, and quantifying and reporting the predicted environmental costs of their AI, to help the field build a better understanding of its footprint and increase accountability.

O'Rafferty et al. (2014) introduced a comprehensive conceptual framework for capacity building in design education, outlining competencies across six clusters. The first cluster centers on fostering creativity, followed by the “Culture and Values Cluster”, the “Intelligence and Insights Cluster”, the “Analytical Cluster”, the “Organizational Cluster”, and the “Methodological Cluster”.

Notably, the fourth cluster, the "Analytical Cluster," holds particular relevance to eco-design, concentrating on the systematic analysis of environmental, social, and economic aspects to facilitate sustainable design practices. This cluster emphasizes key elements such as life cycle analysis, eco-materials knowledge, and the evaluation of energy, packaging, and cost implications in the design process (O'Rafferty et al., 2014). These elements are crucial for eco-design considerations. Life cycle analysis enable designers to assess the environmental impact of a product throughout its entire life span, allowing them to identify areas for implementing sustainable practices. Eco-materials knowledge informs the selection of environmentally friendly materials, minimizing the ecological footprint of the design. Evaluating energy and packaging implications plays an essential role in reducing energy consumption aligning with sustainable principles. And, analyzing cost implications ensures that eco-friendly design practices are economically viable, encouraging the adoption of sustainable solutions.

Additionally, Haraty & Bitar (2019) propose six metrics to minimize environmental impact, toward green technology. These are:

1. **Energy Metric:** concerned with the development of energy-efficient software that aims to preserve device battery life, thereby extending the overall device life cycle and reducing e-waste. It emphasizes the importance of creating software that minimizes energy consumption.
2. **Economic Metric:** focuses on evaluating the return on investment of green software. Despite the potentially higher development costs, green software is anticipated to yield

significant benefits in terms of user preferences and environmental impact in the long run. This metric considers the economic viability of sustainable software solutions.

3. **Performance Metric:** examines the efficiency and effectiveness of software. User adoption is closely tied to performance, and poorly performing applications may lead users to opt for alternatives, thereby undermining the purpose of creating green software. Performance is intricately linked to utilization and quality of service.
4. **Quality of Service Metric:** pertains to delivering features and performance that align with user expectations. A key aspect of service quality involves educating users about the environmental impact, encouraging sustainable behavior patterns. This metric considers the holistic user experience and environmental awareness (see also Bhamra's "design for sustainable behavior" below).
5. **Utilization Metric:** evaluates how software utilizes CPU resources for effective and fast processing, considers RAM usage for multitasking, and emphasizes efficient I/O operations to ensure optimal performance. Proper utilization, including storage considerations, is vital in designing green applications, aligning with the goal of reducing e-waste.
6. **Energy/Performance Metric:** combines energy and performance considerations, offering a comprehensive evaluation of the trade-off between energy efficiency and system effectiveness. It underscores the need for a balanced approach that ensures sustainable software without compromising performance (Haraty & Bitar, 2019).

Haraty & Bitar (2019) conducted a study that compared a green app to a conventional app devoid of environmentally mindful design. The green app demonstrated commendable performance across various eco-metrics above, as the development process actively leveraged these criteria as guiding principles. In this experiment, fifty users evaluated these two apps offering identical services. Users expressed a preference for the green technology, driven by heightened awareness of its positive environmental impact.

These findings suggest that users are drawn to green technology—perhaps because this helps them to feel good about consuming a product. Yet, some scholars suggest that this may be problematic. Tomlinson (2012) reminds us that, while designers might have an intended use in mind, new uses might emerge when the user interacts with the technology. For instance, because consumers are aware that they are choosing a more eco-friendly product, they may use it more or differently than they otherwise would, which may actually increase its harmful environmental or social effects in ways that surpass the product choice that was less eco-friendly – a phenomenon described by Lilley et al. (2005) as a "Rebound Effect".

In fact, Wilson & Bhamra (2020) acknowledge that there are several ways in which users' sustainable behaviors and actions can be influenced by how the product is designed, which may either promote or counteract the rebound effect. Lilley et al. (2005) are some of the pioneers in proposing a framework to reflect this so-called "design for sustainable behavior". Their framework includes a three steps model: "Script and Behavior Steering", "Eco-Feedback" and "Intelligent Products and Systems" (Lilley et al., 2005). Later, Bhamra et al. (2011) refined Lilley et al.'s (2005) three strategies to present a more cohesive 7-level model:

1. **Eco-information** makes the resources used or consumed by the product visible, understandable, and accessible to consumers (e.g., the eco-metrics by Haraty & Bitar, 2019), so they can choose the most sustainable product by reflecting upon its use of resources. Particular attention should be given to the unit of measurement for environmental cost/savings, so that it is comprehensible to consumers.
2. **Eco-Choice** provides consumers with options that would increase the sustainability of the product's use to encourage them to think about their use.
3. **Eco-Feedback** informs consumers about the sustainable use of the product through real-time visual, oral, or tactile feedback, to facilitate environmentally and socially responsible decision-making.
4. **Eco-Spur** reinforces sustainable behaviors with rewards and discourages non-sustainable behaviors through punishment, to prompt users to explore more sustainable usage (e.g., through gamification).
5. **Eco-steer** embeds affordances or constraints in the design to facilitate users' adoption of more environmentally or socially desirable use habits (e.g., through tips and recommendations).
6. **Eco-technical intervention** uses advanced technology and design strategies to automatically restrain, persuade, or control consumers' existing use habits and behaviors.

7. **Clever design** automatically acts environmentally or socially without raising awareness or changing user behavior purely through innovative product design.

Yet, it is critical to pay attention to the context in which the EdTech will be used when applying these sustainability design principles, to help avoid a rebound effect. Let's imagine how applying Bhamra et al. (2011) model might look in building a learning management system (LMS) and how these might promote or counteract the rebound effect. For example, Eco-Information provides users with information about the environmental impact of digital learning activities, fostering eco-awareness, Eco-Choice empowers learners to make sustainable decisions. However, the potential rebound effect needs to be considered; for instance, providing eco-choices may create a perception of sustainability that leads to increased resource utilization. Gamification elements, that build on Eco-Spur concept, could encourage users to prioritize rewards over genuine sustainability. It is essential to combine these design strategies strategically, considering contextual factors and potential unplanned user behaviors, to effectively counteract the rebound effect.

3.4 Multi-stakeholder responsibility

To move forward to a greener and sustainable technological scene, collaboration is needed between multiple stakeholders include policymakers, designers, corporations, and finally users. This quest requires a comprehensive approach, wherein designers engage in extensive collaboration with policy makers, production teams, and businesses. For instance, when designers incorporate considerations for extending the lifespan of technological tools, it influences manufacturers and, ultimately, the decision-making process regarding tool durability. The responsibility for sustainable practices does not rest solely on designers, as the collaborative process involves multiple stakeholders across various stages, from conception to production. Nonetheless, designers play a crucial role in initiating systematic change, serving as the cornerstone for development. Furthermore, policymakers have a role to play in the regulation of these technologies, ensuring that corporations are held accountable for the manufacturing of their products and energy use.

4 Framework: Sustainable EdTech for Sustainability

In an attempt to bridge the gap in the literature in regards to having a framework that guides the design of Sustainable Educational Technology for Sustainability (SETS), we developed an initial conceptual framework that provides guidelines for EdTech practitioners to design EdTech tools that are both eco-friendly (built with sustainability in mind) and promotes education for sustainability (Figure 1).

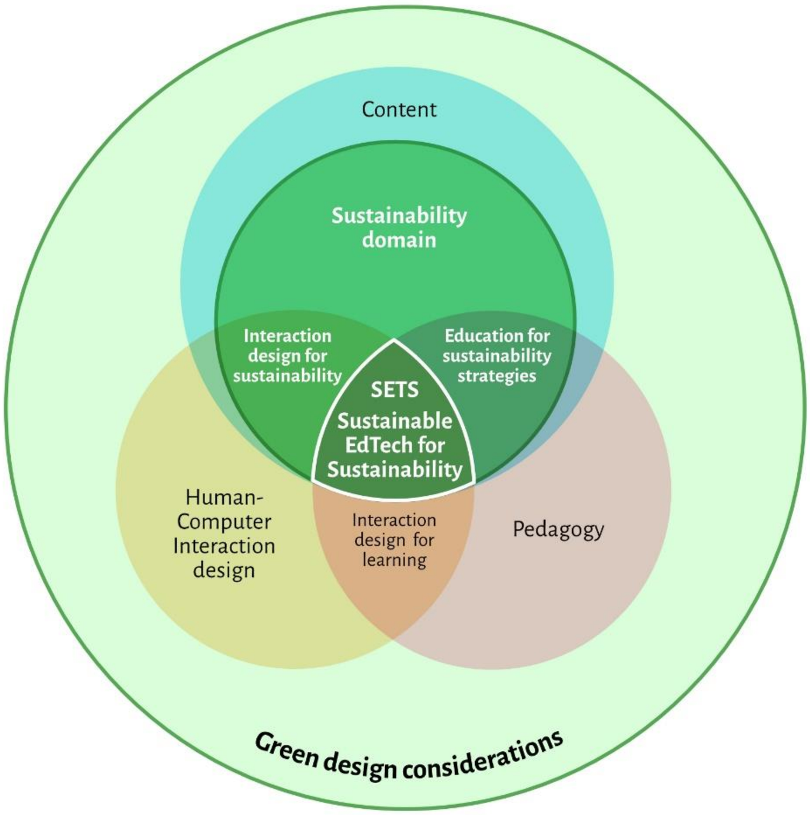

Figure 1. Sustainable Educational Technology for Sustainability (SETS) framework.

The framework comprises four dimensions that serve as a guideline for incorporating sustainability learning and action into the design of EdTech solutions in meaningful ways. This framework encourages designers to take these dimensions into account when creating new EdTech solutions.

Within the framework, three interconnected circles symbolize pedagogy, content, and human-computer interaction design—the core components of EdTech. Content is further drilled down to look at the sustainability domain, specifically. These elements contribute to three overlapping areas, facilitating the development of EdTech for sustainability learning and action, toward sustainable development. In Sections 4.2-4.4, we will focus on the intersecting areas within the small green “sustainability domain” circle in Sections. Additionally, this interconnected core is encompassed by an overarching circle on green design considerations, guiding how EdTech can be designed in an eco-friendly way, which we will discuss first in 4.1. Finally, 4.5 pulls all the concepts together in the creation of SETS.

4.1 Green Design Considerations

The Green Design Considerations dimension is concerned with developing eco-friendly technology solutions. First, the designer should answer (No) to the three questions below posed by Baumer & Silberman (2011):

1. Is there a feasible alternative using low-tech or no-tech methods for the given situation?
2. Could the implementation of technology potentially cause more harm than the situation it is intended to address?
3. Does the technology primarily address a computationally manageable problem rather than effectively resolving the real-world situation it is meant for?

If ‘No’ is answered to these questions, then a new EdTech solution may be warranted. Designers should then consider aspects such as life-cycle analysis, eco-materials, energy and consumption, and the environmental and social impact of such designs. We developed the following questions based on elements suggested by both O’Rafferty et al. (2014) and Haraty & Bitar (2019), which synthesize the environmental considerations that were reviewed in Sections 3:

1. **Environmental & social impact measurement** (O’Rafferty et al., 2014): Have environmental and social impacts been systematically assessed and quantified for the product, process, or activity, considering factors such as ecological impact, resource depletion, pollution, and social aspects like community well-being and equity?
2. **Life-cycle analysis** (O’Rafferty et al., 2014): Has a comprehensive and systematic life-cycle analysis been conducted to evaluate the environmental impact of the product, process, or service throughout its entire life cycle, from raw material extraction to

disposal? Are efforts being made to identify and minimize environmental burdens at each stage?

3. **Carbon/eco-footprint** (O'Rafferty et al., 2014): Is the total carbon or eco-footprint associated with the product, service, or organization being measured, considering both direct and indirect greenhouse gas emissions? Is there an understanding of the overall environmental impact in terms of contributions to climate change? (O'Rafferty et al., 2014)
4. **Eco-materials knowledge** (O'Rafferty et al., 2014; McDonough & Braungart, 2009): Are eco-materials being used and sourced, with a focus on minimal environmental impact? Is there an understanding and utilization of materials that promote sustainability, reduce negative effects on ecosystems, and encourage environmentally friendly practices? For example, is the technology being designed following a "cradle to cradle" methodology?
5. **Understanding Economic and Cost implications** (McDonough & Braungart, 2009; Haraty & Bitar, 2019): Have the cost implications of environmentally conscious practices been thoroughly understood? Is there an assessment of financial aspects related to implementing green initiatives, considering factors such as initial costs, operational expenses, and potential long-term savings? Have the potential higher development costs of green software been considered? Is there an evaluation of the return on investment for the green software? Are the long-term benefits, including user preferences and environmental impact, being taken into account?
6. **Energy auditing** (Haraty & Bitar, 2019): Have energy auditing been conducted? Is the software designed to minimize energy consumption? Does the software contribute to preserving device battery life?
7. **Performance Metric** (Haraty & Bitar, 2019)**:** Has the efficiency and effectiveness of the software been thoroughly examined? Have alternatives been considered to prevent users from opting for less efficient applications?
8. **Quality of Service Metric** (Haraty & Bitar, 2019)**:** Does the software deliver features and performance aligned with user expectations? Is there an effort to educate users about the environmental impact of the software? Does the software encourage sustainable behavior patterns among users?

9. **Utilization Metric** (Haraty & Bitar, 2019)**:** How effectively does the software utilize CPU resources for processing? Is RAM usage optimized for multitasking efficiency? Are I/O operations designed for optimal performance, considering storage considerations?
10. **Energy/Performance Metric** (Haraty & Bitar, 2019) **:** Has there been a balanced approach to energy efficiency and system effectiveness? Does the software offer a comprehensive evaluation of the trade-off between energy efficiency and performance? Is sustainability maintained without compromising overall system effectiveness?

Once these items have been assessed, it must be considered how these statistics will be communicated to consumers. For example, designers can draw on Bhamra et al. (2011) and ask:

1. Can **eco-information** be provided to tell users about the eco-credentials of the product? Is it provided in a format that is easily understood by the average person (e.g., does the unit of measure relate to everyday life)?
2. Can **eco-choice options** be made visible to users, with an understanding of environmental costs/savings, so that they know how to use the product in the most environmentally friendly way?

Furthermore, to counteract the possible rebound effect of making eco-credentials visible, designers should ask:

3. Can **eco-feedback**, **eco-spur**, and/or **eco-steer** strategies be implemented to guide users' behaviors with the technology in an eco-friendlier direction? And,
4. Can **eco-technical** or **clever design** be used to automatically restrict users' interactions with the product to be more sustainable?

4.2 Sustainability domain (content)

The "sustainability domain" dimension serves as an open invitation to conscientiously consider sustainability as a core issue in the lives of children, young people, and society at large, filtering into every aspect (or subject) in education. It prompts designers to ask, "In what ways is the topic I seek to teach related to sustainability? How can it be contextualised to engage learners in sustainability issues?". By considering sustainability as integral to the fabric of everyday life, we see that many challenges we face today relate to it, and so we can situate most education in this context. By doing so, we take steps toward ensuring that our EdTech creations align with a broader global vision of sustainability and contribute to addressing multifaceted challenges that threaten our world.

Having made the decision to design EdTech to promote sustainability awareness, understanding, skills, and/or action, designers will also need to ensure that you meet the curricular objectives of different content or subject domains—at least in countries dominated by subject-based educational systems. One approach, as presented in Section 2.2, is to map SDGs to the curriculum. Doing this can help situate learning in the context of real-world challenges, raising awareness of the SDGs, and making the learning experience more meaningful and engaging for students, all while hitting curricular objectives.

SDGs can be mapped to a variety of subjects and often span multiple disciplines (UNESCO, 2015). Building content around these goals encourages cross-disciplinary connections, fostering a more integrated and holistic understanding of complex issues. Inspired by the SDSN (2020) framework for evaluating the implementation of SDGs into education, we propose a checklist below that acts as a structured guide for designers.

Priority of SDGs

- Have you identified SDGs that align with current global challenges and priorities?
- Have you considered local and regional priorities when selecting SDGs?
- Are the chosen SDGs aligned with broader educational objectives and institutional mission?

Suitability for Courses

- Have you identified SDGs that naturally align with the subject matter of your course?
- Have you identified key concepts within each selected SDG that align with course objectives?
- Have you assessed the interdisciplinary potential of certain SDGs to foster holistic learning?
- Are you integrating the SDG in a way that matches the stage of cognitive and emotional developmental of the learners in the course?

Depth of Integration

- Have you determined the appropriate depth of SDG integration based on the nature of the course?
- Have you planned for a balanced integration, progressing from foundational awareness to advanced application?

Reach

- Is there a plan for gradually introducing SDG concepts at different educational levels, ensuring a progressive understanding from young to adult learner?
- Have you identified strategies to make educational activities more accessible, adaptable, and applicable to a diverse range of learners?
- Have you considered using inclusive language and diverse examples that resonate with a wide range of cultural backgrounds and experiences?

Integrating SDGs into educational content serves as a catalyst for heightened awareness among learners. By incorporating these global goals into the curriculum, educators not only impart knowledge but also instill a sense of responsibility and understanding of the pressing challenges facing our world. In an ideal world, this awareness extends beyond the classroom, fostering a generation of students who are cognizant of their role in contributing to sustainable development. Consequently, mapping SDGs into content becomes a strategic means to broaden perspectives and cultivate a global mindset among learners. However, the effectiveness of this is largely up to how the content is supported by pedagogy.

4.3 Education for sustainability pedagogies

We now turn our hands to pedagogy, a crucial aspect in crafting a successful EdTech solution (Hietajärvi & Maksniemi, 2017). In this dimension, designers should meticulously select the most suitable approaches for their EdTech solutions, informed by pedagogical theory at the intersection of sustainability. However, in a recent review of technologies to support children's engagement in environmental sustainability, Gauthier & Vasalou (2023) found that EdTech designers/researchers drew infrequently upon sustainability theory (e.g., environmental education, environmental psychology) to inform the pedagogical approach of their interventions. As such, we propose a series of theory-driven questions at the intersection of education and sustainability to guide the design of pedagogical approach.

First, we must consider the aspects of good learning more generally (Bedi & Germein, 2016), which are critical in education for sustainability:

1. How can a **constructivist** approach to learning be implemented? How can the approach support learners in constructing knowledge through problem-solving and critical thinking, aligning with the desired knowledge construction approach in pedagogy?
2. How can the **provisional nature of sustainability knowledge** be communicated to learners?
3. How can the **inter- and/or transdisciplinary** nature of the topic be leveraged?
4. How can the learning be **situated in real-world** contexts, that have real-world outcomes? Can connections be made with the local community?
5. How can the activity be **participatory**, encouraging collaboration between students, teachers, and other stakeholders? How should the design of the tool prioritize individual learning activities or collaborative learning experiences, aligning with the pedagogical goals of the educational context?

We then turn to Monroe et al. (2008) and consider the more fine-grained pedagogic dimensions of the approach, with particular attention given to skills development and enablement of sustainable action:

1. **Information Transmission:** How can relevant sustainability-related information be effectively transmitted to the target audience in the design solution?
2. **Building Understanding:** In what ways can learners be engaged in a two-way exchange to develop mental models and comprehension of sustainability concepts, values, or attitudes? In what ways can approach prioritise critical and systems-thinking skills, about the interconnectedness of the environment, society, and economy?
3. **Skill Development:** What strategies can be employed to move beyond knowledge acquisition and focus on cultivating practical abilities that can support sustainable behaviors?

4. **Enablement of Sustainable Action:** How can the design transform learners, issues, and educators to critically address problems with considerations of economic and equity aspects?

This series of questions serves as an attempt to create a guide for designers to integrate pedagogic dimensions suitable for education for sustainability, which must then be integrated into EdTech using interaction design—the focus of the following section.

4.4 Interaction design for sustainability

Finally, we propose a set of guiding questions that designers can use to consider appropriate interaction design themes for digital technologies for sustainability, with items 1-4 based on Vasalou & Gauthier (2023), and item 5 inspired by Trevisan et al. (2023):

1. **Making the Hidden Visible:** How can technology be strategically incorporated into educational activities to unveil hidden aspects of the natural world, fostering a deeper understanding and promoting sustainable behaviors, e.g., through data-visualisation or augmented reality?
2. **Supporting Cause–Effect Relations:** In what ways can technology design create immersive learning experiences that simulate cause-effect relationships, nurturing systems thinking and practical skills in learners, e.g., through simulations or gaming mechanics?
3. **Making as a Way of Expressing Sustainability:** How can learners be empowered to utilize various technologies as tools for expressing their comprehension and values related to environmental sustainability within educational activities, e.g., through game-authoring, internet-of-things monitoring, or educational robotics?
4. **Creating Attachments and Affective Connections:** How might educational technology designs be crafted to facilitate emotional comprehension, aiming to strengthen learners' emotional ties to the physical world and create meaningful attachments, e.g., through mobile technologies that enhance fieldwork or nature appreciation?
5. **Enabling (virtual) collaboration on real-world problems:** In what ways can technology enable collaborative learning on real-world issues, e.g., through video conferencing, online forums, or virtual whiteboards?

4.5 Sustainable Educational Technology for Sustainability

The notion of a Sustainable Educational Technology for Sustainability (SETS) stands as a synthesis of the dynamic interplay between pedagogy, sustainability content, and interaction design, all enveloped within the overarching parameters of green design considerations. This conceptual framework envisions EdTech solutions with dual aims. First, as far as is possible, to avoid contributing to the environmental crisis, by meticulously applying green design principles. And second, to transcend conventional educational paradigms by creating digitally enhanced learning environments that not only builds a holistic, systematic, and situated understanding of sustainability, but also seeks to improve skills and enable real-world sustainable actions. Furthermore, it does so in a way that resonates deeply with learners, fostering a lasting comprehension of the subject matter, sense of responsibility and agency, and sustainable behaviors and habits beyond the classroom.

While this conceptual framework provides a theoretical foundation for the integration of sustainability into EdTech solutions, it is crucial to acknowledge its untested nature. This framework represents a pioneering step toward creating educational technologies that align with environmental and sustainability goals. However, its true efficacy remains to be evaluated through empirical research and real-world applications. Consequently, further studies are indispensable to validate and refine this theoretical framework, offering a promising avenue for future research endeavors in the realm of sustainable educational technology.

5 Conclusion

With consequences of the climate crisis reverberating around the globe, education stands as a potential catalyst for change by promoting holistic understandings of sustainable systems that have potential to support sustainable behaviors beyond the classroom. Given the increased investment and innovation in educational technology (EdTech)—as well as its own contribution to environmental degradation and climate change—we argue that now is the time to begin designing EdTech through the lens of sustainability. However, guidance for designers on how to do this is interdisciplinary and unconsolidated, making this challenging. As such, many publications about EdTech for sustainability are not driven by sustainability-informed learning theory (Vasalou & Gauthier, 2023), with little or no thought given to the eco-friendliness of the EdTech itself.

The aim of this chapter was to present a practical framework to support EdTech designers in developing Sustainable Educational Technology for Sustainability (SETS). Firstly, the framework underscores the necessity of incorporating sustainability considerations into the very fabric of the EdTech solution through the application of green design principles, helping EdTech adhere to environmentally conscious practices. By integrating these principles, designers aspire to reduce the ecological footprint of educational technology, contributing to a more sustainable digital landscape. Secondly, the framework breaks down the pedagogical, content, and interaction design of EdTech in such a way as it supports transformative learning experiences that have real-world relevance and contribute to learners' identities as change agents.

While this framework is a good starting point, it is untested and open to input from others in the field. We encourage EdTech designers to try it and critique it, so we can improve the framework and continue to drive the field forward in a more sustainable way.

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