Editorial

Educational Technology and E-Learning as Pillars for Sustainable Education

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1. Introduction

The rapid advancements in Educational Technology (EdTech) and e-learning necessitate a critical focus on the principles of sustainability to ensure compliance with and the achievement of Sustainable Development Goal 4 (SDG 4), quality and lifelong education, conceived by the United Nations (UN). This closing editorial, for the Special Issue entitled "Sustainable E-Learning and Educational Technology", addresses the significant gap in knowledge between the adoption of technology and its long-term impact in terms of sustainability. The six articles included in this Special Issue present empirical evidence across three main thematic areas: (1) measurement and fostering of sustainable lifelong learning competencies (e.g., self-regulated learning using learning analytics in flipped classrooms); (2) validation of quality and inclusion frameworks (e.g., self-assessment guides for accessible virtual education); and (3) successful application of educational software (such as Scratch) to meet specific pedagogical objectives aligned with SDG 4. In terms of future directions, priority research areas include leveraging artificial intelligence (AI) and green information and communication technologies (ICT) for environmentally and pedagogically sound personalization, conducting longitudinal ethical studies on learning analytics data, and developing sustainable design models for accessible open educational resources (OERs). We aim for this Special Issue to serve as a valuable resource, urging researchers to integrate the principles of equity, accessibility, and long-term viability into future EdTech development.

2. Overview and the Need for Sustainability in E-Learning

The global educational landscape has undergone profound and accelerated transformation in the past decade, facilitated by advances in EdTech and the mass adoption of e-learning. While the COVID-19 pandemic demonstrated technology's capacity to maintain educational continuity, the current challenge is not just digitalization but ensuring that this transformation is sustainable and effectively contributes to achieving SDG 4: ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all.

E-learning, understood as a highly planned method that uses ICT intensively, must extend beyond mere content delivery to focus on the quality, accessibility, and durability of teaching–learning processes. However, in this rapid evolution, a critical knowledge gap has been identified.

3. The Knowledge Gap

The primary gap lies in the holistic integration of sustainability principles with the design, development, and evaluation of educational technologies. Specifically, there is a critical need for empirical research in three key areas:

1. Sustainable Metrics and Competencies: Research is required to further develop our understanding of how e-learning tools can foster competencies that are essential for long-term learning, such as self-regulated learning (SRL), as well as our ability to measure their impact using data and analytics.
2. Inclusion and Standardized Quality: Despite the advances made, accessibility and equity in virtual environments remain unstandardized challenges. The lack of validated guides to ensure inclusive quality limits the sustainability of education for everyone.
3. Pedagogical Impact of Emerging Tools: It is necessary to validate and quantify how novel technologies and methodologies (such as the flipped classroom or early programming) may directly contribute to educational outcomes that are aligned with the principles of sustainability, beyond mere efficiency.

4. Contributions of the Special Issue

This Special Issue, entitled "Sustainable E-Learning and Educational Technology", featured in the journal *Sustainability*, was established precisely to address the aforementioned challenges, as well as our knowledge gap, collating six original articles that present solid empirical evidence and conceptual frameworks. The contributions are grouped into three thematic areas, outlined below.

4.1. Lifelong Learning Competencies and Analytics

A selection of papers has focused on the assessment of skills essential for sustainable learning. In this endeavor, one study [1] examined SRL competence in university students, combining questionnaire data with learning analytics in flipped classroom settings. This analysis not only validates the importance of SRL but also lays groundwork for using learning analytics as a sustainable diagnostic and support tool.

Another study [2] focused on personalized and sustainable learning in online education, emphasizing learner modeling, analytics-based matching (Item Response Theory, knowledge graphs), and optimization of learning paths across courses. These elements are closely aligned with learning analytics, personalization, and support for continuous, lifelong learning processes.

4.2. Quality, Accessibility, and Inclusion

Another fundamental pillar of this Special Issue is equity. A highly relevant study [3] developed and expert-validated a Self-Assessment Guide to Quality in Accessible Virtual Education. This contribution is crucial, as it provides a practical tool with which institutions can evaluate and improve the quality of their virtual environments, ensuring inclusion and accessibility for all students. Other contributions explored the application of various technological and interoperability frameworks to facilitate access to and the use of OERs, promoting equity in knowledge access.

4.3. Technological Integration with Specific Pedagogical Objectives

In terms of the direct application of technological tools, one investigation [4] demonstrated the use of the educational software Scratch to promote sustained attention among primary school students, directly linking the use of a digital tool to a specific pedagogical objective of SDG 4. Scratch exemplifies Technological Integration with Specific Pedagogical Objectives by using a visual programming environment explicitly designed to foster

computational thinking, problem-solving, and creative learning through age-appropriate, constructivist activities. The findings of this study demonstrate that technology can act as a direct catalyst for improving the fundamental quality of learning processes.

Another study [5] centered on micro-credentials as mechanisms for validating skills and knowledge aligned with employability and career development, which are core aspects of lifelong learning. Micro-credentials enable the targeted integration of Specific Pedagogical Objectives by certifying the achievement of clearly defined learning outcomes aligned with particular skills or competencies. By structuring learning activities and assessments around these objectives, micro-credentials support modular, outcomes-driven instruction that can be directly mapped to professional and disciplinary requirements. This study examined how different stakeholders (students and employers) perceive the value of these micro-credentials and how factors such as issuer type and academic rigor influence that value. The main focus is on competencies, credentialing, and sustainable skill development across educational and professional contexts.

Finally, another study [6] focused on the integration of AI-powered automation within virtual learning platforms and learning management systems to enhance student learning experiences and support sustainable education. Its emphasis is on how a specific technology (AI-driven automation in learning management systems and administrative processes) is leveraged to achieve defined educational and sustainability-oriented objectives, rather than on lifelong learning analytics per se or on issues of accessibility and inclusion.

5. Future Directions: Research Areas of Priority

Collectively, these six articles [1–6] advance our understanding of how e-learning can be transformed from a temporary solution into a robust, accessible, and sustainability-aligned educational infrastructure.

Based on the contributions of this Special Issue, the future of research in the field of sustainable e-learning and educational technology should focus on the following key aims:

1. AI and Sustainable Personalization: This entails exploring the use of AI and deep learning models not only to personalize learning but also to assess and optimize the energy efficiency of e-learning platforms (encapsulated in the concept of green ICT in education). Research is needed to prevent personalization at scale from generating negative environmental impacts or exacerbating the digital divide.
2. Longitudinal Validation and Data Ethics: This area involves conducting longitudinal studies, which is necessary to validate the long-term impact of EdTech interventions on the development of professional and sustainable competencies. Simultaneously, research on ethics, privacy, and governance of learning data (learning analytics) must be prioritized to ensure educational environments based on trust.
3. Sustainable Design Frameworks: These require the development and validation of Universal Design for Learning (UDL) and User-Centered Design (UCD) models that are specifically adapted to the creation of OERs and massive open online courses (MOOCs) that are inherently accessible, interoperable, and sustainable at both the technical and pedagogical levels.
4. Extended Reality (XR) and Social Impact: These require us to investigate the potential of virtual and augmented reality (VR/AR) to simulate sustainability challenges and foster digital citizenship and soft skills, measuring their effectiveness in promoting pro-sustainability attitudes.

As we close this Special Issue, we sincerely extend our thanks to the authors, reviewers, and readers for their commitment to the advances in this critical intersection of technology and sustainability. We hope this collection of articles will not only enrich academic dialogue but also inspire those in the research community to address the urgent challenges outlined

with rigor and creativity, ensuring that technology fosters a fairer, more equitable, and more enduring educational future.

Conflicts of Interest: The authors declare no conflict of interest.

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