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SUSTAINABLE INTERACTION DESIGN FOR INNOVATING TECHNOLOGY- ENHANCED LEARNING

This abstract explores the intersection of Human-Computer Interaction (HCI), environmental sustainability, and Technology-Enhanced Education. It establishes a theoretical framework based on Sustainable Interaction Design (SIXD), challenging the field to move beyond user-centered metrics toward a holistic consideration of material effects and resource constraints. By examining the paper critiques the prevailing cornucopian vision of infinite technological resources. It further applies these principles to the domain of education, arguing that while digital advancements offer pedagogical modernization, they must be implemented through Computing Within Limits and in-the-wild methodologies to address global inequalities and environmental realities.

In the contemporary discourse of Human-Computer Interaction (HCI), the definition of design has shifted from the mere creation of artifacts to a broader stewardship of future behaviors. Foundational research in Sustainable Interaction Design (SIXD) posits that design is "the act of choosing among, or informing choices of, future ways of being" (Blevis, 2007). This definition elevates the designer's role, suggesting that sustainability must be a central focus of interaction design, inseparable from functional and aesthetic goals.

However, a Western technocratic cultural bias often obscures this responsibility. Technologists and designers frequently operate under the implicit assumption of infinite resources and limitless potential, deploying powerful digital and cloud-based services for a user base assumed to be fully competent and aware of the technology's capabilities and impacts (Preist, 2016). This mindset, often described as a "cornucopian vision" which posits the availability of endless resources and perpetual technological progress, has been critically challenged in recent years (Widdicks, 2022). To address

this, research must align with the principles of SixD and the concept of Computing Within Limits, acknowledging the finiteness of raw materials and the environmental cost of digital progress.

A pervasive misconception in the digital age is the immateriality of software. While software appears intangible, it is a primary driver of physical consumption. Software updates often render perfectly functional hardware obsolete, necessitating premature disposal and the manufacturing of new devices. This creates a cycle of mutual obsolescence between hardware and software.

Understanding the material effects of technology requires analyzing user behavior. Empirical studies have highlighted a stark disconnect between environmental concern and actual behavior—an "attitude-behavior gap." Research focusing on the Net Generation revealed that while a majority of young participants expressed concern about environmental degradation, these attitudes did not translate into sustainable consumption. High rates of device turnover and rapid obsolescence were common even among environmentally conscious users.

This suggests that reliance on "persuasive technology" or user awareness is insufficient. If users concerned about the environment still engage in unsustainable behaviors, the design of the technology itself must change. This oversight in design often stems from the previously mentioned assumption that users are fully aware of impacts. Consequently, novel ethical considerations for technology-enhanced learning have emerged, echoing concerns within the domain of Sustainable Human-Computer Interaction (DiSalvo, et al. 2010).

The principles of SID are particularly critical when applied to the rapidly evolving sector of education. Technology-enhanced education offers society a substantial modernization of teaching methods, learning approaches, communication, interaction, and accessing and exchanging information among teachers, students, and scientific research (Demitriadou et al. 2020).

Rapid advances in the field of computing and information and communications technologies (ICTs) are providing new, engaging, interactive and customized technology-focused learning experiences that stimulate motivation (Moca, Badulescu, 2023). These technologies adopt a constructivist context of training, utilizing multi-modal and multi-sensory forms of interaction to

foster active and mobile learning (Akçayır and Akçayır 2017; Alkhatabi 2017; Cabero-Almenara et al. 2019; Mastorakis, et al., 2024) through new advanced technologies and digital games. Furthermore, educational tools that adopt Extended Reality (ER), Virtual Reality (VR), and Augmented Reality (AR) can foster embodied and experiential learning capable of reducing the cognitive load related to traditional training practices (Hassan et al. 2022; Kiili 2005).

Despite these advancements, the implementation of technology-enhanced education faces significant obstacles, particularly in resource-constrained environments. The diverse needs of student populations and the varying allocation of financial, in-kind, physical, and human resources present critical challenges. Contemporary global phenomena, including demographic shifts, migration, and rising inequalities, have intensified the diversity within educational communities and classrooms, exposing significant disparities in access to digital technologies and the internet.

A primary concern is that new digital technologies and ICTs are often designed without adequate consideration for the diverse requirements of teachers and students, especially those from marginalized communities . Thinking about technology in education allows us to consider the adoption of technology with limited computational capacity and how it is possible to cope with finiteness. This affects not only the electronics lifecycle and raw material availability—such as the example of copper scarcity—but also the scarcity of resources in terms of technical, human, and physical factors (Pollini, Giacobone, 2024).

To reconcile the promise of educational technology with the imperatives of sustainability, interaction design must adopt ecologically valid approaches. This acknowledges that human action is situated and contingent on contextual factors. Interaction may be studied in the richness of its natural environment, operating 'in-the-wild' and considered with substantial environmental impacts.

Integrating the educational context with foundational SID theory suggests several strategic principles for future design:

- Linking Invention and Disposal: Designers must consider the end-of-life of educational tools at the moment of their creation. Every feature added should be weighed against its eventual disposal cost.

- Promoting Renewal and Reuse: Educational software should facilitate the upgrading of learning experiences without necessitating the disposal of hardware. This challenges the trend of "irresponsible designs," such as devices with sealed batteries or planned obsolescence strategies.

- Decoupling Ownership and Identity: Designs should decouple the concept of learning quality from the ownership of the newest devices, promoting the value of shared, durable, or second-hand tools.

- Quality and Equality: Quality in SlixD is defined as a construct of affect and longevity. High-quality, durable computing promotes equality by ensuring that devices remain functional and dignified tools for diverse student populations, rather than becoming hazardous waste.

The integration of Sustainable Interaction Design with the realities of Technology-Enhanced Education demands a paradigm shift. It requires moving away from a cornucopian vision of infinite digital resources toward a practice of Computing Within Limits. By acknowledging the "in-the-wild" constraints of diverse educational settings, the HCI community can design systems that not only modernize learning but also foster a sustainable relationship with the material world. The goal is to inform choices that ensure a viable future, where longevity, repairability, and shared use are valued over novelty and speed.

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