Social sustainability in interactive learning systems: a systematic review of factors and tensions in vulnerable communities

Carlos Alberto Peláez[1,*,†], Juan Camilo Espinosa[1,†], Juan Esteban Fernández[1,†], Andrés Solano[1,†] and Huizilopoztli Luna-García[2,†]

[1] *Universidad Autónoma de Occidente, Cali, Valle del Cauca, 760030, Colombia*
[2] *Universidad Autónoma de Zacatecas, Zacatecas, 98000, México*

Abstract

This systematic literature review examines the integration of social sustainability factors into interactive learning mediation systems, with a particular focus on vulnerable communities. Using the PRISMA protocol, we analyzed 32 studies selected from 194 initial documents across five major databases (SCOPUS, Springer, ScienceDirect, IEEE, ACM) published between 2020 and 2025. The analysis revealed key social sustainability factors essential for effective learning systems. Simultaneously, we identified significant tensions between sustainability ideals and implementation realities. This review contributes to understanding how interactive educational technologies can be developed to promote genuine social sustainability rather than perpetuate existing inequalities, highlighting the need for balanced approaches that align innovations with the social, cultural and economic realities of vulnerable communities.

Keywords

social sustainability, interactive learning systems, vulnerable communities

1. Introduction

From the current international agenda on climate change, environmental sustainability has emerged as a fundamental principle, guiding how our species can achieve a balanced coexistence with the environment while preventing resource scarcity that could jeopardize our survival on Earth [1]. Within the Information and Communication Technology (ICT) industry, there is not only a significant environmental debt necessitates urgent actions to mitigate its ecological impact, as highlighted by the most recent report from the Global E-waste Monitor (2024), which recorded a global generation of 62 million metric tons of electronic waste—equivalent to approximately 7.8 kilograms per capita [2]. There is also an urgent need for a strategically responsible approach to the democratization of emerging technologies, such as generative Artificial Intelligence (AI). Since 2020, Microsoft has increased its carbon emissions by 30% due to the expansion of its data centers, driven by the rising demand for cloud-based solutions and the substantial growth of generative AI applications [3].

However, the debt of the ICT sector toward sustainability extends beyond environmental factors; it also encompasses a social dimension, reflected in the digital divide, which is particularly pronounced in emerging economies [4]. In contrast, it is undeniable that countries such as Colombia have made significant efforts to prevent the widening of the digital divide among their

Interacción '25: XXV International Conference on Human-Computer Interaction, September 03–05, 2025, Valladolid, Spain
* Corresponding author.
† These authors contributed equally.
capa@uao.edu.co (C. A. Peláez); juan_cam.espinosa@uao.edu.co (J. C. Espinosa); juan_est.fernandez@uao.edu.co (J. E. Fernandez); afsolano@uao.edu.co (A. F. Solano); hlugar@uaz.edu.mx (H. Luna-García)
0000-0003-1747-3691 (C. A. Peláez); 0009-0006-5784-9859 (J. C. Espinosa); 0009-0005-2353-6777 (J. E. Fernandez); 0000-0002-1159-3767 (A. F. Solano); 0000-0001-5714-7482 (H. Luna-García)
© 2025 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-4000/paper16.pdf

citizens compared to industrialized economies. This is exemplified by initiatives to increase investment in information technologies for education, a priority gaining momentum during the COVID-19 pandemic. The pandemic underscored the urgent need to bridge digital gaps and enhance access to technological tools in the educational sector during periods of social distancing. Recent initiatives, such as "Computadores para Educar", along with various projects aimed at expanding connectivity coverage in rural areas [5], are some of the measures undertaken in this direction.

However, these initiatives may not be sufficient to maintain the existing digital divide. The current era of AI democratization [6], particularly through the most recent advancements in generative AI [7], presents not only a significant challenge for emerging economies and their educational systems but also a substantial risk of exacerbating the digital divide to unprecedented and concerning proportions, with severe implications for global social inequalities [8]. The most adversely affected social groups are probably vulnerable communities within these emerging economies that require targeted interventions to ensure their inclusion and social well-being [9]. Mere access to information technologies by these communities does not, in itself, resolve this complex issue.

Related studies suggest that companies and professionals in the interactive software systems development industry have limited knowledge regarding social sustainability and acknowledge the need to incorporate mechanisms for its inclusion in the development processes of such solutions [10]. Recognizing the necessity of implementing specific actions focused on addressing the current needs of vulnerable communities in emerging economies—alongside the challenges posed by the evolution of traditional interactive and multimedia systems toward interactive technologies mediated by emerging innovations such as generative AI, which, on the one hand, offer enhanced user interaction capabilities but, on the other hand, are technically more complex and resource-intensive—this state-of-the-art review aims to examine the effective influence of social sustainability factors in the development of interactive systems for learning mediation. Furthermore, it seeks to identify the tensions that arise between the ideals of social sustainability and contextual and technological limitations in the development of interactive systems, particularly for education in vulnerable communities.

This study is structured into five sections, beginning with the introduction and continuing with a background section that serves as the foundation for the research. Subsequently, the methodology that guided the state-of-the-art review is presented, leading to an analysis of the results derived from the research process. Finally, a discussion section is provided to offer precise responses by synthesizing the research questions.

2. Background

Social sustainability has been recently discussed within the broader framework of sustainable development. It refers to a society's ability to maintain and enhance the well-being of its members over time, ensuring social cohesion, justice, and equity [11]. Key elements of social sustainability include equity and social justice, which promote equal opportunities and fair access to essential resources such as education, employment, healthcare, and housing, regardless of race, gender, socioeconomic status, or other factors. Additionally, social cohesion plays a crucial role by fostering a sense of community, belonging, and mutual support within societies, thereby reducing social divisions, discrimination, and exclusion [12].

In the context of information technologies, some authors, such as Noman et al. [13], have argued that in a landscape where technologies evolve rapidly, it is essential to consider the impacts of software as well as its long-term viability. Moreover, the concept of vulnerability is not limited

to environmental risks; it also encompasses social, economic, and cultural dimensions that affect human well-being [14]. The "research through design" methodology, applied in projects such as Design for Vulnerable in Mexico by the Tecnológico de Monterrey [15], demonstrates how design can serve as a powerful tool to raise awareness and empower communities through solutions tailored to their specific contexts and needs, thereby fostering sustainable and participatory interventions. However, the sustainability factors that may be particularly sensitive in processes involving the development of solutions mediated by information technologies in vulnerable societies remain unclear.

Various studies have been conducted from a broader perspective in software engineering, primarily focusing on environmental sustainability. Lago et al. [16] presented a framework for sustainability analysis that enables software engineers to identify needs related to sustainability factors, primarily emphasizing environmental aspects while also addressing, to a lesser extent, technical, economic, and social elements. Similarly, Khalifeh et al. [17] proposed a conceptual framework for integrating environmentally sustainable software projects. In addition, Naumann et al. [18] defined a sustainable software engineering framework that examined strategies for developing web pages with minimal negative environmental impact or improved energy efficiency and provided specific recommendations for web developers.

Some authors, such as Afshari et al. [19], have investigated social sustainability indicators across various sectors, primarily the energy sector. The authors argue that social sustainability has been overlooked because of the challenging nature of implementing social aspects compared to environmental objectives or because sustainability has largely been discussed theoretically rather than being effectively implemented in practice. This gap represents a significant concern and a motivating factor for this study.

Pham et al. [20] and Condori et al. [21] emphasize the importance of developing frameworks that integrate multidimensional approaches to identify and represent sustainability requirements in software development. The first study introduces the ShapeRE framework, which focuses on the developer's role in gathering requirements by combining goal-based approaches. The second one presents the Sustainability Assessment Framework (SAF), which is supported by a quality model and decision map, was validated through technical and participatory action research. This framework encompasses environmental, social, technical, and economic dimensions.

Sustainability in the technology sector is shaped by the need to minimize the environmental impact of information technologies and by their potential to foster sustainability across other industries. In this regard, recent research, such as that presented by Pazienza et al. [22] and Greif et al. [23], has highlighted strategies, including energy optimization in data centers and the use of shifting techniques to take advantage of periods with lower carbon intensity. Concurrently, the application of AI in educational settings, exemplified by the "YOLO-green" model [24], demonstrates how technology can promote sustainable practices by optimizing processes and reducing environmental impacts.

Various studies have explored conceptual and empirical frameworks for assessing sustainability in software development, as evidenced by the works of Penzenstadler [25], Oyedeji et al. [26], and Lago et al. [27], complemented by critical reviews by Khalifeh et al. [17], Duboc et al. [28], and Swacha [29]. These studies highlight a prevailing trend toward energy efficiency and environmental analysis, often relegating the social dimension to a secondary role. It is imperative to conduct a state-of-the-art review that integrates the different dimensions of sustainability in a balanced manner, particularly the social aspect, to guide responsible design and informed decision-making in the development of information technologies. This approach ensures the creation of comprehensive solutions tailored to the needs of diverse stakeholders.

3. Methodology

The present study was conducted following the PRISMA protocol and was structured into four phases: identification of relevant studies in databases related to the research topic; review of titles and abstracts; analysis and evaluation of the full texts of the selected studies; and extraction of information and data from the articles subjected to analysis [30].

3.1. Research questions

The research questions that guided this study, along with their associated motivation, are detailed in Table 1.

Table 1
Research questions

Code	Question	Motivation
RQ1	How has the integration of social sustainability factors in the development of interactive systems for learning mediation influenced educational paradigms, considering access, usage and technological appropriation in vulnerable communities?	The advancement of interactive technologies in education has provided new opportunities to enhance learning quality in vulnerable communities. However, social sustainability in designing and developing these interactive systems remains a largely unexplored challenge. Despite the increasing digitalization of education, significant gaps persist in access, usage, and technological appropriation in highly vulnerable contexts, raising questions about these solutions' equity and real impact. Traditional educational paradigms in these communities are often shaped by exogenous models that do not always consider sociocultural dynamics, technological limitations, and specific needs. In this regard, social sustainability—the ability to foster community cohesion, inclusion, and long-term equity—emerges as a fundamental criterion for assessing the effectiveness and relevance of interactive systems in mediating learning experiences.
RQ2	What tensions arise between the ideals of social sustainability and the contextual and technological limitations in the development of interactive systems for education in vulnerable communities?	Implementing interactive systems in vulnerable communities with a focus on social sustainability faces multiple challenges that go beyond the mere intention of promoting inclusion and equity. While the ideals of social sustainability aim to ensure fair access to education, foster community participation, and reduce digital divides, their realization is often hindered by structural limitations such as the lack of technological infrastructure, economic constraints, insufficient teacher training, and sociocultural barriers. Moreover, the technical requirements of interactive systems may conflict with the reality of limited resources in these communities, creating a gap between ideal design and effective implementation. This state-of-the-art review seeks to identify and analyze these challenges to understand to what extent technological solutions have managed to balance social sustainability principles with the real conditions of vulnerable educational environments and what strategies have proven effective in mitigating these conflicts.

3.2. Information, resources and search strategies

The research was conducted using a set of five databases: SCOPUS, Springer, ScienceDirect, IEEE, and ACM. The search queries applied considered title, abstract, and keyword searches within the publications. The search strings that were used are presented in Table 2.

Table 2
Search queries

Database	Sentences
SCOPUS	"social sustainability" AND "digital technologies"
Science Direct	TITLE("social sustainability" OR "social inclusion") AND ("interactive systems" OR "digital technologies") AND ("education"), TITLE("social sustainability" OR "social inclusion") AND ("interactive systems" OR "digital technology") AND ("education" OR "learning") AND ("vulnerable populations" OR "vulnerable communities"), TITLE("social sustainability") AND ("software engineering")
Springer	TITLE("social sustainability" OR "social inclusion") AND ("interactive systems" OR "digital technologies") AND ("education")
IEEE	("Document Title":"social sustainability" OR "Document Title":"social inclusion" OR "Document Title":"social gap") AND ("All Metadata":"digital technologies" OR "All Metadata":"interactive systems" OR "All Metadata":"emerging technologies")
ACM	[Abstract: "social sustainability"] OR [Abstract: "social inclusion"] OR [Abstract: "social gap"] AND [[Full Text: "digital technologies"] OR [Full Text: "emerging technologies"] OR [Full Text: "interactive system"]] AND [Full Text: and] AND [[Full Text: education] OR [Full Text: learning] OR [Full Text: educational]

3.3. Inclusion and exclusion criteria

Table 3 specifies the inclusion and exclusion criteria defined for the selection of the retrieved studies.

Table 3
Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
IC1: Studies focused on social sustainability and interactive systems	EC1: The document is not available for download
IC2: Studies written between 2020 and 2025	EC2: Published before 2020
IC3: English and Spanish language	EC3: Social sustainability and digital technologies are not the main focus
IC4: Primary research (papers, books, thesis)	EC4: Not in English or Spanish
	EC5: Not primary research (report, letter, poster)

3.4. Data recovery

A Microsoft Excel template was developed for structured data organization throughout the systematic review process. This template classified initial search results by database and captured metadata for each result, including search protocol, title, authors, publication year, source, abstract, identifiers, and a brief relevance assessment.

The database searches yielded a total of 194 documents. Following the application of the inclusion and exclusion criteria outlined in Table 3, the final selection was refined to 32 relevant studies that specifically addressed the integration of social sustainability in interactive systems for educational contexts in vulnerable communities. The quantitative results of the methodological process are summarized in Table 4.

Table 4
Summary of documents selection process

Database	Search Result	Relevant documents
SCOPUS	80	9
Science Direct	55	8
Springer	34	6
IEEE	6	3
ACM	19	6
Total	194	32

4. Results analysis

The systematic review yielded 32 relevant documents on social sustainability in interactive education systems in vulnerable communities. The analysis revealed significant insights into integrating social sustainability factors and the tensions during implementation.

4.1. Integration of social sustainability factors in interactive systems for learning mediation

Accessibility and inclusion have emerged as fundamental social sustainability elements in educational interactive systems. Qadri et al. [31] documented how emerging technologies contributed to independence for visually impaired students, while Al-Emran [32] demonstrated how these technologies overcame geographical and socioeconomic barriers through immersive learning spaces. Alhassan and Adam [33] and Moreira et al. [34] emphasized that digital inclusion was essential for equitable educational opportunities, with equity defined as the fair treatment of individuals to promote inclusion and eliminate discrimination.

Brenner and Hartl [35] noted that ecological and economic dimensions often overshadowed the social dimension within the broader sustainability framework. This observation was further supported by Szalkowski and Johansen [36], who identified education as an under-researched area in social sustainability and digital technologies.

Cultural and contextual relevance significantly impacted the integration of social sustainability into interactive systems. Espinosa Zárate et al. [37] highlighted the importance of considering local cultural practices rather than applying universal approaches. This contextualization was demonstrated in studies by Nisi et al. [38], who demonstrated how communities developed differentiated forms of technological appropriation, and Hamidi et al. [39], who described assistive technologies created by communities themselves using participatory design approaches. Illustrating the potential of contextually relevant initiatives, Hartikainen et al. [40] presented a project that empowered unemployed youth through digital fabrication tailored to local needs.

Beyond cultural considerations, user satisfaction and technological acceptance are directly related to social sustainability in interactive systems. Yue et al. [41] demonstrated that satisfied users have a higher perception of social support and improved emotional well-being, thus enhancing their ability to access social and community resources. Pech et al. [42] also emphasized the importance of designing intuitive and accessible interfaces, highlighting their effectiveness in improving cognitive and emotional well-being among elderly users. Furthermore, for vulnerable populations, Van Calis et al. [43] identified usability and inclusive design as critical factors for overcoming learning barriers, particularly benefiting individuals with mild intellectual disabilities or low literacy skills. The importance of user understanding was validated by Al-Emran et al. [44], who found that comprehension of generative AI tools increased their use in academic activities. At the same time, Arpaci [45] determined that confidentiality was the most influential variable for sustainable technology use.

Ethical considerations emerged as essential components of social sustainability in these contexts. Moreira et al. [34] identified freedom from risk, legislative compliance, and privacy as fundamental elements in designing systems for vulnerable communities. Building on these principles, Plaza de la Hoz et al. [46] advocated a humanistic perspective in which personal and community development predominated economic gains. The importance of ethical continuity was demonstrated by Padilla et al. [47], who found that successful government initiatives depended on consistent ethical commitment and adaptation to changing community needs.

Several innovative approaches were identified for addressing social sustainability challenges. Reynaga-Pena et al. [48] promoted Universal Design for Learning as an approach considering multiple types of social vulnerability beyond disabilities. Technological advancements offer new possibilities, as Al-Emran et al. [49] demonstrated how AI could personalize educational experiences for traditionally marginalized communities. By creating dedicated spaces for inclusive learning, Fonseca et al. [50] proposed STEAM-Labs as innovative environments to reduce the diversity gap in technological education.

Integrating social sustainability factors into interactive learning systems has thus emerged as a multidimensional challenge requiring attention to accessibility, cultural relevance, user satisfaction, ethical considerations, and universal design principles. Successful implementations prioritized human needs over technological capabilities, incorporated local contexts and practices, and ensured that systems remained accessible to diverse populations with varying levels of technological literacy.

4.2. Tensions between social sustainability ideals and contextual and technological limitations

A fundamental tension in the literature concerned the predominantly economic orientation of digital transformation processes. Qadri et al. [31] and Plaza de la Hoz et al. [46] noted that digitalization processes prioritize economic benefits without adequately considering social effects in vulnerable communities. This economic focus created significant risks. Brenner and Hartl [35] warned about the negative consequences of digitalization for society and demonstrated how it

could aggravate inequalities when implemented without considering the particularities of vulnerable contexts.

The persistence of the digital divide constitutes one of the most extensively documented tensions. Qadri et al. [31] and Jiang et al. [51] identified how age, language, educational level, and limited internet access created significant barriers to effective implementation. These divides had profound social implications, as Travassos Rosário and Carmo Dias [52] warned that digital transition could reinforce existing social inequalities through multiple dimensions, while Gutiérrez-Provecho et al. [53] showed that digital divides generated social fractures that perpetuated inequality. The consequences for specific vulnerable groups were illustrated by Karantalis and Koukopoulos [54], who documented challenges for refugee students, and Sadyrtdinov et al. [55], who provided evidence from the COVID-19 pandemic when vulnerable populations faced technological barriers when digitalization became essential.

Further complicating implementation efforts, Szalkowski and Johansen [36] identified a significant gap in evidence on the impacts of digital technologies, revealing tensions between promised benefits and real implementation risks. Structural factors aggravated this gap, as Su and Yang [56] highlighted how structural inequalities influenced digital competencies, demonstrating that deficiencies in organizational infrastructure and lack of strategic leadership negatively affected implementation in vulnerable contexts.

Resistance to technological change has emerged as another significant obstacle. Jiang et al. [51] and Padilla et al. [47] identified this resistance and associated resource limitations as major barriers and attributed resistance to material constraints and cultural factors that prevented effective technological appropriation. The challenges of inclusive development were further discussed by Ayris et al. [57], who pointed out limitations in including diverse actors in technological development, identifying barriers such as time constraints, language differences, and the absence of clear ethical frameworks.

Privacy and accessibility concerns created additional tensions in the implementation. Al-Emran et al. [49] noted the conflict between data collection requirements for personalization and information protection concerns. The technical complexity of accessibility presented further challenges, as technological limitations in vulnerable contexts made implementing advanced accessibility features difficult. Tymoshchuk et al. [58] quantified the practical consequences of these limitations and showed that only 21.8% of people with disabilities used technologies for educational purposes.

Cultural adaptation is a significant area of tension. Plaza de la Hoz et al. [46] and Costas-Jauregui et al. [59] highlighted how digitalization strategies based on global standards often failed because of insufficient adaptation to specific sociocultural contexts. Financial sustainability introduced additional complexities, as Lambert [60] identified the tension between free access to education and the need for financial investments to maintain quality assurance systems. Policy rigidity further complicated adaptation efforts, with AlKharouf et al. [61] pointing to conflicts between reciprocal adaptation needs and inflexible institutional policies.

The gap between technological access and effective use constitutes a critical tension. Costas-Jauregui et al. [59] and Padilla et al. [47] concluded that insufficient teacher training perpetuated the superficial application of educational technology. Sen et al. [62] emphasized that technological access without skill development is insufficient for social sustainability. This gap was quantified by Tymoshchuk et al. [58], who identified specific obstacles, including a lack of knowledge (47.4%), reading difficulties (24.4%), and an absence of adapted training (23%). The consequences of infrastructure-focused implementation were highlighted by Padilla et al. [47] and Alhassan and Adam [33], who demonstrated how technology implementation often focused on physical

infrastructure without adequate pedagogical integration, which is particularly problematic when systems depend on precarious external factors like unstable electricity or intermittent connectivity.

The implementation of socially sustainable interactive systems in vulnerable communities thus faced significant tensions that needed to be addressed for successful outcomes. These included balancing economic objectives with social needs, bridging persistent digital divides, overcoming resistance to change, addressing privacy concerns, ensuring cultural relevance, resolving financial sustainability challenges, and bridging the gap between technological access and meaningful skill development. Without addressing these tensions, even well-intentioned interactive systems risked perpetuating or worsening existing inequalities rather than promoting genuine social sustainability.

5. Discussion

Integrating social sustainability factors into interactive learning systems is crucial for creating equitable educational opportunities, particularly in vulnerable communities. These factors are essential to address the unique needs of vulnerable populations and enhance educational outcomes. By aligning these findings with the project's justification, the discussion delves into the challenges and opportunities identified in the literature. It addresses how the results contribute to a broader understanding of the intersection between social sustainability, education, and technology.

This study revealed that several social sustainability factors are pivotal to designing and developing interactive education systems in vulnerable communities. These include accessibility and inclusion, cultural and contextual relevance, user satisfaction, technological acceptance, ethical considerations, and transformative approaches for knowledge democratization. One of the most frequently discussed factors is ensuring that educational systems are accessible to all students, regardless of their cultural, social, or economic background.

Moreover, educational technologies must be culturally and contextually appropriate to resonate with the local community. In vulnerable areas, education systems often fail to reflect the lived experiences of students, which can undermine the effectiveness of such technology. Therefore, designing interactive systems incorporating local languages, traditions, and cultural contexts is crucial for fostering a sense of ownership and engagement.

The success of any interactive system depends on user acceptance, particularly among teachers and students. Effective preparation of teachers to mediate and use technology for educational purposes is crucial to ensure the success of such systems. Educational technologies must be intuitive, user-friendly, and aligned with user needs to ensure widespread adoption. In vulnerable communities with low digital literacy, systems should be easily navigated to avoid overwhelming users.

Ethical issues such as privacy, data security, and the potential for technological misuse were also identified as key factors affecting social sustainability. The risks associated with data collection and surveillance are particularly concerning in vulnerable communities. Therefore, design systems must prioritize protecting user data and adhere to ethical standards when using technology.

The concept of democratizing knowledge through technology is central to discussions on social sustainability in education. Interactive systems should be designed to empower students, teachers, and communities by providing equitable access to quality education and promoting lifelong learning. This is especially relevant when discussing education mediation through emerging technologies like AI, as these technologies present a greater challenge for the adopting community. They must be leveraged to foster the development of critical thinking, creativity, and problem-solving skills rather than simply focusing on rote memorization. Moreover, systems should

encourage collaboration and collective learning, enabling communities to share knowledge and resources in ways that promote social cohesion and mutual support.

This review identified several key tensions that must be addressed to ensure the effective implementation of social sustainability principles in educational technologies. One significant tension is the conflict between the economic objectives of educational technology projects and the social goals of inclusion and equity. Many initiatives are driven by the need to achieve financial sustainability or scale, which can compromise the systems' social and cultural relevance.

Despite the growing adoption of digital technologies, the digital divide remains a significant barrier to effectively implementing interactive systems in vulnerable communities. Even when technology is available, many students and teachers lack the necessary digital skills to use it effectively. While many studies have advocated integrating social sustainability principles into interactive systems, limited research has been conducted on the actual outcomes of such systems in vulnerable communities. This highlights the need for more rigorous evaluations, including long-term studies that assess their effectiveness in improving educational outcomes and promoting social sustainability.

Resistance to change within educational institutions and communities represents a significant tension identified in this review. Implementing new technologies often demands changes in attitudes, practices, and organizational structures, posing challenges for teachers, students, and administrators. Additionally, resource limitations—such as insufficient funding, lack of technical support, and inadequate teacher training—can further hinder the adoption and sustainability of interactive systems. Another critical tension discussed is the conflict between financial sustainability and universal access, as many educational technology projects struggle to balance the need for ongoing financial support to provide free or low-cost access to all students. Overcoming these challenges requires a comprehensive approach that includes professional development, ongoing support, and active stakeholder involvement in the decision-making process, ensuring that financial sustainability does not compromise equitable access and facilitating solutions that are both sustainable and accessible to all.

The opportunities identified in the literature align with the project's justification because studies have recognized the growing need for projects that address social sustainability issues in educational systems. This need is especially pressing given the rapid advancements in technologies like AI, which are reshaping human activities and posing new challenges for educational systems worldwide. By providing a clear roadmap for developing interactive systems that are socially sustainable and contextually relevant, the literature highlights the urgency of addressing these issues. Tackling these tensions through integrated approaches and evidence-based practices is crucial for ensuring that interactive systems can effectively contribute to educational transformation in vulnerable communities.

As a result of the state-of-the-art review, a set of Social Sustainability factors will be defined for developing learning experiences mediated by interactive technologies at the elementary education level in the context of vulnerable communities. The objective is for each factor to be associated with a series of recommendations that school stakeholders can implement. Both the factors and the recommendations will be validated with stakeholders.

Acknowledgements

This work has been carried out within the research project entitled "Caracterización de factores de sostenibilidad social asociados al desarrollo de sistemas interactivos en la mediación de experiencias de aprendizaje para educación básica primaria en comunidades vulnerables de la ciudad de Santiago de Cali", Code 25INTER-508, which is funding by the Universidad Autónoma de

Occidente (Colombia), and carried out in cooperation with the Universidad Autónoma de Zacatecas (Mexico).

Declaration on Generative AI

During the preparation of this work, the authors used Grammarly in order to assist in grammar and spelling correction, language clarity improvement, and minor content refinement. After using this tool, the authors carefully reviewed and edited the content to ensure accuracy and take full responsibility for the publication's content.

References

[1] J. Rockström, W. Steffen, K. Noone, Å. Persson, F. S. Chapin, E. F. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. J. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. A. Foley, A safe operating space for humanity, Nature 461.7263 (2009) 472–475. doi:10.1038/461472a.

[2] C. P. Baldé, R. Kuehr, T. Yamamoto, R. McDonald, E. D'Angelo, S. Althaf, G. Bel, O. Deubzer, E. Fernandez-Cubillo, V. Forti, et al., Global e-waste monitor 2024, International Telecommunication Union (ITU) and United Nations Institute for Training and Research (UNITAR), 2024.

[3] S. Kimball, Microsoft's carbon emissions have risen 30% since 2020 due to data center expansion, 2024. URL: https://www.cnbc.com/2024/05/15/microsofts-carbon-emissions-have-risen-30percent-since-2020-due-to-data-center-expansion.html.

[4] I. O. Adam, M. Dzang Alhassan, Bridging the global digital divide through digital inclusion: the role of ICT access and ICT use, Transform. Gov. ahead-of-print.ahead-of-print (2021). doi:10.1108/tg-06-2020-0114.

[5] G. EdTech, Colombia increases access to education technology - Global EdTech, 2020. URL: https://global-edtech.com/colombia-increases-access-to-education-technology.

[6] J. Cupać, H. Schopmans, İ. Tuncer-Ebetürk, Democratization in the age of artificial intelligence: introduction to the special issue, Democratization 31.5 (2024) 899–921. doi:10.1080/13510347.2024.2338852.

[7] N. Bashir, P. Donti, J. Cuff, S. Sroka, M. Ilic, V. Sze, C. Delimitrou, E. Olivetti, The climate and sustainability implications of generative AI, 2024. URL: https://mit-genai.pubpub.org/pub/8ulgrckc/release/2.

[8] V. Eubanks, Automating inequality: how high-tech tools profile, police, and punish the poor, St. Martin's Press, 2018.

[9] D. Mechanic, J. Tanner, Vulnerable people, groups, and populations: societal view, Health Aff. 26.5 (2007) 1220–1230. doi:10.1377/hlthaff.26.5.1220.

[10] T. R. D. Saputri, S.-W. Lee, Integrated framework for incorporating sustainability design in software engineering life-cycle: An empirical study, Inf. Softw. Technol. 129 (2021) 106407. doi:10.1016/j.infsof.2020.106407.

[11] S. Woodcraft, Understanding and measuring social sustainability, J. Urban Regen. Renew. (2015). doi:10.69554/vrwg6415.

[12] E. Eizenberg, Y. Jabareen, Social sustainability: A new conceptual framework, Sustainability 9.1 (2017) 68. doi:10.3390/su9010068.

[13] H. Noman, N. Mahoto, S. Bhatti, A. Rajab, A. Shaikh, Towards sustainable software systems: A software sustainability analysis framework, Inf. Softw. Technol. 169 (2024) 107411. doi:10.1016/j.infsof.2024.107411.

[14] E. Giorgi, T. Cattaneo, K. P. Serrato Guerrero, The principles of design for vulnerable communities: A research by design approach overrunning the disciplinary boundaries, Buildings 12.11 (2022) 1789. doi:10.3390/buildings12111789.

[15] T. de Monterrey, Design for vulnerables. URL: https://www.designforvulnerables.com.

[16] P. Lago, S. A. Koçak, I. Crnkovic, B. Penzenstadler, Framing sustainability as a property of software quality, Commun. ACM 58.10 (2015) 70–78. doi:10.1145/2714560.

[17] A. Khalifeh, P. Farrell, M. Alrousan, S. Alwardat, M. Faisal, Incorporating sustainability into software projects: a conceptual framework, Int. J. Manag. Proj. Bus. 13.6 (2020) 1339–1361. doi:10.1108/ijmpb-12-2019-0289.

[18] S. Naumann, M. Dick, E. Kern, T. Johann, The GREENSOFT Model: A reference model for green and sustainable software and its engineering, Sustain. Comput. 1.4 (2011) 294–304. doi:10.1016/j.suscom.2011.06.004.

[19] H. Afshari, S. Agnihotri, C. Searcy, M. Y. Jaber, Social sustainability indicators: A comprehensive review with application in the energy sector, Sustain. Prod. Consum. 31 (2022) 263–286. doi:10.1016/j.spc.2022.02.018.

[20] Y. D. Pham, A. Bouraffa, W. Maalej, ShapeRE: towards a multi-dimensional representation for requirements of sustainable software, in: 2020 IEEE 28th international requirements engineering conference (RE), IEEE, 2020. doi:10.1109/re48521.2020.00048

[21] N. Condori-Fernandez, P. Lago, M. R. Luaces, Á. S. Places, An action research for improving the sustainability assessment framework instruments, Sustainability 12.4 (2020) 1682. doi:10.3390/su12041682.

[22] A. Pazienza, G. Baselli, D. C. Vinci, M. V. Trussoni, A holistic approach to environmentally sustainable computing, Innov. Syst. Softw. Eng. (2024). doi:10.1007/s11334-023-00548-9.

[23] L. Greif, A. Kimmig, S. El Bobbou, P. Jurisch, J. Ovtcharova, Strategic view on the current role of AI in advancing environmental sustainability: a SWOT analysis, Discov. Artif. Intell. 4.1 (2024). doi:10.1007/s44163-024-00146-z.

[24] W. Lin, YOLO-Green: A real-time classification and object detection model optimized for waste management, in: 2021 IEEE international conference on big data (big data), IEEE, 2021. doi:10.1109/bigdata52589.2021.9671821.

[25] B. Penzenstadler, From requirements engineering to green requirements engineering, in: Green in software engineering, Springer International Publishing, Cham, 2015, pp. 157–186. doi:10.1007/978-3-319-08581-4_7.

[26] S. Oyedeji, M. . Adisa, B. Penzenstadler, A. Wolf, Validation study of a framework for sustainable software system design and development, in: Proc. 6th int. conf. on ICT for sustainability, 2019.

[27] P. Lago, R. Verdecchia, N. Condori-Fernandez, E. Rahmadian, J. Sturm, T. van Nijnanten, R. Bosma, C. Debuysscher, P. Ricardo, Designing for sustainability: lessons learned from four industrial projects, in: A. Kamilaris, V. Wohlgemuth, K. Karatzas, I. N. Athanasiadis (Eds.), Advances and new trends in environmental informatics, Springer International Publishing, Cham, 2021, pp. 3–18.

[28] L. Duboc, B. Penzenstadler, J. Porras, S. Akinli Kocak, S. Betz, R. Chitchyan, O. Leifler, N. Seyff, C. C. Venters, Requirements engineering for sustainability: an awareness framework for designing software systems for a better tomorrow, Requir. Eng. 25.4 (2020) 469–492. doi:10.1007/s00766-020-00336-y.

[29] J. Swacha, Models of sustainable software: A scoping review, Sustainability 14.1 (2022) 551. doi:10.3390/su14010551.

[30] M. J. Page, J. E. McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, J. M. Tetzlaff, E. A. Akl, S. E. Brennan, et al., The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, BMJ (2021) n71. doi:10.1136/bmj.n71.

[31] U. A. Qadri, M. B. A. Ghani, U. Abbas, A. R. Kashif, Digital technologies and social sustainability in the digital transformation age: a systematic analysis and research agenda, Int. J. Syst. (2024). doi:10.1108/ijoes-08-2024-0239.

[32] M. Al-Emran, Beyond technology acceptance: Development and evaluation of technology-environmental, economic, and social sustainability theory, Technol. Soc. 75 (2023) 102383. doi:10.1016/j.techsoc.2023.102383.

[33] M. D. Alhassan, I. O. Adam, Digital inclusion and sustainable development goals, J. Sci. Technol. Policy Manag. (2024). doi:10.1108/jstpm-09-2023-0152.

[34] A. Moreira, J. Araújo, C. Gralha, M. Goulão, I. S. Brito, D. Albuquerque, A social and technical sustainability requirements catalogue, Data & Knowl. Eng. (2022) 102107. doi:10.1016/j.datak.2022.102107.

[35] B. Brenner, B. Hartl, The perceived relationship between digitalization and ecological, economic, and social sustainability, J. Clean. Prod. 315 (2021) 128128. doi:10.1016/j.jclepro.2021.128128.

[36] G. A. Szalkowski, C. Johansen, Defining and measuring the effects of digital technologies on social sustainability: A systematic literature review, Sustain. Dev. (2023). doi:10.1002/sd.2741.

[37] Z. Espinosa Zárate, C. Camilli Trujillo, J. Plaza-de-la-Hoz, Digitalization in vulnerable populations: A systematic review in latin america, Soc. Indic. Res. (2023). doi:10.1007/s11205-023-03239-x.

[38] V. Nisi, P. Bala, V. Ces\'{a}rio, S. James, A. Del Bue, N. J. Nunes, "Connected to the people": social inclusion & cohesion in action through a cultural heritage digital tool, Proc. ACM Hum.-Comput. Interact. 7.CSCW2 (2023). doi:10.1145/3610168.

[39] F. Hamidi, P. M. Owuor, M. Hynie, M. Baljko, "Knowledge comes through participation": understanding disability through the lens of DIY assistive technology in western kenya, Proc. ACM Hum.-Comput. Interact. 6.CSCW1 (2022). doi:10.1145/3512919.

[40] H. Hartikainen, M. C. Orduña, M. Käsmä, I. S. Milara, and L. Ventä-Olkkonen, Make4Change: empowering unemployed youth through digital fabrication, in: FabLearn europe / makeed 2021 - an international conference on computing, design and making in education, Association for Computing Machinery, New York, NY, USA, 2021. doi:10.1145/3466725.3466763.

[41] Z. Yue, R. Zhang, J. Xiao, Social media use, perceived social support, and well-being: Evidence from two waves of surveys peri- and post-COVID-19 lockdown, J. Soc. Pers. Relatsh. (2023). doi:10.1177/02654075231188185.

[42] M. Pech, A. Gbessemehlan, L. Dupuy, H. Sauzéon, S. Lafitte, P. Bachelet, H. Amieva, K. Pérès, Experimentation of the SoBeezy program in older adults during the COVID-19 pandemic: what lessons have we learned? (Preprint), JMIR Form. Res. (2022). doi:10.2196/39185.

[43] J. F. E. van Calis, J. Naaldenberg, A. W. C. van der Cruijsen, M. C. J. Koks-Leensen, G. L. Leusink, K. E. Bevelander, Inclusive digital platforms: Designing for and with users with mild intellectual disabilities or low literacy skills, Comput. Hum. Behav. Rep. 17 (2025) 100617. doi:10.1016/j.chbr.2025.100617.

[44] M. Al-Emran, N. Al-Qaysi, M. A. Al-Sharafi, M. Khoshkam, B. Foroughi, M. Ghobakhloo, Role of perceived threats and knowledge management in shaping generative AI use in education and its impact on social sustainability, Int. J. Manag. Educ. 23.1 (2025) 101105. doi:10.1016/j.ijme.2024.101105.

[45] I. Arpaci, A multi-analytical SEM-ANN approach to investigate the social sustainability of AI chatbots based on cybersecurity and protection motivation theory, IEEE Trans. Eng. Manag. (2023) 1–13. doi:10.1109/tem.2023.3339578.

[46] J. Plaza de la Hoz, Z. Espinosa Zárate, C. Camilli Trujillo, Digitalisation and poverty in Latin America: a theoretical review with a focus on education, Humanit. Soc. Sci. Commun. 11.1 (2024). doi:10.1057/s41599-024-03692-0.

[47] M. O. Padilla, R. Soto-Varela, L. O. Berrocal, From digital divide to digital inclusion in colombia: A systematic literature review of strategies from education, in: From digital divide to digital inclusion, Springer Nature Singapore, Singapore, 2023, pp. 123–147. doi:10.1007/978-981-99-7645-4_6.

[48] C. G. Reynaga-Pena, I. M. Santillan-Rosas, M. E. Gil-Rendon, Contribution of graduate courses in education towards educational and social inclusion mediated by technology, in: 2022 international conference on inclusive technologies and education (CONTIE), IEEE, 2022. doi:10.1109/contie56301.2022.10004439.

[49] M. Al-Emran, B. Abu-Hijleh, A. A. Alsewari, Exploring the effect of generative AI on social sustainability through integrating AI attributes, TPB, and T-EESST: A deep learning-based hybrid SEM-ANN approach, IEEE Trans. Eng. Manag. (2024) 1–14. doi:10.1109/tem.2024.3454169.

[50] D. Fonseca, A. García-Holgado, F. J. García-Peñalvo, E. Jurado, R. Olivella, D. Amo, G. Maffeo, Ö. Yigit, Y. Keskin, G. Sevinç, et al., CreaSTEAM. Hacia la mejora de brechas en diversidad mediante la recopilación de proyectos, buenas prácticas y espacios STEAM - [CreaSTEAM.

Towards the improvement of diversity gaps through the compilation of projects, best practices and STEAM spaces], in: Innovaciones docentes en tiempos de pandemia. Actas del VI Congreso Internacional sobre aprendizaje, innovación y cooperación, CINAIC 2021, Servicio de Publicaciones Universidad, Zaragoza, 2021. doi:10.26754/cinaic.2021.0007.

[51] M. Jiang, F. Jia, L. Chen, X. Xing, Technology adoption in socially sustainable supply chain management: Towards an integrated conceptual framework, Technol. Forecast. Soc. Chang. 206 (2024) 123537. doi:10.1016/j.techfore.2024.123537.

[52] A. T. Rosário, J. C. Dias, Sustainability and the digital transition: A literature review, Sustainability 14.7 (2022) 4072. doi:10.3390/su14074072.

[53] M. L. Gutiérrez-Provecho, M. López-Aguado, J. L. García LLamas, J. Quintanal Diaz, La brecha digital en población en riesgo de exclusión social, Pedagog. Soc. Rev. Interuniv. No. 39 (2021). doi:10.7179/psri_2021.39.08.

[54] N. Karantalis, D. Koukopoulos, The role of cultural heritage and digital media in the inclusive education of refugee students, SN Soc. Sci. 4.11 (2024). doi:10.1007/s43545-024-01012-6.

[55] R. Sadyrtdinov, E. Eremeeva, J. Varlamova, The digital inequality in the light of the sustainable development goals: case of the covid-19 pandemic, in: 23rd SGEM international multidisciplinary scientific geoconference 2023, STEF92 Technology, 2023. doi:10.5593/sgem2023/5.1/s21.63.

[56] J. Su, W. Yang, Digital competence in early childhood education: A systematic review, Educ. Inf. Technol. (2023). doi:10.1007/s10639-023-11972-6.

[57] K. Ayris, E. Dixon, A. Mauchline, D. C. Rose, Investigating stakeholder participation in UK agricultural robotics development, in: Proceedings of the first international symposium on trustworthy autonomous systems, Association for Computing Machinery, New York, NY, USA, 2023. doi:10.1145/3597512.3597531.

[58] O. Tymoshchuk, I. C. Martins, A. M. P. Almeida, C. R. Cartaxo, E. Albuquerque, Digital technologies as a promotor of well-being and inclusion of people with intellectual and developmental disabilities: what is the current situation?, in: Proceedings of the 10th international conference on software development and technologies for enhancing accessibility and fighting info-exclusion, Association for Computing Machinery, New York, NY, USA, 2023, pp. 50–56. doi:10.1145/3563137.3563161.

[59] V. Costas-Jauregui, S. Manzur, V. Costas-Jauregui, Critical considerations on the digital potentialities, vocations, and needs of teachers in training in bolivia, in: Digital literacy for teachers, Springer Nature Singapore, Singapore, 2022, pp. 57–81. doi:10.1007/978-981-19-1738-7_4.

[60] S. R. Lambert, Do MOOCs contribute to student equity and social inclusion? A systematic review 2014–18, Comput. & Educ. 145 (2020) 103693. doi:10.1016/j.compedu.2019.103693.

[61] R. AlKharouf, A. Shehadeh, A. Alrefaee, O. Alshboul, Integrative strategies for social inclusion and equity: enhancing refugee access to higher education in jordan, Heliyon (2024) e31762. doi:10.1016/j.heliyon.2024.e31762.

[62] K. Sen, G. Prybutok, V. Prybutok, The use of digital technology for social wellbeing reduces social isolation in older adults: A systematic review, SSM - Popul. Health 17 (2022) 101020. doi:10.1016/j.ssmph.2021.101020.