Review Article

The role of technology in enhancing sustainable education in elementary schools: opportunities and challenges

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KEYWORDS	ABSTRACT
technology sustainable education elementary schools opportunities challenges	This research aims to explore the role of technology in enhancing sustainable education in elementary schools, while also identifying associated opportunities and challenges. The method employed in this study is a systematic literature review, with sources drawn from Google Scholar, DOAJ, and Scopus, covering publications between 2013 and 2024. The findings indicate that technologies such as augmented reality (AR) and Internet of Things (IoT) provide students with immersive learning experiences to understand environmental issues like air pollution. Moreover, the Community Science Technology (CST) method engages students in practical community-oriented projects, shaping both cognitive and emotional aspects of environmental understanding. Online learning platforms like WhatsApp offer interactive and easily accessible learning opportunities that foster the development of Higher Order Thinking Skills (HOTS) relevant to environmental education. However, there are several challenges that need to be addressed in integrating technology into sustainable education in elementary schools. Some of these include the lack of accessibility and training for teachers to effectively utilize technology, as well as the need for adequate infrastructure to support technology usage. Additionally, ensuring that the technology used aligns with students' needs and learning contexts, as well as expanding educational accessibility for all students, including those in remote or low-income areas, is crucial. By understanding the role of technology and addressing the existing challenges, elementary schools can create sustainable learning environments that positively impact students and communities as a whole. Future research should focus on further evaluating the effectiveness of technology usage in the context of sustainable education and developing more targeted strategies to address the challenges faced in integrating technology into elementary school curricula.

1. INTRODUCTION

Sustainable education at the elementary school level serves as a cornerstone in shaping understanding and awareness of responsibilities towards the environment, society, and economy in the future [1]. Elementary schools are not merely venues for imparting basic academic knowledge but also crucial platforms for instilling values of sustainability that will guide future generations in facing global challenges [2]. Through sustainable education, children are taught to cultivate critical and creative thinking abilities, as well as to develop an awareness of their responsibilities towards the surrounding Moreover [3], sustainable education at the elementary school level plays a significant role in introducing concepts related to environmental conservation, responsible resource management, and fostering a sense of concern for global issues such as climate change and the sustainability of natural resources [4]. Therefore, sustainable education at the elementary school level aims not only to steer children towards their personal futures but also seeks to mold them into agents of change capable of making positive contributions to the development of a sustainable society as a whole [5].

Technology plays a crucial role in enhancing the quality of education, particularly in the current digital era [6]. The integration of technology into educational practices has fundamentally transformed traditional teaching methods, offering dynamic and interactive learning experiences [7]. Through technology, students gain access to a diverse array of resources and multimedia materials that cater to various learning styles [8], fostering deeper understanding and active engagement in the learning process [9]. Furthermore, technology enables the creation of personalized learning pathways, allowing educators to tailor instruction to the individual needs and preferences of students [10]. Moreover, the use of educational technology promotes collaboration and communication among students and educators, transcending geographical boundaries and expanding the global exchange of knowledge and ideas [11]. Overall, technology serves as a catalyst for innovation in education, empowering both teachers and students to achieve higher levels of educational attainment and proficiency [12]

The role of technology in the context of sustainable education in elementary schools encompasses complex and profound dimensions [13]. Technology serves as a potent tool for instilling principles of sustainability by providing platforms for interactive and experiential learning [14]. Through educational software, simulations, and virtual environments, students can explore complex concepts related to environmental conservation, resource management, and global citizenship in engaging and profound ways [15]. Additionally, technology facilitates access to up-to-date information and educational resources, enabling educators to integrate real-world examples and case studies into their lessons to illustrate the importance of sustainability in daily life [16]. Furthermore, technological innovations such as smart classroom infrastructure and online collaboration platforms offer opportunities to reduce the environmental footprint of educational institutions while promoting efficient resource utilization and effective communication [17]. By leveraging technology, elementary schools can not only disseminate knowledge about sustainability but also nurture digital literacy and critical thinking skills necessary for students to become active participants in building a more sustainable future [18].

Technology plays a significant role in reshaping the learning paradigm in elementary schools by enhancing educational practices and student engagement [19]. The integration of interactive digital technologies, such as LearningApps, Kahoot, and Scratch, holds significant potential to improve learning outcomes by providing interactive and engaging learning experiences [20]. Moreover, the introduction of computer science and computational thinking at the elementary level is becoming increasingly common, aiming to develop essential 21st-century skills necessary for navigating the challenges of the digital era [21]. Teachers have adapted to effectively utilize technology, employing tools such as video calling applications, Microsoft PowerPoint, and Google Forms for online teaching, underscoring the importance of integrating technology into the learning process [22]. Furthermore, the use of virtual reality (VR) technology has shown positive results in enhancing student engagement and creativity in the learning process, emphasizing the transformative impact of technology in elementary education [23].

Various educational technologies have been successfully implemented, revolutionizing traditional teaching and learning methods [24]. The integration of audio-visual equipment, computer systems, and innovative media has significantly enhanced the educational process, making it more engaging and effective for students [25]. Additionally, the use of technology-based tools such as Zoom meetings, Google Meet, wikis, Google Docs, and cloud-based applications has facilitated communication, collaboration, and group projects among students, transcending geographical boundaries and enabling seamless sharing of learning materials [26]). Furthermore, the utilization of information and communication technology (ICT) has expanded access to education, increased its relevance to the digital workplace, and improved the quality of education by transforming teaching and learning into interactive processes connected to real life [27]. The successful implementation of these educational technologies not only enriches the learning experience but also enhances student achievement in various educational settings, as evidenced by studies conducted in Saudi Arabia [28].

The research highlights the importance of teacher politeness in integrating character education into Indonesian language learning [29]. This finding is in line with the emphasis on the close relationship between schools and communities in supporting the education process [30]. In the context of technology, the research underscores the significance of integrating communication and information technology in language teaching at the elementary level, with an emphasis on the educator's role in leveraging technology [31]. Effective elementary school management also plays a crucial role in supporting the integration of technology in sustainable education [32].

From the series of studies presented, several gaps can be identified in the current literature regarding the role of technology in enhancing sustainable education in elementary schools. Firstly, although many studies highlight the benefits of technology in improving educational practices and student engagement in elementary schools, there is still a lack of research specifically exploring the concrete challenges faced in effectively integrating this technology in the context of sustainable education. Secondly, while numerous studies have demonstrated the potential of technology to enhance student engagement and creativity in learning, there remains a need to further understand how technology can be effectively utilized to achieve the goals of sustainable education, including how it can help promote environmental awareness and social responsibility among students. Thirdly, in the context

of integrating technology with language learning, there is a gap in understanding how teachers can optimally leverage communication and information technology to enhance language learning in elementary schools, particularly in integrating character education into language learning. Furthermore, further research is needed to identify specific barriers and solutions related to effective technology management in elementary schools to support sustainable education.

In the context of this report, the main objective is to conduct a systematic review of the existing literature to identify research gaps and challenges faced in integrating technology into sustainable education in elementary schools. By understanding these gaps, subsequent research can lead to the development of more effective strategies and approaches in harnessing technology to enhance sustainable education in elementary schools, while addressing emerging challenges.

2. METHOD

This research employs a Systematic Literature Review (SLR) approach, which utilizes a descriptive qualitative methodology to examine findings from multiple research endeavors. Descriptive qualitative research is an investigative form that outlines the outcomes of research projects. Systematic Literature Review (SLR) is a technique involving the identification, evaluation, and interpretation of all relevant research materials related to a specific question or issue under study. Various components of the research process include article compilation, article reduction, and article review. Regarding the utilization of the Systematic Literature Review (SLR) method, the initial step of the research involves searching for articles presenting research findings on blended learning. The subsequent step is article reduction, wherein the researcher selects articles and proceedings from national and international journals. Finally, the researcher proceeds to review the collected articles. During the article review phase, the researcher outlines strategies for implementing blended learning to enhance student autonomy in the learning process. To conduct this research, a series of steps were undertaken by the researchers. The initial step involved identifying data sources, which included utilizing Google, Google Scholar, Scopus, and DOAJ. Subsequently, determination of search keywords was carried out, wherein the authors used " Technology, Sustainable Education, Elementary Schools, Opportunities, Challenges" as the designated keywords. Once the necessary articles were obtained, a duplication filter was applied to ensure the uniqueness of the data. Finally, analysis of these articles was conducted by the researchers.

Subsequently, the review protocol was applied by formulating research questions and categorizing keywords based on the Population, Intervention, Comparison, Outcome, and Context (PICOC) strategy of the obtained articles. Inclusion and exclusion criteria were established by selecting articles that aligned with the research questions, excluding any subjective assessments made by the researchers during the article selection process. The Mendeley software was utilized to organize the selected articles for easy management and referencing. The process of data extraction and synthesis was carried out through the application of thematic analysis and meta-analysis to present findings methodically and comprehensively. In the conclusive section of the investigation, the researchers compared

3. RESULTS AND DISCUSSION

Based on the search result, several relevant research findings have been identified that can elucidate the focus and objectives of this study. We have formulated several aspects that need to be described, including; (1) Technology utilized in sustainable education in elementary schools; (2) Opportunities presented by the use of technology in enhancing sustainable education in elementary schools; (3) Challenges are encountered in integrating technology into sustainable education in elementary schools; (4) Effective is technology in enhancing students' understanding of environmental issues and social responsibility in elementary schools.

Table.1 Focus and insights into research result according to eligibility criteria

No.	Focus	Authors	Insight or Research Variables
1.	Integration of Technology in Elementary Education for Sustainability	[33], [34], [35], [36], 37], [38], [40], [41], [42].	Development of Digital Educational Resources like serious games "Sustainability at Play. Utilization of Educational Robotics, Gestalt principles, and Information Technology to enhance students' understanding of sustainability issues. Implementation of Interdisciplinary and Meaningful Learning approaches to integrate environmental issues into the curriculum
2.	Potential of Technology in Sustainable Education	[43], [44], [45], [46], [47].	Utilization of digital educational resources such as serious games to enhance skills for sustainable development. Success of educational robotics, Gestalt principles, and information technology in engaging students in sustainability-related knowledge.
3.	Technology Use in Primary Education for Sustainability	[48], [49], [50], [52], [51], [53].	Enhancement of environmental understanding and social responsibility through technologies like AR and IoT. Variation in the effectiveness of technology in improving student learning outcomes depending on context and implementation.
4.	Challenges in Technology Integration	[54], [55], [56], [57], [58], [59], [60].	Challenges in technology integration include lack of training and support for teachers, as well as infrastructure and financial constraints in rural areas. Presentation of potential solutions through the Sustainability via Active Garden Education (SAGE) program emphasizing a garden-based approach to promote physical activity and healthy eating, collaboration, and group projects among students.
5.	Technology Use in Environmental Education and Social Responsibility	[65], [66], [67], [68], [69].	Use of e-learning platforms like WhatsApp to enhance Higher Order Thinking Skills (HOTS) and environmental education among elementary school students. Application of the Community Science Technology (CST) approach to enhance environmental literacy.
6.	Effectiveness of Technology Use in Sustainable Education	[70], [71], [72], [73], [74].	Research on the effectiveness of technology in enhancing understanding of environmental issues and social responsibility among elementary school students. Emphasis on the importance of integrating ICT into teaching programs for effective learning outcomes.

a. **Technology utilized in sustainable education in elementary schools**

In elementary schools, technology plays a crucial role in promoting sustainable education [33]. Various innovative approaches have been implemented to integrate sustainability concepts into the academic curriculum [34]. One such method involves the development of Digital Educational Resources (DER), such as serious games like "Sustainability at Play," which focuses on ecological footprints and is designed through Educational Design Research (EDR) processes [35]. Additionally, the use of Educational Robotics, Gestalt principles, and information technology has been observed in public elementary schools in Brazil to enhance students' understanding of sustainability issues [36]. Students participate in workshops where they create robot resources such as

mobile robots and gas sensor boxes to learn about food footprints and recycling, showcasing successful and sustainable experiments [37]. Furthermore, efforts are underway to address educational challenges in rural areas through sustainable interactive learning media, emphasizing educational equality and the reuse of electronic waste [38].

Digital technology plays a significant role in advancing environmental education and sustainable actions in elementary schools [39]. Buchanan specifically emphasizes the role of video conferencing, mobile applications, and virtual and augmented reality in engaging students in environmental conservation efforts [40]. On the other hand, Matias highlights the effectiveness of Project-Based Learning, Interdisciplinary approaches, and Meaningful Learning in integrating environmental issues into the curriculum and school community [41]. These approaches not only enhance student participation and involvement but also contribute to achieving sustainable education goals. Furthermore, they can have a long-term positive impact on the economy, environment, and society [42].

This study highlights the significant role of digital technology in advancing environmental education and sustainable practices within elementary schools. Various approaches, including the development of digital educational resources, utilization of educational robotics, and application of Gestalt principles alongside information technology, have contributed to enhancing students' understanding of sustainability issues. Moreover, project-based approaches, interdisciplinary methods, and meaningful learning strategies have proven effective in integrating environmental concerns into the curriculum and school community. The research provides profound insights into how digital technology can serve as a potent tool in enhancing environmental education and sustainable initiatives within elementary school settings. However, several aspects necessitate further consideration, such as addressing technical and logistical challenges in implementing these technologies across diverse educational environments and ensuring the sustainability of the adopted approaches in the long term.

b. Opportunities presented by the use of technology in enhancing sustainable education in elementary schools

The integration of technology in elementary schools presents significant opportunities for enhancing sustainable education [43]. Leveraging digital educational resources such as serious games focusing on sustainability enables students to develop crucial skills to promote sustainable development in line with the Sustainable Development Goals [44]. Educational Robotics, Gestalt principles, and information technology have proven successful in engaging students in sustainability-related knowledge through the creation of robotic resources aiding in the understanding of ecological footprints and food consumption habits [45]. Furthermore, incorporating widely available technology into simple tasks can expose students to biodiversity, invasive species, and sustainable behaviors, thereby fostering pro-environmental actions beyond the classroom setting [46]. Additionally, the use of interactive and engaging learning media, such as real-world games developed through Stanford design thinking practices, can address educational challenges in rural areas, promoting equitable and sustainable education for all students [47].

The utilization of technology in primary education holds promise for enhancing sustainable education, as indicated by several studies [48]. Ongoing professional development, including training in technology utilization, leads to sustained

improvements in teachers' perceptions and skills in science instruction [49]. However, the effectiveness of delivering digital content, such as through laptops, in enhancing student learning outcomes is uncertain [50]. Significant differences in student learning outcomes between laptops and traditional textbooks in primary schools were not evident [51]. Conversely, notable improvements in English and Kiswahili test scores were observed when tablets and e-readers were utilized in primary schools [52]. These findings suggest that while technology can serve as a valuable tool in improving education, its impact may vary depending on specific contexts and implementations [53].

Research indicates that the use of technology in primary education holds promise for enhancing sustainable education. Various approaches, such as serious games, educational robotics, and integrating technology into simple tasks, have proven successful in engaging students in sustainability-related learning. However, some studies also suggest that the effectiveness of technology in improving student learning outcomes may vary depending on the context and implementation. The research provides valuable insights into the potential of technology in primary education to enhance sustainable education. However, several questions remain unanswered, such as how technology can be effectively integrated into the curriculum to achieve optimal learning outcomes. Additionally, the role of professional development in enhancing teachers' understanding and skills in teaching science for sustainability is also crucial to consider.

c. **Challenges are encountered in integrating technology into sustainable education in elementary schools**

Integrating technology into sustainable education in elementary schools encounters various challenges [54]. Teachers often lack confidence and appropriate training in teaching STEM subjects and technology, leading to difficulties in technology integration [55]. Sustainability curriculum reforms, including Digital Education (DE), are hindered by factors such as limited time, lack of specific assessment tools, and low teacher support for teaching computational thinking (CT) [56]. In rural areas, limited infrastructure and financial resources impede the implementation of interactive and enjoyable learning media, affecting equitable educational access [57]. Additionally, barriers in implementing STEAM learning in elementary schools further highlight the challenges faced by elementary school teachers in adopting innovative educational approaches [58]. Overcoming these barriers through proper training, support, and infrastructure is crucial for the successful integration of technology into sustainable elementary education [59].

The integration of technology into sustainable education in elementary schools faces several challenges [60]. While computer-assisted learning platforms and Khan Academy have a positive impact on students' attitudes towards mathematics, they do not significantly improve mathematical proficiency [61]. These findings highlight the difficulty in achieving tangible academic outcomes through technology integration [62]. The importance of integrating ICT into the teaching program, rather than using technology as a standalone tool, for effective learning outcomes is emphasized [63]. A potential solution is introduced through the Sustainability via Active Garden Education (SAGE) program, which utilizes a garden-based approach to promote physical activity and healthy eating [64]. Although this approach is not directly related to technology, it

underscores the need for innovative and holistic strategies in sustainable education [38].

Research indicates that integrating technology into sustainable education in elementary schools faces significant challenges, particularly concerning teacher readiness and support, resource availability, and the development of suitable curricula. The lack of training and support for teachers can be a major barrier to adopting and integrating technology into teaching. Additionally, infrastructure constraints and resource limitations in rural areas also impact the accessibility of education. While technology can be a useful tool, these challenges underscore the need for holistic and innovative approaches in sustainable education at the elementary level. The research provides valuable insights into the challenges encountered in integrating technology into sustainable education in elementary schools. However, several aspects need to be considered, such as expanding research to further understand the impact of technology on students' academic outcomes and improving teacher instruction. Furthermore, attention is needed to provide adequate training and support for teachers, as well as investing in educational infrastructure, particularly in rural areas, to enhance the accessibility and effectiveness of sustainable education.

d. **Effective is technology in enhancing students' understanding of environmental issues and social responsibility in elementary schools**

Technology plays a pivotal role in enhancing elementary school students' understanding of environmental issues and social responsibility [65]. Various studies underscore the effectiveness of different technological approaches in achieving this goal [66]. For instance, augmented reality (AR) and Internet of Things (IoT) have significantly improved students' knowledge of air pollution, emphasizing the importance of fostering environmental awareness among children [67]. Additionally, the Community Science Technology (CST) approach has been successfully applied to enhance environmental literacy among elementary school students, demonstrating improvements in both cognitive and affective aspects of environmental understanding [68]. Furthermore, the utilization of e-learning platforms such as WhatsApp has been identified as a popular and beneficial tool for enhancing Higher Order Thinking Skills (HOTS) among elementary school students, highlighting the significance of technology-based learning media in promoting environmental education and social responsibility [69].

The utilization of technology in elementary schools has demonstrated varied outcomes in enhancing students' understanding of environmental issues and social responsibility [70]. Location-based exergames have been shown to improve physical activity, yet contextual factors such as school policies and teacher involvement can influence their effectiveness [71]. Online sustainability learning tools integrating Systems Thinking and System Dynamics simulation have significantly enhanced comprehension of environmental problems [72]. However, the effectiveness of ICT interventions in improving learning outcomes depends on their integration into the teaching program [73]. Hence, while technology holds the potential to enhance students' understanding of environmental issues and social responsibility, its effectiveness relies on various contextual and instructional factor [74].

The study indicates that technology holds promise as an effective tool for instilling environmental literacy and social responsibility among elementary school students. For instance, augmented reality (AR) and Internet of Things (IoT) technologies provide

immersive experiences that deepen students' understanding of environmental issues like air pollution. Furthermore, Community Science Technology (CST) methods involve students in practical, community-oriented projects, nurturing both cognitive and emotional aspects of environmental comprehension. E-learning platforms like WhatsApp offer accessible and interactive learning opportunities that foster Higher Order Thinking Skills (HOTS) relevant to environmental education. However, the effectiveness of these technological tools may vary due to contextual factors such as school policies, teacher involvement, and the degree of integration into the curriculum. The study offers a thorough examination of technology's potential in elementary education to promote environmental awareness and social responsibility. It provides valuable insights into various technological approaches and their impact on student learning outcomes. Nonetheless, certain limitations need acknowledgment, such as the necessity for further exploration into the long-term effects of these technologies on students' environmental attitudes and behaviors. Moreover, the role of teachers in effectively incorporating technology into the curriculum and guiding its use requires further investigation
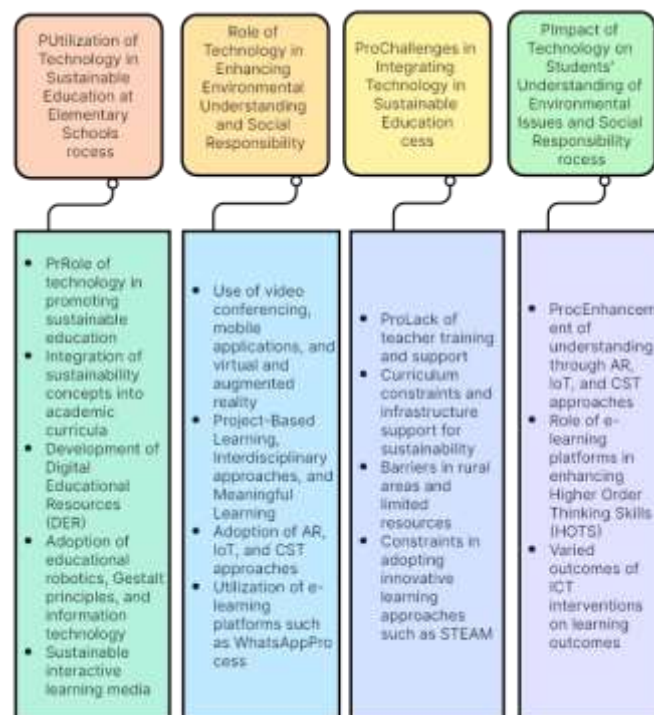

Figure 1. Flow of research findings

4. CONCLUSION AND SUGGESTIONS

Based on the evaluation of the findings presented, it can be concluded that the integration of technology in sustainable education at the elementary school level offers significant opportunities to enhance students' understanding of environmental issues and social responsibility. However, to maximize the potential of this technology, a comprehensive and integrated approach is needed, involving the development of appropriate educational resources, adequate teacher training, and support for the integration of technology into the curriculum and daily teaching practices. Nevertheless, challenges such as teacher readiness, infrastructure availability , and alignment with students' learning contexts remain obstacles that need to be addressed.

The evaluation highlights a gap between the potential of technology in elementary sustainable education and the challenges faced in its implementation. Therefore, an urgent research topic for the future is identifying effective strategies to overcome these barriers in integrating technology into sustainable education at the elementary school level. This research may include the development of effective teacher training models in utilizing technology, policy analysis in support of educational technology infrastructure in elementary schools, and studies on the influence of learning contexts on the success of technology implementation in sustainable education. Thus, future research needs to focus on developing contextually appropriate solutions to address barriers in implementing technology in sustainable education at the elementary school level. With a holistic and integrated approach, technology can be an effective tool in helping create a more equitable, inclusive, and sustainable education for all students at the elementary school level.

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