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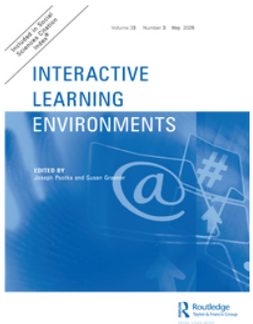

Interactive Learning Environments

ISSN: 1049-4820 (Print) 1744-5191 (Online) Journal homepage: www.tandfonline.com/journals/nile20

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To cite this article: Tarlan Ahmadov, Ayaz Karimov, Susanne Durst, Mirka Saarela, Wolfgang Gerstlberger, Mike Franz Wahl & Tommi Karkkainen (2025) A two-phase systematic literature review on the use of serious games for sustainable environmental education, Interactive Learning Environments, 33:3, 1945-1966, DOI: 10.1080/10494820.2024.2414429

To link to this article: https://doi.org/10.1080/10494820.2024.2414429

INTERACTIVE LEARNING ENVIRONMENTS
2025, VOL. 33, NO. 3, 1945–1966
https://doi.org/10.1080/10494820.2024.2414429

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REVIEW ARTICLE

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A two-phase systematic literature review on the use of serious games for sustainable environmental education

Tarlan Ahmadov [a,b], Ayaz Karimov [c], Susanne Durst [d,e], Mirka Saarela [c], Wolfgang Gerstlberger [a], Mike Franz Wahl [a] and Tommi Karkkainen[c]

[a]School of Business and Governance, Tallinn University of Technology, Tallinn, Estonia; [b]RISE Research Institutes of Sweden, Gothenburg, Sweden; [c]Faculty of Information Technology, University of Jyvaskyla, Jyvaskyla, Finland; [d]School of Business, Innovation and Sustainability, Halmstad University, Halmstad, Sweden; [e]Department of Business and Economics, Reykjavik University, Reykjavik, Iceland

ABSTRACT

This study explores the landscape of serious games for sustainable environmental education, focusing on game types, theoretical foundations, and pedagogical approaches to provide valuable insights for educators, researchers, and policymakers. Using an umbrella literature review methodology, it examines empirical studies published between 2006 and 2023 on serious games in this field. The findings reveal a growing interest in serious games for sustainability, highlighting advancements in gaming technologies. It also identifies various game types, theoretical perspectives, and pedagogical strategies used to promote sustainability education. The study offers a comprehensive overview of the role of serious games in fostering sustainable behaviors, synthesizing key empirical studies, frameworks, and practical applications. Its insights can help educators design and implement serious games that effectively integrate diverse pedagogical and theoretical approaches, enhancing learning outcomes and raising sustainability awareness.

ARTICLE HISTORY
Received 14 May 2024
Accepted 4 October 2024

KEYWORDS
Quality education; Serious games; Sustainability; Environmental education; Systematic literature review

1. Introduction

The rising trend of serious games (SGs) in sustainability education is evident from the increasing number of studies and implementations across various educational settings. SGs, which are not only to entertain the player but also to develop a skill (de Carvalho et al., 2023), are being recognised for their potential to engage learners in complex sustainability issues through interactive and immersive experiences (Hallinger et al., 2020; Stanitsas et al., 2019).

The integration of educational games into sustainability education holds the potential to offer more immersive and interactive learning experiences compared to the traditional methods, by creating a hybrid format that balances gaming and learning challenges with the learner's abilities (Dib & Adamo-Villani, 2014; Kickmeier-Rust et al., 2007). It has been argued that through gameplay, learners can engage with complex environmental concepts (Vázquez-Vílchez et al., 2021), explore interconnected socio-economic systems (Irabor et al., 2023), and develop critical thinking skills necessary for addressing sustainability challenges (Janakiraman, 2020; Sousa & Wilks, 2018). Moreover, amidst growing awareness of the interconnectedness of social, environmental, and economic sustainability, there is a pressing need for effective educational strategies to foster a systemic understanding and action-oriented competencies among learners (Wals, 2011). Traditional instructional methods, such as for example case studies,

CONTACT Tarlan Ahmadov tarlan.ahmadov@taltech.ee

often struggle to convey the complexity of sustainability challenges and the interconnected nature of its components (Kalamas Hedden et al., 2017). In this context, SGs have emerged as a promising educational tool (Dimitriadou et al., 2021; Low & Ellefson, 2024; Xie & von Zuydtwyck, 2021).

Douglas and Brauer (2021) conducted a review of games and gamified apps for sustainability. Their research found that gamification and games can be used to improve environmentally sustainable behaviour and that board games are the most efficient games to visualize the effects of climate change. Hallinger et al. (2020) conducted a systematic literature review of 376 papers that focus on simulation SGs utilized in educating for sustainability published between 1997 and 2019. They found that the most famous types of SGs are the ones that are delivered through web technologies, computers, and board games. The topics of these topics changed from natural resources, social sustainability, energy, and waste management to general sustainability. Stanitsas et al. (2019) also conducted a systematic literature review of papers published during 1990–2018 where they reviewed 77 games that were utilized with the aim of teaching sustainability. They found that most of the games were simulation, tabletop, computer, card, and mobile games and the most of these games were organized/used by organizations that need to be clearly aware of sustainability topics for their own reasons.

However, despite the growing body of research on SGs for sustainable environmental education, there remains a gap in the literature regarding a systematic evaluation of the existing studies. While individual studies have provided valuable insights, there is a lack of synthesis that could offer a broader understanding of the field. This is particularly crucial as SGs gain traction in pedagogical discourse and this recent trend has only been superficially evaluated by scientific research, there currently is a research gap in terms of systematic examination of existing literature to identify potential development trends and effective educational practices, as well as demonstrate potential limitations of existing scientific and practical concepts (Alba-Hidalgo et al., 2018; Martínez-Pernía et al., 2023). By synthesizing empirical studies, theoretical frameworks, and practical implementations, this review aims to provide educators, and researchers with actionable insights. For this, we conducted two-phase review process where we started by reviewing the published review papers on SGs for sustainable environmental education, then as a second step, we conducted literature review on the empirical studies.

Based on the summarized arguments, our research aim is to synthesize empirical studies, theoretical frameworks, and practical implementations to identify development trends, effective educational practices, and potential limitations in the utilization of SGs for sustainable environmental education. Through this synthesis, our goal is to provide educators and researchers with actionable insights that can inform future research directions and enhance the efficacy of SGs in promoting sustainable environmental education. Moreover, we have derived the following research questions from this research aim:

- What is the current state of research on the use of serious games for sustainable environmental education?
- What are the emerging trends in the development and application of serious games in this educational field?
- What are the predominant educational practices associated with the use of serious games for sustainability education?
- What are the key limitations and challenges in the utilization of serious games for sustainable environmental education?

These questions will guide our systematic literature review to address the gaps in understanding and provide comprehensive insights into the use of SGs for sustainable environmental education.

2. Literature background

2.1. Sustainable environmental education

Sustainable environmental education is recognized as a critical component in fostering a society that values and practices sustainability. It encompasses the development of knowledge, skills, values, and

attitudes necessary for individuals to contribute to the protection and improvement of the environment for future generations (Aggarwal, 2023; Guler & Afacan, 2012). Mian et al. (2020) highlighted the transformative impact of Industry 4.0 on industries globally, emphasizing the need for adaptive skills in the workforce. The results advocate for an assertive strategy, emphasizing financial planning, skilled staff, industrial partnerships, infrastructure, revised curricula, and workshops to equip learners with Industry 4.0-related skills. Papenfuss et al. (2019) addressed the post-decade of education for sustainable development era, emphasizing the importance of transformative and emancipatory pedagogies. Their proposed framework integrates various pedagogies, guiding facilitators and learners toward transformative and emancipatory learning. Porter and Córdoba (2009) explored the role of systems thinking in sustainability education, extending it into three broad approaches: functionalist, interpretive, and complex adaptive systems. The authors aimed to provide practical ideas and tools for management educators to adopt systems thinking in sustainability pedagogy.

Koehn and Uitto (2014) emphasized the global commitment to environmental sustainability in higher education and the lack of a comprehensive evaluation framework for sustainability programs. Their proposed multidimensional framework covers process, outputs, outcomes, impacts, and continuous improvement, serving purposes such as management evaluation, capacity, and capability development evaluation, and sustainability evaluation. In complement to studies on Industry 4.0 and sustainability education, Fisher and McAdams (2015) specifically examined the influence of academic coursework on students' conceptualizations of sustainability. Analysing data from the 2011 Sustainability Survey with 552 students, their findings indicated that the type of course significantly impacted how students perceive sustainability. Surprisingly, the quantity of courses taken did not show a statistically significant impact. This underscores the importance of thematic exposure in classes, rather than sheer volume, in shaping students' understanding of sustainability.

Marouli (2021) critically assesses Education for Sustainable Development (ESD) and its objective of sustainable development, informed by the structure-agency debate and critical pedagogy theory. Identifying areas for improvement within ESD, Marouli advocates for a shift towards Education for Eco-communities, emphasizing community-centered approaches, understanding natural laws, sociological imagination, and political acumen to align education with twenty-first-century challenges. Addressing teachers' challenges in integrating sustainability education in primary schools, Green and Somerville (2015) provides insights into overcoming barriers such as confidence, skills, and curriculum integration concerns. From a longitudinal study in Victoria, Australia, the research explores how sustainability education unfolds in primary schools. The findings highlight sustainability education as an emerging practice shaped by dynamic relationships between teachers, students, community members, and local places.

While existing literature predominantly explores various teaching methods and factors influencing sustainable environmental education, our study investigates by critically reviewing this body of work. We conduct a review of existing literature, exploring established methodologies and influential factors. Simultaneously, we provide an updated overview of the current state of research on the application of SGs in sustainable environmental education.

2.2. Serious games for sustainable environmental education

Empirical studies and bibliometric analyses have identified a surge in research activity surrounding simulation-based learning and SGs, particularly in the context of sustainability-related topics (Hallinger & Wang, 2020). This trend reflects a recognition of the need for innovative educational approaches to address complex global challenges and empower learners to contribute to a more sustainable future. SGs leverage the immersive and interactive nature of gaming to engage users in learning experiences focused on real-world problems, including sustainability issues. By incorporating gameplay elements from entertainment games and aligning them with educational objectives, SGs offer a unique platform for experiential learning (Rossano et al., 2018). Specifically, SGs addressing sustainability concepts have demonstrated the ability to enhance user engagement,

comprehension, and application of theoretical knowledge in practical scenarios (Botella et al., 2011; Karimov et al., 2023a; Lamb et al., 2018; Wattanasoontorn et al., 2013).

Previous research has shown various applications of educational games in sustainability education (Dieleman & Huisingh, 2006; dos Santos et al., 2018; Gervich et al., 2016). Xu et al. (2014) presents *Makahiki* that is an open-source SG framework for sustainability and the framework supports organizations to develop their sustainability games. They demonstrate built-in content and games related to the sustainability. While they highlight that the learner engages with the platform more and it motivates them, they think that the tool would need to expand its users to be able to provide more general results. De la Torre et al. (2021) explored the need for sustainable natural resource management, emphasizing the role of energy knowledge and the importance of resource preservation. The study examined trends, challenges, and the role of simulation and SGs as learning tools for these concepts. Despite efforts to integrate such content, the findings revealed a need for further work, particularly in university management, and noted that SGs were not widely implemented, although successful in fostering active student learning.

Gheorghe et al. (2020) focused on the rising importance of sustainability skills in the last decade and the role of SGs in reshaping learning environments for developing these skills. Analysing three specific games, the paper delved into their narrative, educational context, target group, game mechanics, and the sustainability skills and competencies acquired during gameplay. Tan and Nurul-Asna (2023) conducted a systematic review on the increasing popularity of SGs in various fields, particularly in education and environmental engagement. Examining 56 papers spanning from 2009 to 2023, the study revealed a growing interest in SGs for environmental education. Successful SGs were characterized by immersive experiences, meaningful engagement, learn-by-doing involvement, simulation of real-world environmental problems, autonomy in decision-making, and the presence of a guiding host. The review identified digital and physical categories of SGs and highlighted gaps in understanding the impacts of commercial games, variations in player experiences, and the effects of complex SGs on adult learning. The study also noted the shift towards digitization and advancements in location-based, alternate reality, augmented reality, and virtual reality SGs, which can enhance environmental awareness and appreciation.

Dib and Adamo-Villani (2014) enhanced building sustainability education with SGs. Amidst a growing global population and increased resource demands, sustainable buildings are crucial. The study tackles the challenge of integrating building sustainability into the curriculum for architects, engineers, and construction professionals. Researchers developed and assessed a SG focused on sustainable building design principles. Findings from studies with students and faculty indicated positive perceptions of the game's usability, engagement, and educational value. A summative study revealed significant increases in declarative knowledge by 22% and procedural knowledge by 37% among game-playing students, particularly in procedural knowledge compared to traditional learning methods. Weijs et al. (2016) recognized the imperative for focused Sustainable Development education in business curricula. The lack of effective teaching methods for sustainability competences led the researchers to explore gaming as a suitable approach due to its action-oriented nature, direct feedback, and high motivation. Three simulation games were employed with 160 s-year business students. While the results indicated limited cognitive learning about Sustainable Development, a majority of respondents acknowledged the additional value of gaming in their education. The study highlights the potential and challenges of incorporating simulation games into business education for sustainability.

3. Research approach

3.1. Data collection procedure

This study employed a two-phase systematic literature review, as it ensures both breadth and depth in the exploration of the research area, offering a comprehensive understanding (Aromataris et al.,

2015; Belbasis et al., 2022). The initial phase, an umbrella review, synthesized high-level evidence from existing systematic reviews, laying a robust foundation for the subsequent in-depth analysis. Subsequently, the review delved into empirical studies, providing a nuanced understanding of the topic by examining primary research findings in detail (Figure 1).

The two-phase systematic literature review adhered to the analytical standards of the PRISMA guidelines (Moher et al., 2009). These guidelines are recognized and widely adopted in the scientific community to ensure the transparency and accuracy of literature review processes. During both phase one and phase two of the review, a consistent search strategy was employed. The researchers utilised the same search string to access peer-reviewed studies, ensuring the integrity and comparability of the findings. The search was conducted in two scientific databases, Scopus and WOS, similar to previous studies (Ahmadov et al., 2023; Boncu et al., 2022; Tan & Nurul-Asna, 2023).

The chosen search string was strategically designed to identify relevant literature on the topic of SGs in sustainable environmental education. The string incorporated a combination of specific keywords and Boolean operators to maximize the retrieval of pertinent articles. It was as follows: (“serious game” OR “educational game”) AND ((“education” OR “learning”) AND (“sustainable” OR “sustainability” OR “environmental” OR “climate change”)).

To maintain the focus of the study and to ensure the inclusion of recent research, the article search was restricted to peer-reviewed studies published in the English language up until August 1st, 2023. This temporal limitation allowed the researchers to capture the most up-to-date and relevant literature available at the time of the review.

In the first phase, 13 reviews and meta-analyses were selected through an umbrella review process. Phase two followed a similar procedure. After systematically examining study abstracts and eliminating irrelevant articles, 305 papers were eligible for full-text reviews. These were screened based on specific inclusion criteria, focusing on SGs for sustainable environmental education. Eventually, 167 articles discussing empirical investigations were selected for in-depth evaluation.

3.2. Data analysis procedures

In the umbrella review phase, the main findings from the identified reviews and meta-analyses were carefully documented, which helped reveal the current state of the field. In the subsequent phase,

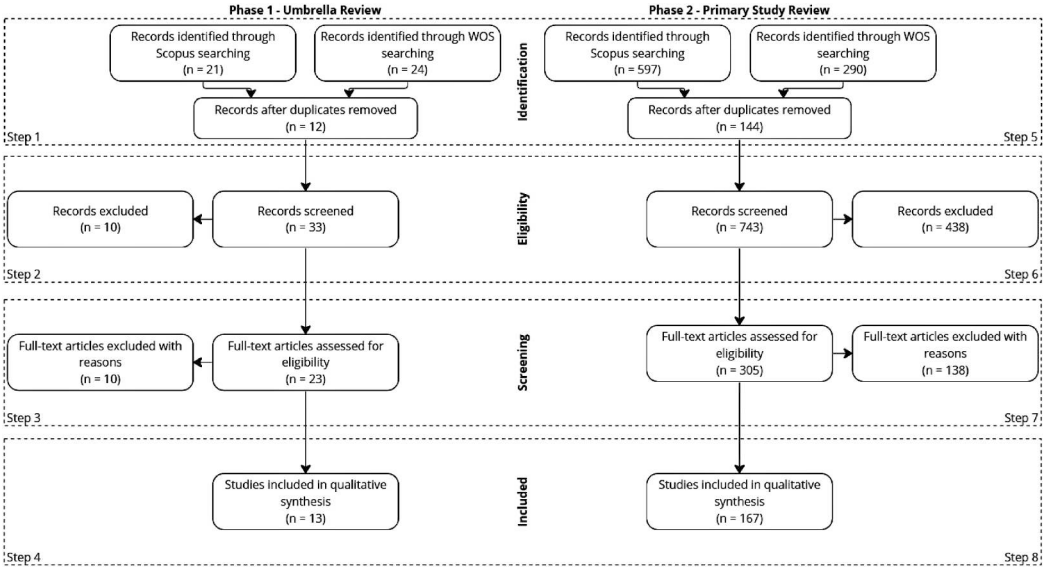

Figure 1. Two-phase review PRISMA chart.

the primary study review, a thematic analysis approach (Braun & Clarke, 2006) was employed. Initially, the research team familiarized themselves with the data gathered from the empirical studies. A researcher conducted a close reading of each individual empirical study to extract essential information relevant to the research questions of the study. During this process, detailed notes were taken, capturing crucial insights from each empirical study. These notes were then discussed and shared with the entire research team to ensure a comprehensive understanding of the extracted information.

4. Findings and discussion

4.1. Umbrella review: research findings on serious games for sustainable environmental education

The umbrella review was designed to establish the status of research on SGs for sustainable environmental education and thereby set the starting point for the primary study review (Table 1). The results reveal a comprehensive examination of the role of SGs in fostering sustainability. Several articles, including Madani et al. (2017), Oliveira et al. (2021), Stanitsas et al. (2019), and Tan and Nurul-Asna (2023) shed light on the potential of SGs for environmental management and sustainability education. Madani et al. (2017) emphasizes the benefits of game-based learning in addressing practical environmental sustainability issues, while Stanitsas et al. (2019) introduces the 7GOALS framework to organize gamification elements in e-learning to promote behavioural attitudes and ensure educational quality. Oliveira et al. (2021) complements this by proposing the integration of gamification elements with the PDCA cycle for enhanced sustainability learning. By doing so,

Table 1. Summary of the main results of the umbrella review.

Authors	Research Focus and Findings
(Morganti et al., 2017)	Explored the use of SGs and gamification to engage individuals in pro-environmental behaviours for energy efficiency. Identified effective strategies and highlighted the need for tailored interventions.
(den Haan & van der Voort, 2018)	Reviewed methods used to assess social learning outcomes in collaborative SGs addressing sustainability issues. Identified gaps in assessment approaches and recommended improvements for future research.
(Madani et al., 2017)	Investigated the use of SGs for environmental management, emphasizing their benefits in enhancing understanding and promoting engagement with practical sustainability challenges. Provided examples and suggested areas for further development.
(Marini et al., 2018)	Explored the potential of SGs to promote values in water resource management decision-making. Identified challenges and suggested design strategies for enhancing cooperation among stakeholders.
(Hallinger et al., 2020)	Conducted a bibliometric review of simulations and SGs in sustainability education, identifying trends and gaps to guide future research efforts.
(Flood et al., 2018)	Reviewed current research on SGs for climate change engagement, identifying effective strategies and areas for improvement in future development.
(Stanitsas et al., 2019)	Examined SGs as tools for sustainability education, providing an overview of their current state and proposing a research agenda for further advancement in the field.
(Boncu et al., 2022)	Analyzed quantitative studies on SGs for promoting pro-environmental outcomes, identifying effective intervention strategies and areas for refinement in future research.
(Gerber et al., 2021)	Conducted a mapping review of games addressing climate change, identifying characteristics and gaps to inform future game development efforts.
(Fernández Galeote et al., 2021)	Reviewed research on gamification for climate change engagement, identifying effective approaches and areas needing further exploration.
(Oliveira et al., 2021)	Introduced a theoretical framework for gamified e-learning related to sustainability, outlining its potential impact and applications for promoting sustainable behaviors.
(Douglas & Brauer, 2021)	Provided a comprehensive review of gamification for sustainability, summarizing existing studies and resources while identifying areas requiring further investigation.
(Tan & Nurul-Asna, 2023)	Synthesized successful game features for environmental education, emphasizing the potential impact of game-based learning and the need for additional research to understand long-term effects.

these articles underscore the potential of SGs and gamified approaches in fostering a holistic understanding of sustainability principles.

Climate change engagement remains a prominent concern within the collection. Boncu et al. (2022) Douglas and Brauer (2021) and Gerber et al. (2021) illuminate the role of SGs in addressing climate change-related challenges. Boncu et al. (2022) systematically reviews the efficiency of gamification interventions for promoting pro-environmental information, attitudes, and behaviours, showcasing their potential as tools for change. Gerber et al. (2021) undertakes a systematic mapping review to identify games related to climate change and establishes a foundation for their further development. Douglas and Brauer (2021) contributes a comprehensive list of gamified apps for sustainability and climate change, providing a valuable resource for researchers, practitioners, and developers.

Flood et al. (2018) and Marini et al. (2018), for instance, delve into the potential of social learning outcomes and adaptive climate futures facilitated by these interventions, shedding light on the ways these approaches can drive collaborative decision-making and address complex environmental challenges. Similarly, Hallinger et al. (2020) contribute to the educational aspect, with one focusing on simulations and SGs in sustainability education. Conversely, Morganti et al. (2017), approaches the subject of pro-environmental behaviours and attitudes from different angles and investigating games' potential in addressing climate change. Meanwhile, den Haan and van der Voort (2018) and Fernández Galeote et al. (2021) offer varied perspectives on the broader theme of SGs and gamification for sustainability, examining social learning outcomes, gamification for climate change engagement, and the state of research along with available games and apps.

The collection of articles provides a multifaceted exploration of the utilization of SGs, and gamified interventions as effective tools for promoting pro-environmental behaviours, sustainable environmental education, and climate change engagement. This body of work collectively acknowledges the limitations of traditional methods in inspiring sustainable actions and recognizes the potential of interactive and engaging approaches to drive meaningful behavioural change. While each article delves into specific aspects of this overarching theme, they share commonalities and differences in their methodologies, objectives, and findings.

However, despite the progress made, the existing body of literature presents an opportunity for further exploration. Given the evolving nature of technology, pedagogy, and environmental challenges, conducting another systematic literature review on the use of SGs for Sustainable environmental education can offer valuable insights. Such a review could provide a consolidated view of emerging trends, identify gaps and limitations, and propose a forward-looking research agenda. By addressing the existing limitations, building upon the current knowledge, and directing future research efforts, this review can contribute to enhancing the impact of SGs in promoting sustainable behaviours, education, and climate change engagement.

4.2. Descriptive analysis of reviewed empirical articles.

Figure 2 illustrates the trajectory of scholarly articles published between 2006 and 2023. A notable trend emerges, indicating a steady but relatively modest growth in publications from 2006 to 2020. However, a substantial surge in scholarly output becomes evident from 2021 onwards. Prior to 2021, the annual publication rates remained relatively stable, with a gradual increase observed over the years. Specifically, in 2020, the number of articles reached a notable milestone, totalling 25 publications. This figure suggests a growing interest and engagement within the field. However, the most significant shift occurs in 2021, where there is a substantial uptick in scholarly activity. The momentum continues to build in 2022, with a further increase to 40.0% of the total articles. Despite a slight dip in 2023, where publications totalled 15 (due to limited until August 1st), the overall trend signifies a remarkable advancement in scholarly contributions, reflecting a dynamic and evolving landscape.

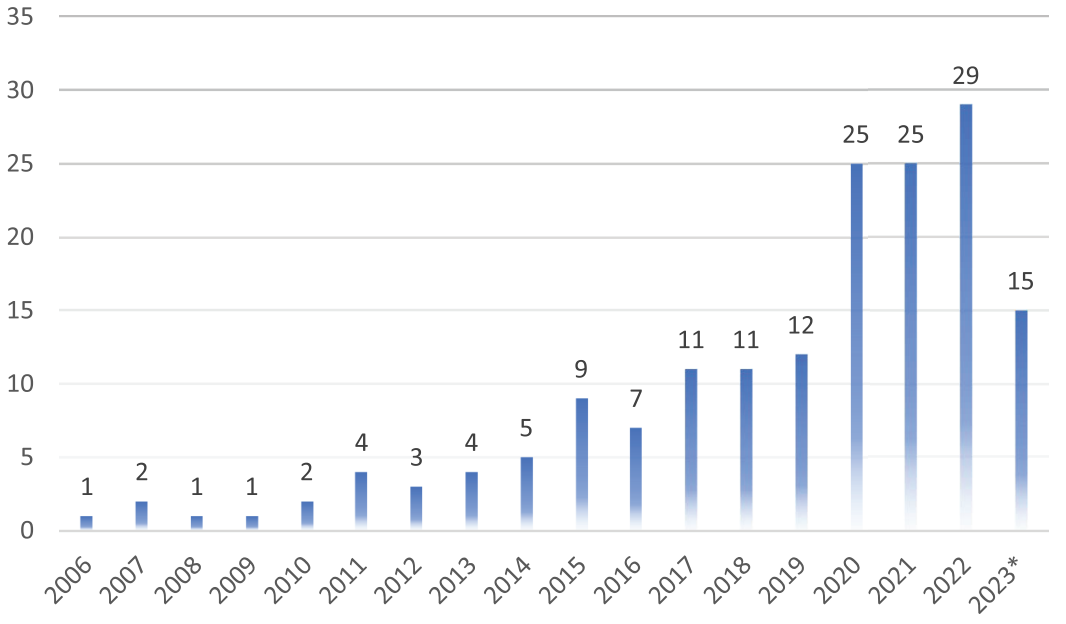

Figure 2. Evolution of publications by year across the period of analysis. * Until August 1st, 2023.

The analysis of research aims, following Durst et al. (2015) categorization, provides insightful observations regarding the theoretical contributions of the articles examined. As shown in Figure 3, predominantly, a significant portion of articles (85) are focused on developing or elaborating existing concepts. This underscores a concerted effort within the field towards developing new educational games and simulation tools for sustainable environmental education, demonstrate a collective effort to advance practical applications in sustainable environmental education. Additionally, exploration of new phenomena is evident in 33 articles, indicative of a proactive approach towards expanding the boundaries of knowledge and exploring the impact of SGs. Furthermore, a substantial number of articles (34) are dedicated to the testing or validation of established games, emphasizing the importance of empirical rigor and validation within the academic discourse.

In contrast, a relatively smaller proportion of articles pursue a dual aim of both exploration and development, with only 4 instances identified. Similarly, articles aiming to develop and validate SGs are represented by 11 instances. This nuanced understanding of research aims highlights the diverse scholarly orientations within the field, ranging from refinement to empirical validation, thus enriching our comprehension of the landscape and scholarly contributions in the domain.

In our analysis of empirical studies, we uncover a rich tapestry of theoretical perspectives that underpin the scholarly discourse. From seminal works like Bandura's Social Cognitive Theory, as exemplified in studies investigating the role of self-efficacy in environmental decision-making (Ouariachi & Elving, 2020), to the innovative applications of dynamical systems theory used to simulate ecological processes within virtual environments (Lombana et al., 2023), our analysis reveals the breadth and depth of theoretical engagement within the field. Furthermore, the incorporation of socioconstructivist principles underscores the pivotal role of social interactions and language in shaping individual understandings of sustainability concepts (Lalicic & Weber-Sabil, 2021). Similarly, the utilization of the Theory of Planned Behaviour offers valuable insights into the determinants of pro-environmental intentions and behaviours among learners (Knol & De Vries, 2010).

Beyond these established theories, we encounter emerging frameworks that push the boundaries of traditional pedagogical paradigms. For instance, the application of the Four-Dimensional-Framework (4DF) provides a comprehensive approach to assess the effectiveness of SGs (Pisithpunth et al.,

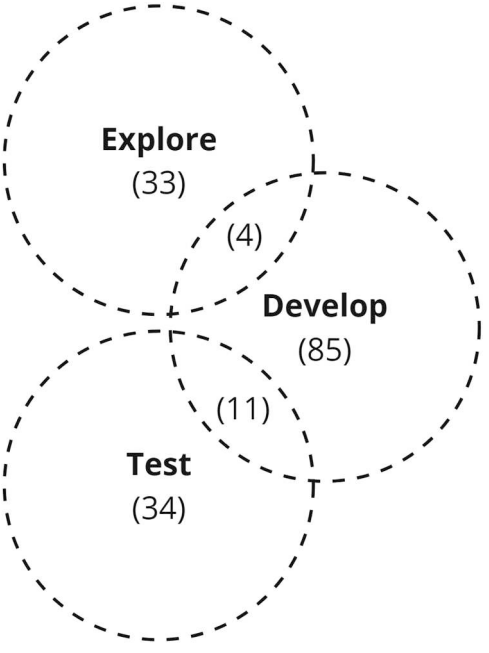

Figure 3. Distribution of research aim types in analysed empirical studies.

2014). Similarly, the integration of the Theory of Change offers a dynamic approach to understanding behaviour change within game-based interventions (Tribaldos & Schneider, 2021). However, our analysis revealed a surprising finding: only 38 out of 167 articles acknowledged or mentioned the use of theoretical frameworks. This concerning result warrant the further discussion which will be in the following section.

4.3. The type, genre, and mechanisms of educational games used

4.3.1. Game types

Our investigation into the educational games employed for teaching sustainable environmental education indicated a diverse game type. These games were designed based on different learning preferences and environments, incorporating both physical and virtual formats. The use of board games and their virtual versions were the most famous type and this highlights a balance between traditional and digital learning tools (e.g. Arslan et al., 2011; Bascoul et al., 2013; Gugerell & Zuidema, 2017; Mostowfi et al., 2016). Simulations, in various forms such as computer and online simulations (De la Torre et al., 2021; Ong & Araral, 2022), and role-playing simulations (e.g. de Kraker et al., 2021; Hossard et al., 2022; Nadzir & Pillay, 2022; Segoni, 2022), were identified as central to providing a realistic and immersive understanding of sustainability challenges.

Mobile and online games reflected a shift towards technology-driven educational tools that offer accessibility and engagement for learners in contemporary settings (Hossard et al., 2022; Santos et al., 2020; Thomas-Walters & Veríssimo, 2022). Additionally, 3D Virtual World games provide an interactive and visually stimulating platform. This type of setting enhances the learning experience through immersive environments, and it also promotes the learning-by-doing approach, where students learn through active participation and engagement with the virtual environment (e.g. Harker-Schuch et al., 2020; Leon-Paredes et al., 2022; Ong & Araral, 2022; Strada et al., 2023; Wang et al., 2021).

Traditional learning tools like tabletop games persisted as effective educational tools since they combine tactile learning with strategic thinking (Boissier et al., 2023; Martindale et al., 2024; Meunier

et al., 2022). Moreover, real-time strategy games were recognized for emphasizing strategic decision-making skills in sustainability education (Huda & Ramadhan, 2021; Wang & Tseng, 2014). Role-playing games in both online and offline formats provided opportunities for students to assume different roles and engage in scenarios, fostering a deeper understanding of sustainability challenges.

Interactive and experiential learning games, including high-touch educational games, were found to promote hands-on learning (Gervich et al., 2016; Whalen et al., 2018). Various digital and video games, featuring character-based narratives, scenario-based content, and augmented reality elements, were identified as engaging platforms for sustainability education (e.g. Barcena-Vazquez et al., 2023; Bárcena-Vázquez & Caro, 2019; Essokolo & Robinot, 2022; Neset et al., 2020). Games incorporating quizzes and puzzles indicated a focus on assessing and reinforcing knowledge. Augmented Reality (AR) Games showcased an innovative approach to blending digital content with the physical environment, providing a unique learning experience (Strada et al., 2023; Wang et al., 2021).

The evolution of educational games mirrors the dynamic fusion of traditional and digital formats, adapting to technological advancements and shifting educational paradigms. Initially dominated by board games and their virtual renditions, the landscape expanded to encompass immersive simulations, mobile gaming, and online platforms. These changes democratized access to educational content, catering to diverse learning preferences and fostering deeper engagement. Augmented reality and virtual reality experiences further blurred the lines between physical and digital realms, offering innovative learning environments.

4.3.2. Game genres

The studies analyzed span a range of game genres, each offering unique features that can influence learning outcomes in specific ways. These genres not only differ in terms of content and objectives but also in the mechanics and engagement strategies they use to drive educational benefits.

Simulation games allow players to engage in real-world scenarios in a controlled environment. They often focus on mimicking processes or systems, enabling experiential learning. Yan and Liu (2007) present a simulation game to integrate building information modeling for architectural education. Their game facilitates hands-on learning by allowing players to simulate architectural design processes, enhancing understanding and decision-making in a simulated environment. Torabkhani et al. (2007) utilize simulation to model and teach manufacturing decisions with a focus on environmental sustainability, showcasing the relevance of simulation in sustainable manufacturing education. Judmaier et al. (2008) designed a multiplayer educational simulation game aimed at promoting sustainable consumption, providing a collaborative platform for players to make ecodesign decisions.

Strategy games focus on resource management, decision-making, and long-term planning. They often require players to think critically and make decisions under constraints, making them effective for teaching problem-solving and strategic thinking. Many simulation games like those mentioned by Judmaier et al. (2008) involve strategic decision-making, where players must consider multiple variables to make informed choices about resource use and sustainability.

Board games, both physical and digital, offer structured, rule-based environments that promote collaborative and competitive learning. In education, board games are particularly valuable for teaching complex systems through visual and interactive elements, enabling players to engage in turn-based gameplay that fosters deeper cognitive processing. Michelin et al. (2006) developed both a board and a virtual version of a game aimed at teaching engineering students core concepts. This dual format allowed the game to engage different types of learners – those who prefer physical, tactile learning through traditional board games and those who are more comfortable with digital environments. In both cases, the board game structure encouraged active participation and peer learning, as players were required to make decisions, solve problems, and discuss strategies with their teammates or opponents.

Casual games are known for their simplicity, accessibility, and brief play sessions. These games usually involve easy-to-understand mechanics and can be played repeatedly in short bursts. Casual games are ideal for informal learning contexts, as they promote gradual learning through frequent interaction, often focusing on awareness-building or behavioral change. Gustafsson et al. (2009) designed "Power Explorer," a casual game aimed at promoting energy-conscious behavior among its players. The game used real-time data to give feedback on players' energy consumption, helping them understand the environmental consequences of their actions. Power Explorer demonstrates how casual games can influence behavior by making learning fun and accessible while reinforcing important concepts like sustainability through gameplay repetition. The simple mechanics made the game highly engaging without overwhelming the players with complex information.

4.3.3. Game mechanisms

Game mechanisms, or the core rules and systems that drive player interaction, play a crucial role in determining how educational games engage learners and facilitate learning outcomes. Resource management is a fundamental game mechanism where players are required to allocate limited resources (e.g. time, energy, money) efficiently to achieve specific goals. In Torabkhani et al. (2007), a simulation game is designed to teach manufacturing decisions with a focus on environmental sustainability. Players must manage resources such as materials and energy, balancing economic benefits with environmental impact. This type of resource management encourages players to think strategically about long-term consequences and trade-offs, simulating real-world decision-making challenges in industries.

Real-time feedback allows players to receive immediate responses to their in-game actions, helping them adjust their strategies dynamically. Michelin et al. (2006)'s virtual and board game for engineering students uses real-time feedback to simulate the results of engineering decisions. Players can immediately see how their design choices affect the structural integrity and efficiency of engineering projects, helping them understand complex engineering concepts through direct consequences.

Turn-based mechanics allow players to take actions in a structured sequence, encouraging careful consideration of each move. In Yan and Liu (2007)'s BIM simulation, while not a strict turn-based game, players are required to make sequential decisions regarding building design and resource management. This structure mirrors real-world architectural processes where steps must be carefully planned and executed.

4.4 Themes in sustainable environmental education literature

4.4.1. Water

In our analysis of 167 articles investigating SGs for sustainable environmental education, articles predominantly concentrate on water-related issues such as water management, water conservation, and marine pollution. This indicates a recognition of the critical importance of water resources in environmental sustainability efforts. Key themes include water conservation, where serious games aim to raise awareness of the importance of minimizing water usage in personal, agricultural, and industrial contexts. These games often simulate real-world scenarios that require players to make decisions that balance water use with sustainability goals, thus reinforcing responsible water consumption practices. Another prominent theme is water resource management, which addresses the complex challenges involved in distributing and managing water resources equitably and efficiently. Through gameplay, learners are exposed to the interconnectedness of water systems and the critical importance of sustainable water management practices, particularly in regions facing water scarcity. In addition to conservation and management, marine pollution emerges as a key topic, with games designed to educate players on the detrimental effects of water pollution on marine ecosystems. These games help learners understand the impact of human activities such as plastic waste and chemical runoff on water quality and biodiversity. By engaging with

these themes, SGs not only foster a deeper understanding of water-related sustainability challenges but also encourage players to think critically about solutions and adopt water-saving behaviors in their daily lives.

4.4.2. Energy

Additionally, there is a notable emphasis on energy-related topics, including energy conservation, energy consumption, and energy preservation. This suggests a growing awareness of the significant role that energy plays in environmental sustainability and the need for strategies to reduce energy usage and promote renewable energy sources. Furthermore, climate change emerges as a prominent theme, with articles addressing climate change adaptation, mitigation, and the broader implications of global climate shifts. This underscores the urgency of addressing climate change and its far-reaching impacts on environmental sustainability. Another central theme is renewable energy sources, with games designed to promote awareness and understanding of alternative energy options such as solar, wind, and hydropower. These games engage learners in exploring the potential of renewable energy to reduce dependency on fossil fuels and mitigate the environmental impacts of traditional energy production. In addition to these educational aspects, the games frequently address energy management, encouraging players to balance energy supply and demand in a sustainable way. Through simulation and role-playing, learners gain insights into how effective energy management can contribute to broader sustainability goals, such as reducing carbon emissions and promoting green technologies. Overall, the focus on energy in SGs helps players understand the complexities of energy systems and fosters critical thinking about how individuals and organizations can contribute to a more sustainable energy future.

4.4.3. Economic sustainability

In addition to environmental concerns, there is a notable emphasis on the economic dimension of sustainability, with several distinct areas of focus identified. Articles on economic sustainability cover various aspects crucial for the balance between economic growth and environmental preservation. They delve into topics such as urban planning to ensure cities are developed sustainably, sustainable manufacturing practices to reduce environmental impact, and efficient supply chain management for resource optimization. Additionally, they explore strategies for both short-term and long-term profit while considering the broader implications of resource management. Moreover, some articles discuss the integration of sustainability into product development and manufacturing processes, emphasizing the importance of lifecycle assessments and the implementation of cap-and-trade systems. Another prominent theme is sustainable manufacturing practices, where SGs highlight the importance of reducing the environmental footprint of production processes. Players are tasked with optimizing resource use, minimizing waste, and implementing circular economy principles such as recycling and upcycling in manufacturing contexts. Additionally, the games often explore supply chain management strategies that focus on resource optimization and sustainability, challenging players to make decisions that balance profitability with environmental responsibility. Lifecycle assessments and the integration of cap-and-trade systems are also frequent topics, as games simulate real-world scenarios where players must account for the environmental impacts of products throughout their entire lifecycle, from raw material extraction to disposal. By addressing these economic dimensions, SGs not only foster an understanding of the complexities involved in achieving economic sustainability but also empower learners to consider innovative solutions that can drive both economic and environmental success.

4.4.4. Social sustainability

While the environmental and economic dimensions dominate the literature, there is also a recognisable, albeit minor, focus on social sustainability (Tab 2.). Empirical studies on social sustainability explored the concept of sustainable cities. Additionally, these articles delve into sustainability concepts integrated into everyday life activities, emphasizing the importance of individual and collective

actions in fostering social cohesion and resilience. Another common topic discussed in these articles are public construction projects through a social sustainability lens, considering how infrastructure development can enhance community engagement, health, and safety while minimizing negative impacts on marginalized groups. SGs simulate the challenges of building public infrastructure – such as transportation systems, housing, and public spaces – that meets the needs of all societal groups while minimizing negative impacts on marginalized populations. The games also delve into individual and collective actions for sustainability, encouraging players to engage with everyday practices that promote social well-being, such as responsible consumption, volunteering, and community-led initiatives.

Of the 167 articles analysed, 29 articles address the topic of sustainability in a general sense by taking into account environmental, economic and social aspects of sustainability. These articles can contribute to the diversity of the concept of sustainability by analysing its multiple aspects, their connectivity and potential impact on different areas of human activity Table 2.

The analysis of 167 articles on sustainable environmental education literature reveals a focused distribution of themes. Water-related issues, energy conservation, and climate change emerge as prominent topics, reflecting their critical importance in sustainability efforts. While there is significant attention to environmental and economic dimensions, social sustainability receives relatively less focus. This highlights a potential gap in educational approaches, necessitating a more balanced integration of societal considerations. This disparity invites further exploration into how SGs can effectively address the interconnectedness of environmental, economic, and social dimensions to empower learners in driving holistic sustainability solutions. This nuanced understanding not only enriches the discourse on sustainable environmental education but also offers valuable insights for refining educational strategies to meet the diverse and evolving needs of learners in navigating complex global challenges (Hallinger & Wang, 2020; Rossano et al., 2018).

4.5 Pedagogical approaches and their effectiveness

The pedagogical approaches employed in serious games for sustainable environmental education were explicitly mentioned and described in only 15 of the reviewed articles (Table 3). These approaches include behaviorism, cognitivism, constructivism, humanism, and connectivism, utilizing mechanisms such as role-playing, adaptive learning, feedback, reflection, and problem-based learning. However, the actual learning effectiveness of these methods is not frequently assessed across the reviewed studies. Several pedagogical approaches are employed in SGs for sustainable environmental education (Table 3). These approaches aim to enhance learning outcomes and engage players effectively in understanding and adopting sustainable practices.

Table 2. Summary of sustainability focus in analysed articles.

Focus taken		Number of articles
Environmental		117
	General	41
	Awareness	17
	Energy	14
	Water	12
	Resources	8
	Climate Change	7
	Behaviour	6
	Climate Change	6
	Waste	6
Economic		15
Social		6
General focus (multiple aspects of sustainability)		29
Total number		***167***

Table 3. Pedagogical approaches found in relation to SGs.

Pedagogy	Description	Source	
Behaviourism	Role-Playing	SGs often incorporate role-playing elements, allowing players to assume roles related to sustainability, such as environmental activists, policymakers, or community leaders. This approach enables players to learning-by-do, explore different perspectives and understand the complexities of sustainable decision-making.	(Bifulco et al., 2011; Gervich et al., 2016; Gustafsson et al., 2009)
Cognitivism	Adaptive Learning	Some SGs incorporate adaptive learning mechanisms, tailoring the gameplay experience based on individual players' progress and performance. Adaptive learning ensures that the content matches the learner's pace and level of understanding.	(Strada et al., 2023)
	Feedback and Reflection	SGs provide immediate feedback on players' decisions, allowing for reflection and improvement. Reflection prompts encourage players to think critically about their choices and consider alternative approaches to sustainability.	(Gao et al., 2021; Gustafsson et al., 2009; Manshoven & Gillabel, 2021)
	Simulations and Modelling	SGs use simulations to model real-world sustainability scenarios, allowing players to interact with dynamic systems. Players gain insights into the complexities of sustainability challenges and experiment with different strategies to achieve positive outcomes.	(Gervich et al., 2016)
Humanism	Experiential Learning	SGs provide a simulated environment where players can actively engage with sustainability concepts and experience the consequences of their decisions. Learning occurs through hands-on experiences and experimentation, fostering a deeper understanding of sustainability principles.	(Angel et al., 2015; Bifulco et al., 2011; Keys & Keys, 2022; Manshoven & Gillabel, 2021; Yan & Liu, 2007)
	Inquiry-Based Learning	SGs often encourage players to ask questions, seek information, and investigate sustainability topics independently. This approach fosters a sense of curiosity and self-directed learning.	(Pisithpunth et al., 2014)
	Scenario-Based Learning	Games use scenarios that mimic real-world situations to contextualize sustainability concepts. Players navigate through these scenarios, making decisions and observing the consequences, which enhances their ability to apply sustainability principles in various situations.	(Angel et al., 2015)
	Narrative-Based Learning	Incorporating engaging narratives in SGs helps contextualize sustainability concepts and creates a storyline that motivates players to explore and learn. Narratives enhance the emotional and experiential aspects of learning.	(Feltrero et al., 2023; Yan & Liu, 2007)
Constructivism	Connectivism	SGs often embrace connectivism, allowing players to construct their knowledge by actively participating in the learning process, including learning that lies outside the learner, in social networks and technological tools. Players learn by making decisions, solving problems, and adapting their understanding based on the outcomes of their actions within the game.	(Bifulco et al., 2011; Feltrero et al., 2023; Michelin et al., 2006; Yan & Liu, 2007)
	Problem-Based Learning	Sustainability-focused SGs often present players with real-world problems related to environmental, social, or economic sustainability. Players are challenged to analyse	(Behrendt et al., 2021; Nafidiah et al., 2023; Saitua-Iribar et al., 2020; Yan & Liu, 2007)

(*Continued*)

Table 3. Continued.

Pedagogy	Description	Source	
		and solve these problems, promoting critical thinking and problem-solving skills.	
	Collaborative Learning	Multiplayer and collaborative features within SGs promote teamwork and collective problem-solving. Players work together to achieve sustainability goals, emphasizing the importance of collaboration in addressing complex global challenges.	(Hedin et al., 2017; Manshoven & Gillabel, 2021; Saitua-Iribar et al., 2020; Yan & Liu, 2007)

Gervich et al. (2016): This study found that games using simulation and feedback mechanisms improved understanding of hazardous pollution. Feedback loops allowed players to correct mistakes in real-time, enhancing retention of complex environmental concepts. Weijs et al. (2016): This study found limited cognitive learning outcomes from simulation games focusing on sustainability competences. The findings suggest that while games engage learners, knowledge transfer depends on the integration of experiential learning into gameplay.

There are notable differences in learning outcomes between games that employ pedagogical strategies and those that do not:

– Games using adaptive learning and feedback mechanisms, such as those reviewed by Strada et al. (2023), demonstrated higher engagement and knowledge retention than games lacking these features.
– Experiential learning games that focus on problem-solving, like those studied by Behrendt et al. (2021), produced positive learning outcomes even without explicitly applying pedagogical frameworks.

Connectivism is a pedagogy for the digital age which includes learning that lies outside the learner. However, it seems that integrating behaviourism, cognitivism, humanism, and constructivism into SGs for sustainable environmental education strive to create engaging, effective, and efficient learning experiences that inspire players to adopt sustainable practices in their everyday lives.

These methodologies pedagogies include problem-based learning, experiential learning, collaborative workshops, and gamification experiences. Each approach is tailored to engage learners actively and cater to different learning styles, showcasing the adaptability of SGs in promoting sustainable environmental education. Several articles emphasize active learning engagement, encouraging participants to immerse themselves in the learning process through experimentation, feedback, and interactive gameplay. This approach enhances engagement and facilitates deeper knowledge retention and application among learners.

Interdisciplinary perspectives are evident in the pedagogical strategies pedagogies employed, drawing insights from fields such as environmental science, toxicology, business, and urban development. By integrating diverse perspectives, SGs provide a comprehensive understanding of sustainability challenges, encouraging exploration of multifaceted solutions. A common thematic focus across the articles is on promoting behaviour change towards sustainable practices. Pedagogical approaches aim to motivate players to adopt energy-saving behaviours, explore sustainability solutions, and consider the future impacts of climate change.

5. Contribution to the field

This study contributes to the growing body of literature on serious games for sustainable environmental education by offering a comprehensive synthesis of empirical studies and reviews. Unlike

previous literature that primarily focuses on the technical and practical aspects of game development (Hallinger et al., 2020; Karimov et al., 2023b; Stanitsas et al., 2019), our research provides a broader perspective by identifying key trends, gaps, and future directions in the field. Specifically, our work highlights the underutilization of immersive technologies such as AR and VR, and the limited application of theoretical frameworks in game design and evaluation. These findings offer new insights for educators, policymakers, and game developers who are interested in leveraging SGs to promote sustainability. Furthermore, by addressing the gap in research on the long-term impact of SGs on learner behavior, this study lays the foundation for future research aimed at improving the efficacy of serious games in sustainability education.

6. Conclusion

The analysis of SGs for sustainable environmental education from 2006 to 2023 reveals a significant increase in scholarly interest, indicating the recognition of interactive learning environments for addressing sustainability challenges. However, many articles lack empirical rigor and validation, highlighting the need for more robust research methodologies. The gaming landscape has evolved dynamically, embracing traditional and modern technologies to meet gamers' preferences. While a rich diversity of theoretical frameworks underpins scholarly discourse, there's limited acknowledgment of theoretical frameworks in articles, suggesting a gap in conceptual rigor and integration.

The two-stage review findings suggest practical strategies for higher education teachers to enhance sustainability education. By prioritizing empirically validated SGs interventions (Gervich et al., 2016), educators can ensure the effectiveness of their instructional approaches. Integrating established learning theories into instructional design can maximize the learning outcomes of SGs. Moreover, expanding the focus of sustainability education beyond environmental aspects to include social sustainability dimensions empowers students to address multifaceted societal challenges. Teachers should actively engage with diverse game formats (Strada et al., 2023), experimenting to create immersive learning experiences. Facilitating interdisciplinary collaboration among educators, game developers, and researchers (Feltrero et al., 2023) can lead to the creation of innovative SGs that effectively promote sustainability knowledge and action. By implementing these strategies, educators can enhance student engagement, foster critical thinking skills, and inspire meaningful action towards sustainability.

Understanding limitations is crucial; reliance on retrospective analysis introduces biases, and the focus solely on SGs for sustainable environmental education may overlook other interventions. These limitations suggest several avenues for future research. Firstly, conducting longitudinal studies to track the long-term impacts of SGs interventions on learners' knowledge, attitudes, and behaviours towards sustainability would provide valuable insights into their effectiveness over time. Secondly, expanding the scope of research to include qualitative inquiries, such as interviews or focus groups with educators and learners, can offer deeper understandings of the facilitators and barriers to implementing SGs in educational settings. Thirdly, exploring the potential of integrating diverse educational interventions, such as gamified activities or multimedia resources, alongside SGs could enhance the comprehensiveness and effectiveness of sustainability education programs. Lastly, investigating the intersectionality of sustainability issues, such as the interconnectedness between environmental, economic, and social dimensions, within SGs interventions can contribute to more holistic and nuanced approaches to sustainability education.

Acknowledgments

We would like to extend our sincere gratitude to the reviewers for their constructive and insightful feedback, which has significantly contributed to the improvement of this manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Estonian Ministry of Education and Research through the Centre of Excellence in Circular Economy for Strategic Minerals and Carbon Resources (grant number TK228).

Notes on contributors

Tarlan Ahmadov is a PhD candidate at Tallinn University of Technology, Department of Business Administration and a visiting researcher at RISE, Research Institute of Sweden. His research revolves around Small and Medium Sized Enterprises (SMEs) transitioning to Circular Economy models. He's dedicated to exploring practical solutions to sustainability challenges, aiming to bridge theory and practice. His work seeks to contribute to a more eco-friendly business landscape, understanding various stakeholders' interests and helping SMEs to navigate the transition process.

Ayaz Karimov is a doctoral researcher at the Faculty of Information Technology, and he is part of the Human and Machine-based Intelligence in Learning (Humble) research group. His focus lies in investigating online educational platforms, particularly delving into their gamification features through the implementation of data analysis algorithms. His work aims to enhance the understanding of how technology can support learning processes effectively.

Susanne Durst is a Professor of Management at Reykjavik University, Iceland as well as visiting lecturer at Halmstad University, School of Business, Innovation and Sustainability. Her research focuses on risks related to knowledge, responsible knowledge management, business development, and digital transformation in smaller entrepreneurial organizations. She aims to advance sustainable and ethical business practices in the digital age.

Mirka Saarela's research sits at the intersection of data mining, education, and machine learning, with a keen interest in explainability and fairness within algorithmic decision-making. Mirka is driven by a desire to ensure that the systems we develop are not only effective but also transparent and equitable. By exploring these themes, Mirka aims to contribute to the development of more responsible and inclusive technological solutions.

Wolfgang Gerstlberger is a professor at Tallinn University of Technology, and his interests and projects revolve around sustainable innovation, Industry 4.0, and the development of emerging technology clusters. He employ a diverse range of methodologies, including quantitative, qualitative, and mixed methods, to comprehensively investigate these topics. His work aims to uncover insights that can inform strategies for fostering sustainable development and leveraging emerging technologies for industrial advancement.

Mike Wahl is an associate professor specializing in general management. He defended his PhD from Tallinn University of Technology in 2011 and has since been actively engaged in teaching Management and Strategic Management across various levels of higher education. Since 2018, he has also held the qualification of an International Engineering Educator. Mike's research primarily centers around ownership strategies and values.

Tommi Kärkkäinen, obtained his Ph.D. in mathematical information technology from the University of Jyväskylä (JYU) in 1995. Since 2002, he has held the position of Full Professor of mathematical information technology at the Faculty of Information Technology (FIT), JYU. Currently, he leads both the Research Division and the Research Group focusing on human and machine-based intelligence in learning. Over the years, Tommi has undertaken numerous administrative roles within FIT and JYU, showcasing his dedication to both academic leadership and research excellence.

ORCID

Tarlan Ahmadov http://orcid.org/0000-0002-6010-9097
Ayaz Karimov http://orcid.org/0000-0001-8868-4408
Susanne Durst http://orcid.org/0000-0001-8469-2427
Mirka Saarela http://orcid.org/0000-0002-1559-154X
Wolfgang Gerstlberger http://orcid.org/0000-0001-6200-5737
Mike Franz Wahl http://orcid.org/0000-0002-1530-3747

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