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REVIEW ARTICLE

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Serious games for environmental education

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Abstract

Serious games are increasingly popular in multiple fields, including education and environmental engagement. We conducted a systematic review to examine the reasons for this increasing popularity, the features of successful serious games and the current trend of serious games application in environmental education. Our systematic search revealed 56 records of papers (from years 2009 to 2023) on the use of serious games for environmental education. Thirty-five were published in the recent 5 years reflecting a growing interest in this area. The games were aimed at imparting knowledge ($N = 28$), changing attitude ($N = 28$) and changing behaviour ($N = 19$). Reasons for the increased application of serious games include the raising awareness on serious games and growing investment in serious games development and research, as well as better technological access through mobile devices. Successful serious games exhibit the following features: an immersive experience, meaningful engagement, a learn-by-doing involvement, simulation of real-world environmental problems, autonomy in game decisions and the presence of a guiding host. This review also revealed two categories of digital serious games: computer games ($N = 14$) and mobile apps (N = 11), and three categories of physical games: board games ($N = 6$), card game ($N = 1$) and role-playing games ($N = 2$). The gaps include (1) the lack of in-game experience data that limits our understanding of the impacts of commercial games, (2) variation in game experience and conservation experience among participants and how this translates to the impacts of serious games, and (3) lack of understanding of how the effects of serious games with high complexities on adults learning. Serious games are increasingly being digitised and moving towards location-based games, alternate reality, augmented reality and virtual reality. These games can facilitate interaction between learners and the natural environment, and in turn strengthen environmental awareness and appreciation.

KEYWORDS

digital game, environmental education, gamification, serious games

Plain language summary

Games are increasingly used for environmental education. We conducted a review of 56 research studies on this topic and we revealed that the popularity is explained by raising awareness on games, growing investment in game development and research, as well as better technological access through mobile devices. Successful serious games exhibit the following features: immersive experience, meaningful engagement, a learn-by-doing involvement, simulation of

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real-world environmental problems, choices in game decisions and the presence of a host. Currently, we improve our understanding about the effects of commercial games, how the game and educational experience varies with socioeconomic factors and the effects of complex games on adult learning. Serious games are increasingly being digitised, providing a real-world reality online. These games enable learners to interact with the natural environment, and in turn strengthen their environmental appreciation.

1 | INTRODUCTION

1.1 | Popularity of serious games has grown

Games were primarily used for entertainment but have been applied to nonentertainment functions such as education and motivation at the workplace. These are termed as serious games. The adjective 'serious' refers to games developed for nonentertainment industries like defence, education, scientific exploration, health care, emergency management, city planning, engineering and politics (Abt, 1987). They add the elements of fun, competition, and engagement to the intended purposes such as learning in education and changing individual's behaviour to be more environmentally sustainable.

The popularity of serious games in education has grown worldwide, with an estimated market worth $5.94 billion in 2020 and a growth rate, over the last 2 years, of nearly 100% per year (Gaikwad, 2022). Additionally, 97% of all US teenagers play digital games (Lenhart et al., 2018) and 74% of teachers implement digital game-based learning (DGBL) into their lessons, enabling serious games to be highly relatable to the general population (Takeuchi & Vaala, 2014). The increasing awareness of serious games or game-based learning, growing investment by recognized companies into the industry and growing need for serious gaming on mobile are the major drivers of the increasing popularity of serious games in the Asia-Pacific region (Zhonggen, 2019). The coronavirus disease 2019 pandemic and nationwide lockdowns, as well as governments giving attention to educational gaming, are some of the factors expected to augment the adoption of serious games in the future. It is estimated that the serious games market will keep growing quickly to reach a value of $32.72 billion by 2030 (Gaikwad, 2022). This predicted economic growth reflects a future significant usage among consumers and enterprises to adopt serious games in training and development.

Other than the gaming industry, serious games are also growing rapidly in the field of academic research. There has been an exponential growth in the number of research papers published in the field, starting from one publication on serious games in Scopus in 1984 to about 950 papers in 2019. This indicates the increased interest of the research community in serious games (Irmade et al., 2021). The drive is to elucidate the benefits and cons of serious games and the mechanisms underlying the impacts of serious games. Advantages of serious games include increased motivation to do work, enhanced learning and increased social bonding among participants (Bergeron, 2008; Breuer & Bente, 2010; Ramachandran et al., 2016). Disadvantages include the possible increased levels of anxiety and aggression from playing violent games, but this effect is still under debate (Susi et al., 2007). On average, the pros of serious games outweigh the cons (Connolly et al., 2012; Girard et al., 2013), accounting for the rise in the popularity of serious games in various industries.

Similarly, the popularity of serious games in environmental education has grown. The last systematic literature review conducted in 2019 revealed that the number of published serious games about sustainable development rose from 2 during the years 1990–1995 to 26 during the period 2014–2018 (Stanitsas et al., 2019). This paper, together with an earlier review, revealed that serious games in general enhanced learning experience and cognitive ability, as well as increased engagement in learning about sustainability (Madani et al., 2017; Stanitsas et al., 2019). Nevertheless, the literature on these serious games for environmental education highlights the limitations: lack of a systematic approach to examining the pedagogical efficacy of serious games and the presence of only a few studies investigating

Practitioner points

- We conducted a review of the topic 'serious games for conservation education' and revealed that games are beneficial for learning and for increasing proenvironmental attitude and behaviour.
- These outcomes are due to the immersion, meaningful engagement, learn-by-doing involvement, simulation of real-world environmental problems, autonomy in game decisions and the presence of a guiding host.
- Games are increasingly being digitised and this facilitates learners interacting with the natural environment.

the long-term impacts of serious games (Hallinger et al., 2020; Madani et al., 2017; Stanitsas et al., 2019). Indeed, serious games have an immense potential of changing perceptions about environmental conservation and of increasing proenvironmental behaviours; these are the ultimate intended outcomes of environmental education (Morganti et al., 2017). Limitations of past studies aside, there is a need to consolidate the defining features of impactful serious games, to guide the creation of future serious games.

1.2 | Why games are popular?

Games exhibit features that tap on the basic motivators of humans, enabling the amotivated and even motivated students to have an increased drive to learn, when compared to the conventional teaching style (Juan & Chao, 2015; Madani et al., 2017). These basic motivators can be categorized in a hierarchical manner based on Maslow's framework: physiological needs, safety needs, love and belonging, esteem and self-actualization (Madani et al., 2017). Physiological needs are met with the attainment of resources in the game, whereas territoriality (like owning land) and having sufficient health feed safety needs. Interacting and perhaps bonding with others provide a sense of belonging (Vella et al., 2019). When achieving a goal in the game, the associated sense of accomplishment increases one's self-esteem (Juan & Chao, 2015). Finally, games require problem-solving or creative thinking skills to attain a goal, this fulfils the motivator of self-actualization (Madani et al., 2017). Undeniably, games capitalize on instinctive human motivation to attract people to play and sometimes replay (Chappin et al., 2017).

1.3 | What is the current technology in serious game?

As outlined by Prensky (2001), DGBL is a particular type of game-based learning. It combines the educational content and games on computers or online to stimulate learners' interest and provide them with the opportunity for continuous learning. Interactive technology such as virtual reality could foster an effective learning process, especially among young learners (Latif, 2007). Alongside the advancement of technology in recent decades, digital games have become more accessible, portable and affordable for the masses. Digital games can take on the form of web-based apps, computer software or mobile applications.

1.4 | Aims

In this paper, we conducted a systematic search for papers that examined serious games used for environmental education. Our systematic review revealed four specific areas for a general discussion on the subject. First, we reviewed the reasons for the increased use of serious games in education. Then, we examine the appropriateness of serious games in environmental education and identify the features of the successful ones. Third, we discuss the current gaps and challenges. Finally, we examine the current trend of this topic.

Recent reviews on 'serious games for environmental education' identified the aims of the serious games, that is, what topics were they trying to teach, as well as to examine the main effects of serious games on intended educational outcomes (Boncu et al., 2022; Scurati et al., 2020; Stanitsas et al., 2019). The consolidated view from these studies is that serious games facilitate learning of environmental knowledge and encourage proenvironmental perception and behavioural change. Our study builds on this and is also unique in that it synthesizes the results of past studies to consolidate the features of successful games and provides an insight into the current trends in the creation of new games.

2 | METHODS

We searched the databases Scopus and Web of Science for the following search terms 'serious game' OR 'game-based learning' AND 'sustainability education' OR 'environmental education'. The searches were made within the articles' abstract, title, and keywords. The search was finalized on 23 November 2022. We used the following inclusion criteria: (a) the study was peer-reviewed; (b) the paper either reviewed or conducted a study of serious games on environmental education; (c) the studies were published in English.

The initial search in the databases resulted in 120 sources. After the exclusion of duplicates and the evaluation based on the inclusion criteria, we had 56 records (Figure 1).

3 | RESULTS AND INTERPRETATION

Table 1 shows the 56 records and summarizes the aims and results of each paper. These records consisted of 45 empirical studies and 11 reviews. There is an increasing number of papers published on this subject, with five papers in the first 5 years (2009–2013) to 35 papers in the recent 5 years (2017–2022). This might reflect an increasing interest on this topic, a message congruent with similar previous literature reviews (Boncu et al., 2022; Stanitsas et al., 2019).

Our results revealed a general research interest in whether players learn, how they learn and the changes that the serious games bring about. Most of the studies included in the review aimed at imparting knowledge ($N = 28$) and at changing attitude ($N = 28$), followed by behavioural change ($N = 19$). The variety of games, type of audience and learning styles make this a complex subject whereby the effects of playing games may be variable. In general, the literature paints a positive light on serious games in environmental

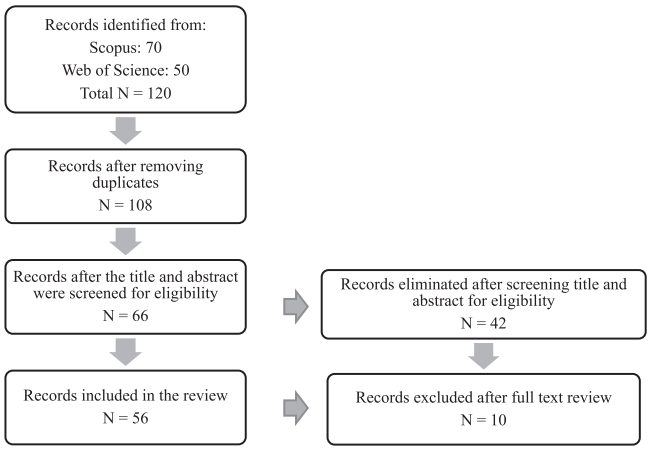

FIGURE 1 Flowchart detailing article search, article screening, data inclusions and data exclusions.

education. Benefits include increased learning (e.g., Robertson, 2022), increased interest in sustainability (e.g., Juan & Chao, 2015), enhanced conservation awareness (e.g., Fjællingsdal & Klöckner, 2019), proenvironmental attitude (e.g., Kumar et al., 2021) and proenvironmental behaviour (e.g., Marconi et al., 2018). Overall, these studies revealed the multiple benefits of using serious games in environmental education.

Fourteen papers focused on evaluating the design of the serious game. These papers discussed the use of technology, different game elements and participants' characteristics (Table 1). Based on preliminary studies, they suggested improvements to better attract and engage the players, these include improving the user interface, incorporating certain game elements and considering the learners' parameters.

A majority of the game types were computer games ($N = 14$), followed by mobile apps ($N = 11$). Physical games included board games ($N = 6$), a card game ($N = 1$) and role-playing games ($N = 2$). This indicates the popularity of using technology in game creation and testing. More recent studies (1 in Year 2018 and 3 in Year 2022) developed and tested augmented reality and virtual reality games.

Based on these findings, we identified four trending topics for subsequent discussion:

- Why are serious games increasingly being used in environmental education?
- What makes a game successful?
- What are the current gaps and challenges?
- What are the future directions in research and game development?

4 | WHY SERIOUS GAMES ARE SUITABLE FOR ENVIRONMENTAL EDUCATION

Environmental education is defined as a pedagogical process to teach individuals to understand environmental issues and to take action to improve the environment. It is a multidisciplinary field that involves disciplines such as biology, chemistry, physics, ecology, earth science, atmospheric science, mathematics and geography.

As described by the United States Environmental Protection Agency, the intended outcomes of environmental education are:

> Awareness and sensitivity to the environment and environmental challenges.
>
> Knowledge and understanding of the environment and environmental challenges.
>
> Attitudes of concern for the environment and motivation to improve or maintain environmental quality.
>
> Skills to identify and help resolve environmental challenges.
>
> Participation in activities that lead to the resolution of environmental challenges (United States Environmental Protection Agency, 2012).

Serious games can cater to these intended outcomes, in particular, to impart environmental knowledge (e.g., Juan & Chao, 2015), to teach skills to identify and solve challenges (e.g., Koenigstein et al., 2020), to create a sense of conservation awareness (e.g., Terton & White, 2014), to increase concern for the environment (e.g., Henriques & Fernandes, 2020) and finally to inspire proenvironmental actions (e.g., Chiang, 2021). It is believed that environmental education should start at an earlier age as nurturing a harmonious relationship with nature needs to happen during the early development phase of a child to ensure a lasting impact of environmental appreciation (Crohn & Birnbaum, 2010). As such, games are particularly adept at creating an environment where children can learn while having fun (Wang et al., 2019). Indeed, our results have shown that games have been gaining a lot more interest among educators and learners recently and that games can be used as creative and interactive approaches to educate on environmental issues by tapping on intrinsic and extrinsic motivators.

4.1 | Serious games can motivate intrinsically and extrinsically

Learners range in their levels of motivation for learning, and serious games can cater to this range of motivation. On one end of the scale, there is the amotivated, which refers to people who lack the drive to do something. Then comes extrinsic motivation, which refers to doing something because it leads to a separable outcome, and finally on the other end of the scale intrinsic motivation, which refers to doing something because it is inherently interesting or enjoyable (Deci et al., 2001). For the amotivated, serious games appeal to the basic human motivators and can increase motivation through extrinsic means like the rewards and points incorporated in games (Sealover & Henderson, 2005). For those who are extrinsically motivated by things such as grades and job

TABLE 1 Results of systematic search.

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
Edited by Dr Melanie Cussi Ciussi (2018)	NA	Serious games	Showcase game-based learning research.	115 papers	NA	Knowledge, attitude and behaviour	Review
Adanali (2021)	Geogames	Mobile application	Question how Geogames can support geographical education.	9 games	These games can be used in the teaching of physical and human geography topics.	Knowledge	Empirical
Ambarwati and Ardi (2019)	No name	Computer game	Develop a preliminary model for waste electrical and electronic equipment. Management serious simulation game to educate the stakeholder.	No testing on thepopulation involved	Preliminary model developed in this research will include the conceptual model of the WEEE management system under study, the input, action and output of the stakeholders, as well as the information flow between them.	Behaviour	Empirical
Arnold and Jantke (2022)	The Flying Classroom—Time travel exploratory games	Computer game	Deploy artificial intelligence techniques for the design of digital games aiming at affective and effective education.	No testing on the population involved	Advocate digital storyboarding as a methodology of truly dovetailed pedagogical and game design.	Game design	Empirical
Boncu et al. (2022)	NA	Serious games and mobile apps	Verify which proenvironmental information, attitudes and behaviors are targeted by serious games and gamified apps, how their efficiency is tested and the main results.	29 studies	Most of the studies included in the present review focused mainly on proenvironmental behavior change $N = 14$, followed by studies addressing proenvironmental information or knowledge $N = 9$ and attitude development $N = 6$.	Knowledge, attitude and behaviour	Review
Busch et al. (2015)	NA	Serious games	Explore relevant dimensions for personalization, the effect of personalization, models for personalization, design practices, the differences and communalities between personalization, customization, adaption and tailoring, guidelines, case studies of personalized serious games and gamified systems and market-relevant considerations.	Sample size not mentioned. Academic and industrial audiences from a diverse range of backgrounds and roles, such as research, product development, engineering, design and marketing	No results mentioned	Design	Review

(Continues)

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
Chappin et al. (2017)	Settles of Catan Catan: Oil Springs	Board game	Explore the effectiveness of serious games or sustainability education to a potential large outreach by using an existing extension to a popular board game, Settlers of Catan.	35 participants—Workshop	Six educational mechanisms were identified, which are believed to drive learning in the game. Four of these six are identified as the drivers behind players' strategies and overall game dynamics being: competition, managing the commons, learning from disasters and free-riding the commons.	Attitude and behaviour	Empirical
Cheah et al. (2013)	LifeTree	Mobile application	Presents an approach to use an interactive mobile game to teach about sustainability issues.	20 volunteers	Initial user testing indicated that the mobile game is found to be interesting and relevant to the learning of environmental issues that challenge the world today.	Attitude	Empirical
Cheng et al. (2013)	No name	Online game	Investigate elementary school students' acceptance of technology applying digital game-based learning (DGBL) to environmental education.	32 fourth graders	The results of the present study show that a learner's gender, whether he/she is a self-taught computer user, or whether the learner had previous DGBL experience does not have a significant difference in terms of acceptance toward using the DGBL system.	Attitude	Empirical
Chiang (2021)	No name	Virtual reality	Increase students' immersion in class would generate empathy toward the natural environment and perform actual behaviors to protect it.	Junior and senior high school students 38 females, 26 males	Both male and female students presented a higher level of immersion without a significant difference as well as developed greater empathy, although the significance was higher for female students than it was for male students.	Attitude	Empirical
Coakley and Garvey (2015)	NA	Serious games	Map a range of such skills and learning to a spectrum of existing commercial and serious video game titles, across a wide range of game genre.	11 games	The use of serious games can help participants learn conventional skills and knowledge development related to sustainable development. They also help promote a shift in fundamental attitudinal dimensions by constituting a form of procedural rhetoric based on the learner	Knowledge and attitude	Review

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
					experiences of rule-governed variables related to sustainability education.		
de Barros et al. (2018)	ReadAct	Alternate Reality	Innovate teaching strategies and to provide a system that motivates players to read and to apply acquired knowledge towards actions to address social challenges within their community.	145 teachers	ReadAct games' facilities and resources motivate players to transcend their original roles as students, teachers and appointed tutors towards the role of voluntary social actors, and they also positively influence success indicators defined for reading and social activities.	Behaviour	Empirical
Despeisse (2018)	Factory Heroes	Board game	Discusses its potential in raising awareness and fostering the skills and knowledge for sustainability leadership in manufacturing.	29 participants—PhD students and researchers with the expertise in industrial sustainability	Early findings from eight pilot sessions are presented along with some of the benefits and pitfalls of gamification.	Knowledge and attitude	Empirical
Dib and Adamo-Villani (2014)	Sustainability Challenge	Computer game	Describe the development and initial evaluation of a serious game for learning sustainable building design principles and practices.	17 undergraduates in the formative study and 42 undergraduates in the summative study	Playing the game led to an increase in subjects' declarative knowledge by 22% and procedural knowledge by 37%.	Knowledge	Empirical
Fjællingsdal and Klöckner (2019)	Eco	Computer game	Examined the educational potential of the digital simulated ecosystem.	7 respondents	Viable tool for promoting some aspects of environmental consciousness about ecosystems.	Attitude	Empirical
Henriques and Fernandes (2020)	No name	Serious game versus gamified approach	Study the applicability of gamification to education and increase the awareness of children to environmental issues.	75 pax total—35 pax gamified	Game-based learning processes are able to increase children's awareness of environmental sustainability, and that gamified processes guarantee their changes in behavior and sensitivity.	Knowledge and behaviour	Empirical
Jaisli et al. (2019)	Ecoconfessional	Interactive exhibit	Increase sustainable behaviour by influencing both the desire and the ability to make sustainable decisions.	Public and private organisations at 16 venues	Valuation revealed that these goals were mostly achieved. By combining lifecycle data with gamification elements, the ecoconfessional succeeded in implementing a new	Behaviour	Empirical

(Continues)

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
					scientainment approach to environmental education, which promotes lifecycle thinking among the public.		
Janakiraman (2020)	EnerCities	Standalone 3D game	Explain the insights gathered while conducting three research studies that used DGBL in Environmental Sustainability Education.	Undergraduate students in the USA, high school in India.	DGBL is more effective in attitudinal learning because learners can test their behaviours and see the consequences of harmful behaviours immediately within the game environment.	Attitude	Empirical
Janakiraman et al. (2021)	EnerCities	Standalone 3D game	Examined the effectiveness of DGBL in producing attitudinal and behavioural changes regarding environmental sustainability and about learning experiences from a game, through a mixed methods study.	Undergraduate students	The influence of affective, behavioural and social learning on environment-related behavioural intentions for those who played the EnerCities game was significantly higher than those who played the control game after 1 week of gameplay. However, there was no significant difference in the influence of cognitive learning on behavioural intentions between the two groups.	Knowledge, attitude and behaviour	Empirical
Juan and Chao (2015)	GBGame	Board game	Game to improve education regarding sustainability and green buildings.	72 architecture students	Experimental subjects exhibited strong learning motivation towards the game process, implying that the game was both practical and entertaining and that it could stimulate players' attention and interest, as well as help them to acquire useful knowledge relating to green building, thereby yielding a high degree of satisfaction.	Knowledge and attitude	Empirical
Klisch et al. (2012)	Uncommon Scents	Online game	Investigate the knowledge gains and attitude shifts attributable to a unique online science education game.	444 middle school students	Environmental science approach used in games is an efficacious strategy for delivering both basic science content and influencing perceived harm relating to the inhalation of toxic	Knowledge	Empirical

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
					chemicals from common household products.		
Koenigstein et al. (2020)	Ocean Limited	Tabletop role-playing game	Game used to teach marine sustainability education at the high school level and above.	8 test games with students and young adults aged 14–25	Games can demonstrate and teach real-world marine sustainability issues, and could support collective learning of problem-solving capacities for social–ecological conflicts and trade-offs in ocean uses.	Knowledge	Review
Kumar et al. (2021)	City Settlers	Mixed reality—Whole room immersive simulations	Investigate how the multiplayer city management game could help learners experience and engage in rich and complex, collective world-building	10 middle school students from a summer camp, in the midwestern United States	Present cases of how game and interaction design can foster different procedural collaborations, and how City Settlers enables these procedural collaborations to represent developing understandings of a complex systems perspective on sustainable development.	Attitude and behaviour	Empirical
Lee (2013)	NA	Online games	Analyze how educational messages are communicated to players.	108 web-based educational games	Majority of games communicated environmental messages not as problems to solve and reflect upon, but as explicit values and facts to accept and memorize.	Knowledge	Review
Liang et al. (2021)		Alternate Reality	Examine the learning effect of alternate reality games and concept mapping questioning.	44 elementary school children aged from 10–12 years old	Proposed approach had a more significant effect on learning achievement, critical thinking, and learning attitude than the conventional questioning approach. However, cognitive overload negatively affected the children's learning.	Knowledge and attitude	Empirical
Lombana et al. (2022)	No name	Online game	Develop game, do usability test and assess performance.	10–14-year-old adolescents	Proposed serious game could be a viable tool to engage youth in environmental education about freshwater ecosystems.	Knowledge	Empirical
Madani et al. (2017)	NA	Serious games	Overview of game-based learning and the state of serious games for environmental management,	25 serious games	(1) The effectiveness of games is not universal for educational purposes, it depends on the design and components of each	Knowledge, attitude and behaviour	Review

(Continues)

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
			offering insight into their potential as effective tools in facilitating environmental education.		game. (2) Many studies of educational games contain methodological problems and lack quantitative results, making it difficult to assess the accuracy of the findings. (3) There is a need to investigate longitudinal studies to determine the influence, if any, on the effectiveness of games. (4) Debriefing is an important element of GBL, allowing participant's time to reflect over their experiences and understand the connections between gameplay and instructional objectives. (5) GBL can increase motivation and engagement, which has beneficial effects on learning outcomes.		
Marconi et al. (2018)	NA	Computer game	Promotes sustainable and active mobility by leveraging the daily journey to school into a collaborative educational experience.	87 pupils and 6 teachers	Positive effect in terms of children's behavioural change as well as educational value.	Knowledge and behaviour	Empirical
Morganti et al. (2017)	NA	Serious games	Provide an overview of serious games and gamification to engage individuals in proenvironmental behaviours for energy efficiency.	10 games	Serious games and gamification have been used in three different areas related to energy efficiency: environmental education, consumption awareness, and proenvironmental behaviours. Applied gaming interventions can be used in more than one of these three areas comprehensive interventions. Both serious games and gamification can foster energy-saving behaviours and vary widely in terms of the type of games and features that might be appealing and motivating.	Knowledge, attitude and behaviour	Review

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
Nunes et al. (2016)	Protecting the Earth	Mobile game	Assess the proposed tool's interface.	10 children 7–10 years	Need for adjustments in the interface to achieve greater accessibility and user satisfaction.	Design	Empirical
Orduña Alegría et al. (2020)	MAHIZ	Board game	Evaluated MAHIZ as (1) an innovative science communication and sustainability education approach and (2) a data collection method to inform sociohydrological theory and models.	35 recorded game sessions	MAHIZ is an effective education tool about the tragedy of commons in agrohydrology and was able to identify important decision-making processes and associations between critical social parameters and the evolution of collective action.	Behaviour	Empirical
Ou et al. (2021)	Taipei tree frog	Virtual reality	Investigate students' learning effectiveness and the senses of presence and anxiety after using the virtual ecological environment.	40 in control and 40 in experimental	Design of role-playing game can enhance learners' interest and motivation.	Attitude	Empirical
Priyadarshini et al. (2021)	Carbon Warrior	Mobile app	Validate the usability of game elements of Carbon Warrior.	5 students	Users appreciated the elements of the game encouraging the further extension of the work.	Attitude and design	Empirical
Robertson (2022)	Hydrologic Cycle Game	Board game	Examine effects of game on learning.	115 students	Scores increased significantly $p < 0.05$ after gameplay with a large effect size $d > 0.8$, and learning gains persisted through mid-semester evaluations.	Knowledge	Empirical
Rossano et al. (2017)	SeAdventure	Serious game	Presents a serious game addressed to primary school pupils aimed at transferring knowledge about marine litter and four species of Mediterranean Sea that are estimated to be at risk of extinction.	46 fourth-grade pupils	Pilot study revealed that students and teachers appreciated the approach, and the preliminary data gave good results also in the students' perception of usefulness and satisfaction.	Attitude and design	Empirical
Sajjadi et al. (2022)	CZ Investigator	Computer game	Whether teaching the public about the "critical zone"—the Earth's outer skin, critical to all life—via a digital serious game can affect adults' systems thinking about the environment and support	152 persons	The serious game, relative to the static website, increased perceptions of the strength of interconnections across food, energy, and water systems p <0.01 and support for policies that regulated human impacts on the environment.	Attitude	Empirical

(Continues)

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
			policies to protect the environment.				
Sanchez Burbano et al. (2018)	NA	Serious games	An exploration of serious games focused on environmental issues as well as identifying some of its features and opportunities for improvement.	No sample size mentioned	Elements that will be useful when developing technological tools such as initiatives and innovations in environmental education are presented.	Design	Review
Schaal et al. (2018)	FindeVielfalt Simulation	Mobile app	Examine the predictive potential of game-related enjoyment and of personal prerequisites such as general ecological behaviour on outcomes measuring the acquisition of knowledge and attitude.	206 German grammar school students	Every player within the game was able to learn irrespective of personal prerequisites or game enjoyment. However, the results also demonstrate that an increase in attitude towards nature is significantly influenced by game-related enjoyment and general ecological behaviour, with game-related enjoyment being the stronger predictor.	Knowledge and attitude	Empirical
Schneider and Schaal (2018)	No name	Mobile app	Assess if smartphone games are suitable to foster connectedness to nature and if there are differences between a complex Geogame and a less-demanding treasure hunt.	339 secondary school students from Germany	A significant increase in the inclusion of nature in self for both game formats, with the strongest effect for the former more nature-distant subjects.	Attitude	Empirical
Schneider et al. (2017)	No name	Mobile app	Address the design problem of integrating a simulation into the game mechanic of a Geogame that supports learning in the field of Environmental Education.	264 secondary school children	Showed that the simplified simulation is still playable and positively contributes to the gameplay.	Design	Empirical
Schulze et al. (2015)	LandYOUs	Computer game	Present an educational game, which aims at illustrating options for sustainable land management to the interested public, students and stakeholders.	352 plays	Showed that the game is a valuable tool in environmental education initiating learning the complexity of feedbacks in land use and resources appropriation.	Knowledge	Empirical

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
Scurati et al. (2020)	NA	Serious games	A systematic mapping of the use of games on sustainability for companies and organizations.	65 publications	Showed current trends and voids in research concerning a series of categories and provide insights on possible future directions in this area.	Design	Review
Segoni (2022)	No name	Role-playing game	Test a role-playing game in which students acted as typical characters involved in a simulated public debate concerning the possible development of a geothermal plant in a rural environment.	16 persons	The students reported that: (i) they had fun; (ii) they put into practice some theoretical concepts learned during the lessons; (iii) they understood that aspects other than technical ones can be involved in decision processes and dealing with them without proper preparation is very difficult.	Knowledge and behaviour	Empirical
Seppelt et al. (2014)	LandYOUs	Online game	We present LandYOUs: an educational online game, which aims at explaining and illustrating various options and feedbacks on sustainable land management SLM to the interested public, students and stakeholders.	352 plays	Game has a potential to be used for educational purposes, environmental planning or stakeholder meetings.	Design	Empirical
Stanitsas et al. (2019)	NA	Serious games	Focuses on serious games, and how users can increase their understanding of sustainability issues and their familiarity with sustainable development strategies.	77 games	Showed the growing number of serious games that seek to educate in sustainability and the categorization of these games according to the triple-bottom line of sustainability, giving clarification hints to users wishing to select the relevant tool that offers an understanding of specific sustainability issues. Limitations in their effectiveness are also identified and a research agenda for new, relevant serious games is proposed that will enhance holistic knowledge and make it easier to clarify their pedagogical basis.	Knowledge, attitude and behaviour	Review

(Continues)

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
Terton and White (2014)	Jumping the Fence	Computer game	Discusses the development of a computer-based educational game, which challenges children to interact with the natural environment through physical exploration and experimentation.	37 primary school kids	Game requires children to reflect critically on their computer use, become more physically active, gain social skills and develop an affinity towards nature.	Knowledge, attitude and behaviour	Empirical
Thomas-Walters and Veríssimo (2022)	Save the purple frog	Mobile app	First cross-cultural evaluation of an environmental mobile game, Save The Purple Frog.	422 participants	Save The Purple Frog had a positive impact on learning effect size 0.62, $p = 0.0001$, but no evidence that it affected behaviors or attitudes.	Knowledge	Empirical
Tragazikis and Meimaris (2009)	COTS (Commercial off-the-shelf games for learning)	Computer game	Focuses on the use of a commercial game, COTS, as a main motivating and educational tool, to make kids of 11 years old aware of the relationship, between everyday actions and activities with emissions.	32 students	A satisfactory level of modified behaviour towards the concept of sustainability is achieved by changing attitudes and taking actions.	Attitude and behaviour	Empirical
Väljataga and Mettis (2018)	No name	Mobile app	Presents an attempt to design and develop a web-based application for the zoos in the Central Baltic region to support zoo visitors' engagement in learning and to provide smart learning experiences through creating and playing games in the zoos with a personal mobile device.	26 students from K-12, 12 students from formal higher education	Demonstrated that aiming to transform the zoos into smart learning ecosystems through the technological solution requires reconceptualization of 'smart' and identification of the most adequate factors that determine the smartness of a zoo to avoid technodeterministic learning experiences.	Design	Empirical
Vasconcelos and Seingyai (2022)	No name	Card game	Present the planning for a sustainable development simulation game, developed to stimulate creativity and dialogue to achieve sustainable development goals (SDGs).	56 students	Appeared to enhance the ability of the participants to articulate different aspects of sustainability in hypothetical applied scenarios, while stimulating innovative attitudes and critical evaluation based on social interactions.	Knowledge, attitude and behaviour	Empirical

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
Verutes and Rosenthal (2014)	Tradeoff!	Board game	Tested the effect of game-based learning for educating people about ecosystem services and valuation.	More than 1000 participants	Developed a set of learning principles for educational ecosystem service games.	Design	Empirical
C. H. Wang et al. (2019)	Counter-attack of urban heat island	Computer game	Design a digital game that imparts the concept of urban heat island effects to aid in environmental education.	209 sixth graders	Heavy gamers are less interested in serious games; they exhibit shorter periods of concentration and lower levels of immersion. If an individual exhibits a high level of fluency in the dimensions of challenge, player skills, control, and clear goals, then they are able to acquire knowledge through message involvement when gaming.	Knowledge	Empirical
K. Wang et al. (2021)	PEAR	Mobile app	Conducted a study with participants who played the game, gauging their knowledge of and attitudes towards climate change issues before and after playing the game.	85 participants	Game significantly improved participants' knowledge on sustainability and climate-change-related issues, and significantly improved their attitudes towards these topics, thus proving that serious games have the potential to impart knowledge and promote sustainable behaviours.	Knowledge and attitude	Empirical
T.-L. Wang and Tseng (2014)	No name	Mobile app	Propose a model	NA	A causal model is proposed by combining motivation theory, flow theory and cognitive load theory and is empirically evaluated to investigate how learner characteristics skill, challenge, incentives and cognitive load and attitudes playfulness influence learning outcome by playing a serious game.	Design	Empirical
X.-M. Wang et al. (2022)	Waste sorting	Computer game	Proposed a two-tier testing-based digital gaming approach.	32 students in the experimental group 17 boys and 15 girls and 35 in the control group 19 boys and 16 girls.	Digital game-based learning with two-tier testing model was conducive to students' improved academic performance compared with the	Design	Empirical

(Continues)

TABLE 1 (Continued)

Authors	Name of game/app	Type	Aim	Population	Results	How games impact learning	Type of paper
					conventional digital game-based learning model, especially for students in the low-level group, who were able to make greater progress. The approach was effective in terms of reducing students' cognitive load and improving their flow experience.		
Xu et al. (2017)	Makahiki	Computer and mobile game	Present Makahiki as a serious game.	NA	Successful implementation of six sustainability educational games.	Design, knowledge, attitude and behaviour	Empirical

Note: Fifty-six records are included based on the inclusion/exclusion criteria.

opportunities, the enjoyment while playing can transform the motivation into an intrinsic one (Deen & Schouten, 2011; Drummond et al., 2017). For the already intrinsically motivated, games provide rewards that can shift the motivation to an extrinsic one, which might in turn decrease the enjoyment in learning (Deci et al., 2001). Nevertheless, games play upon the different motivational levels of players and can increase or decrease the enjoyment in learning.

Although knowledge has been perceived as the main goal in environmental education, it has been reported that having a high environmental knowledge alone is not enough to translate into proenvironmental actions (Boncu et al., 2022). To encourage the audience to be active advocates of environmental issues, it is important to nurture personal responsibility towards nature. One study revealed that one can be motivated to practice good environmental behaviour with the combination of immersion, empathy and personal connection to the story (Chiang, 2021). Another study revealed that a combination of knowledge, values and personal connection managed to encourage a 76%–94% increase in proenvironmental behaviour (Kaiser et al., 1999).

Enercities is a game developed with the aim of educating on environmental sustainability (Janakiraman, 2020; Janakiraman et al., 2021). Players role-play as a city planner. To win the game, players need to be able to balance environmental well-being, citizen's happiness, resource exploitation and economic growth in a mission to build a sustainable city. Mechanistically, the game extrinsically motivates players when they attain resources and finances. It also intrinsically motivates with novel situations, appealing aesthetics and challenges; these three are elements of intrinsically motivated behaviour (Deci et al., 2001).

4.2 | Complexities behind environmental issues can be illustrated using serious games

Serious games are especially appropriate for environmental education due to the complexities behind environmental issues (e.g., social responsibility and governance), and the involvement of multiple stakeholders in environmental issues (Ambarwati & Ardi, 2019). Given that there are multiple considerations such as economy, governance and availability of natural resources, decisions made in the game may require players to draw on knowledge from multiple disciplines. Serious games often simulate the real world, allowing participants to deal with environmental issues within the confines of a fail-safe environment, yet enabling the consequences of decisions to play out (Koenigstein et al., 2020; Schulze et al., 2015). The use of role-play during the game (Janakiraman et al., 2021) play can help players understand the

perspectives and the demands of different roles by playing with or against each other. As such, learning in the affective domain takes place (Janakiraman et al., 2021). Conflict might arise through the gameplay because of opposing interests, which are reflective of the real world. Consequently, in resolving conflicts, players may learn transferable skills such as communication, negotiation, and mitigation (Ambarwati & Ardi, 2019; Segoni, 2022).

For example, a game called 'The Climate Adaption' (Neset et al., 2020) was developed to educate on sustainable development, encouraging systems thinking and the creation of democratic action-oriented strategies. The game has an objective of integrating knowledge of climate adaptation with management decisions while considering other dimensions of the proposed actions such as costing, climate variabilities and conflicting multi-stakeholders' demands. The game requires the player to reduce the impact of climate change. In each mission, the players were given a few alternatives, each with different costs and consequences to decide on as a group. They would also have to consider different scenarios of climate change. The game simulates a long-term climate adaptation whereby players need to make different decisions every 10–50 years until the year 2100.

Despite the potential of serious games in conveying complex situations, there are some challenges of incorporating serious games in structured lessons within a classroom setting. As most, if not all, lessons in long-standing classroom teaching are already predetermined and structured, it can be challenging to figure out the appropriateness of this approach in a time-limited teaching session. Additionally, there is still a stigma around the utilization of games as educational tools in a conventional classroom and many educators may not be comfortable with adopting a novel approach of teaching.

4.3 | Serious games support learning in multiple cognitive dimensions

Our tabulated records demonstrate that participants learn in multiple ways when playing serious games (see 'Table 1' explained in 'Results and interpretation' section). These include knowledge increase, attitude change, behaviour change, awareness, empathy, connection with others and communication skills. Therefore, serious games can benefit learning in multiple cognitive dimensions, from the lower-order thinking skills such as remembering and understanding (e.g., Ambarwati & Ardi, 2019; Juan & Chao, 2015) to the higher-order thinking skills such as synthesis and evaluation, and these critical thinking skills would then translate to changes to emotions, attitudes and behaviours (Thomas, 2002).

Serious games in environmental education have been documented to induce systems thinking, which is the ability to understand the interrelationships between different individuals in an interconnected system (Aronson, 1996). A study was done on a group of individuals who were invited to play a simulation game named 'Red Redemption's Fate of World' featuring a 200-year period of societal and environmental impacts of global warming. This group was reported to show a higher degree of environmental systems thinking as compared to the control group (Waddington & Fennewald, 2018).

4.4 | Increase in the number of existing games modified with a green message enables the environmental message to reach out to a wider audience

In response to the increased demand for environmental education and awareness, an increasing number of existing games have been observed to include an environmental message (Tragazikis & Meimaris, 2009). Specifically, the mechanism of the game is retained and the content is altered to communicate environmental issues. In short, the game communicates environmental awareness by transforming the 'for-fun' game into a serious game aimed at raising environmental awareness.

The modification of commercial games to include a green message caters to the aim of knowledge acquisition or status quo realization. There is a focus on developing familiarity with the environmental topic (Ouariachi et al., 2019). The games mostly communicate the cause and effect of certain decisions instead of encouraging critical thinking in providing solutions for the worrying decline of environmental health. Apart from that, the games sometimes leave out other important dimensions such as social and economic factors, which should be incorporated to ensure that a holistic intervention is implemented to tackle complex environmental issues (Ouariachi et al., 2019).

An example of this is the Monopoly Go Green edition. The game still revolves around buying, selling, and trading property and the green twist made is the additional option of making the property more environmentally friendly with solar and wind energy (Vincent, 2021). The mechanism of the game remains the same as that of the original Monopoly game: a higher investment in property will increase its value. There is no clear communication on how this green option is beneficial to nature. The end goal of the game is still about monopolizing all available property and becoming the richest player.

Digital open-world and sandbox games are highly adaptable to be redesigned as serious games as the mechanics are more fluid and customizable. An example of this is Minecraft, which is a pixelated, procedurally generated three-dimensional virtual world developed by Mojang studio, and Minecraft has been modified to encourage people's interest in environmental issues.

The developer is taking a serious effort to transform the commercially designed video game into an educational tool. In 2016, they announced a classroom-friendly version of Minecraft known as Minecraft: education edition. Academic institutions are encouraged to create educational content in the Minecraft education library and all educational contents are made available with the purchase of educational licences. In contrast, the commercial Minecraft requires multiple in-game microtransactions to obtain more in-game content (van Berlo et al., 2016).

In response to the availability of the education-tailored version of Minecraft, there has been a rise in the number of environmental education content created by institutions (*United for Wildlife - Minecraft - We Are The Rangers*, n.d.) and environmental NGOs (*Minecraft*, n.d.) in the Minecraft library. For instance, in 2018, the Zoological Society of London together with the Royal Foundation collaborated with Minecraft under the United for Wildlife initiative to create five new adventure worlds in Minecraft named 'We Are The Rangers'. The world was developed with the setting of African Savannah where players can role-play as wildlife rangers to help save endangered species. They do this by collecting elephant faecal matter for DNA coding, working with communities to mitigate human–elephant conflicts and saving pangolins from wildlife trades. A total of 113,000 players were reported to take part when the pack was launched, and this pack is still popular to this date in Minecraft: Education Edition (*United for Wildlife - Minecraft - We Are The Rangers*, n.d.).

Aside from developing educational content in Minecraft: Education Edition, Minecraft started to bring in serious games into the commercial version (Java edition and Bedrock Edition) in late 2018. By partnering with World Wildlife Fund for Nature (WWF), the developer introduced pandas in the global update of all Minecraft editions to raise awareness on this species and its conservation (Pandas and more now on Minecraft Bedrock, Stone, 2018). The global update invited players from all over the world to plant bamboo and build panda habitats within the game and this communicated the importance of habitat conservation for the survival of this vulnerable species. The commercial Minecraft not only took up the challenge of incorporating serious games, the developer donated $100,000 to WWF's global conservation work after players had placed 10 million bamboo blocks in-game. A year later, Minecraft introduced bees in its global update to raise awareness on the important roles of bees as pollinators, which is vital for a healthy ecosystem. Indeed, the incorporation of an environmental message in an existing popular gaming platform can facilitate the dissemination of environmental awareness. In the year 2021, the number of monthly active users of Minecraft is 93 million (Curry, 2022), suggesting the potential of reaching out to a large audience base.

5 | FEATURES OF SUCCESSFUL GAMES

5.1 | Immersive experience

Most serious games incorporate a back story, an epic quest and roleplay activities to engage the players (Naul & Liu, 2020). These elements encourage players to focus on the game by engaging with the players' emotion and cognition (Lai & Yang, 2015). This deep connection with the game activities often results in an immersion effect, which is also known as flow experience (Wang et al., 2019). Flow experience is explained by Flow Theory as a state of full focus and attention given to the present moment. During the flow experience, other irrelevant emotions, sensations and thoughts are blocked, resulting in optimum concentration and performance (Csikszentmihalyi, 1988).

The usage of technology such as virtual reality or mixed reality in serious games can increase the immersion and enable the message of environmental education to be conveyed effectively. Immersive experiences encountered during serious gaming sessions facilitate effective learning of procedural and descriptive knowledge (Wang et al., 2019).

5.2 | Meaningful engagement

Serious games in multiplayer mode encourage interactions and engagement among players (Garneli et al., 2021). Positive engagement during gaming sessions carves out an easy path for the students to achieve the learning objectives (García-Bárcena & García-Crespo, 2007; Vasiliou & Economides, 2007). This is because games nudge the players to either play with or against other players/colearners resulting in meaningful engagement such as thoughtful discussions on complex conservation issues (Neset et al., 2020).

The engagement among players allows peer-to-peer and collective learning (Koenigstein et al., 2020), beneficial to the teaching and learning process. As some serious games were designed to allow dialogues on complex environmental issues, innovative attitudes and critical thinking within these social settings might also be encouraged through these in-game dialogues and debates (Vasconcelos & Seingyai, 2022).

5.3 | Learning by doing

Environmental issues generally require hands-on actions and interventions. Serious games enable participants to experience the process, conduct actions and strategize, all of which are often limited during didactic conventional teaching. This process facilitated by serious games is also known as learning by doing, and has been observed to

enhance the knowledge acquisition process among learners (Thirouard et al., 2015). Hands-on learning also helps the memory consolidation process, which benefits long knowledge retention (Ninaus et al., 2015) for players. Practical movements also can transform the experience of procedural and descriptive knowledge into concrete learning (Wang et al., 2019).

5.4 | Simulation of real-world environmental problems

Serious environmental games designed to simulate real-world environmental problems encourage higher-order thinking, specifically during the creation of problem-solving strategies (Gros, 2007). Real-world simulations in serious games allow the participant to see, plan, implement and strategize without the fear of making mistakes or of failing (Rumore et al., 2016). This also encourages systemic thinking. With systemic thinking, the learners can understand that their presence and actions are 'a part of the bigger picture' and can hence be motivated to be part of the transformational unit of the ecosystem (Dieleman & Huisingh, 2006).

Apart from the complex real-world simulation in serious games, technology such as virtual reality has enabled the simulation of impossible real-world environments (e.g., organs in the human body, ocean exploration) (Chiang, 2021). All these simulations benefit the learning experience in a positive manner making serious games outstanding learning tools.

5.5 | Autonomy in decisions

Autonomy is a personal perception on the ownership of choice held by an individual when making a decision (Mandigo et al., 2008). Autonomy in serious games can be as simple as deciding on aesthetic looks of chosen characters and game tokens built (Leventhal, 2018) or as complex as deciding next actions and consequences (Chik, 2014).

Elements of autonomy in serious games empower the learners to take ownership of their decisions and hence to stay engaged during the learning sessions (Wouters et al., 2013). As serious games allow multiple paths to achieve the aim, low-achiever learners have been observed to be able to keep up with the high achievers by embarking on alternative paths to win the game (Cheng et al., 2013). The ownership of decision and multiple mastery paths give rise to autonomy, which contributes to the success of serious games in environmental education.

5.6 | Hosting by moderator

The presence of a moderator has been reported to be another key feature of successful games as the guidance provided throughout the process helped the audience to relate better to the environmental message delivered by the serious games (Taylor, 2014). Additionally, the debriefing at the end plays an important role. The conclusion of the experience by the moderator, as well as the self-reflection by participants, contributes to the learning (Crookall, 2014). Successful moderation through guidance and debriefing contributes to the participants' learning experience and hence is a factor in successful serious games.

6 | GAPS AND CHALLENGES

There are a few important gaps in our understanding of the impacts of serious games. First, the impact of some serious games developed for the public is not fully understood because the games were made for public access and the learning analytic data on the effectiveness of these games may not be easily retrievable (Trampas, 2017).

Additionally, some serious games were built on complex real-world sandbox platforms such as Minecraft and Roblox, which made in-game data hardly accessible, except for data set of players from gameplay recordings (Guss et al., 2019). Currently, the impact of serious games is only reported in controlled situations in which the gaming sessions are accompanied by hosted training (Ampatzidou et al., 2018). Pre- and postsurveys are widely used to assess the effectiveness of serious games, in particular, only through sessions that are hosted. As such, we know little about the effects of serious games during nonhosted sessions. Additionally, responses gathered from pre- and postsurveys on controlled hosted gaming sessions might also be confounded by the quality of the training and competency of the moderator or the host (Roukouni et al., 2020).

A prior knowledge of environmental issues together with the ability to navigate the game might also affect the experience of the audience (Cheng et al., 2013). This might skew our understanding of the effectiveness of serious game implementation in environmental education (Janakiraman et al., 2021). For instance, a steep learning curve might impact the enjoyment of the session, which in turn directly affects the learning experience (Ampatzidou et al., 2018; Gordon et al., 2017). Also, environmentally conscious individuals who are already intrinsically motivated towards the cause might enjoy the serious games as it is novel to them (Cugelman, 2013). Individuals who may have no prior knowledge of game mechanics or limited computer skills might find it more challenging and this might negatively impact the whole experience (Poplin, 2014). Both situations might lead to a misleading conclusion that serious games are not an effective educational tool.

Most of the serious games developed are targeted at the younger generation ranging from

early childhood learners and primary school children to high schoolers (Latif, 2007). This indicates that we might have less understanding of the effect of serious games among adults. Targeting serious games to children also introduces another challenge in which complex environmental issues need to be integrated into the curriculum to fit relevant learning outcomes while being time-effective (Neset et al., 2020). The serious games designed must strike a balance between the complexity of the issues and the students' learning capacity and additionally overcome any potential bias of the educators against games as a learning approach (Romero et al., 2015).

7 | CURRENT TRENDS

As digital games became more popular and accessible, the trend of serious digital games followed suit. Serious digital games applied in the classroom were observed to increase students' interest towards education and to engage amotivated students who were having a hard time following conventional teaching methods (Janakiraman et al., 2021). As audiences nowadays are becoming more familiar with online learning, studies have shown that the achievement of learners in understanding complex real-world events is far better when using digital games in mobile devices as compared to when using online eBook applications (Hung et al., 2014).

Digital games have evolved into more immersive technologies such as location-based games, alternate reality, augmented reality and virtual reality. Developing serious games on such technology might also benefit environmental education efforts. By bridging the imaginative digital world with real-world physical spaces, the gaming experience is immersive, which might lead to an increased connection with nature and increased proenvironmental behaviour among the audience (Ouariachi et al., 2019).

Location-based games are games played in the real world with mobile devices and the games are designed to evolve and progress according to the player's real-world location captured by the GPS function in handheld devices. The commercial for-fun game example of a location-based game is Pokémon Go, which requires the players to walk to certain real-world locations to collect points or replenish their resources (Vella et al., 2019). The utilization of this type of game might encourage the audience to visit important ecological sites to collect points, which can then encourage nature appreciation.

The alternate reality game is an interactive network narrative developed based on the real world and encourages the player to be involved in the storyline. The actions taken are happening in real time and the game is controlled by the game master who will refer to real-world situations and incorporate the consequences in the game. This kind of game, which allows players' involvement within the gameplay, might help with the long-term simulation of environmental crisis and indirectly lead to long-term learning and behavioural change. An example of a successful alternate reality game is Evoke game supported by the World Bank to help combat social and environmental issues in Africa (Freeman & Hawkins, 2017; Waddington, 2013). Players have to perform real-world actions outside the game environment. These actions include volunteering or networking with related organizations and thereafter contributing their findings online.

Augmented reality implementations in serious games can help with the visualization of complex environmental processes or features. Augmented reality has been utilized by WWF in the app named 'WWF Free Rivers', which simulates the water cycle in an immersive augmented reality to explain the flow of rivers and its benefit to the ecology and survival of the community around it (Stolyar, 2018).

Finally, virtual reality allows immersive hands-on experience to tackle environmental issues in a curated digital world. The example of a VR-integrated game is Cleanopolis VR in which the player can join the game by using a VR headset to learn about CO_2 while battling alongside Captain Clean to improve air quality in the world (Ouariachi et al., 2019).

8 | CONCLUSION

This review provides an overview of serious games used in environmental education. Undeniably, the trend of newly developed serious games has been growing alongside the number of studies on this topic. Knowledge increase, attitude change, behavioural change and game design were observed to be among the consistent theme among the papers reviewed. These research articles have their limitations, particularly the lack of a control for comparison and unstandardized measures of the impacts of the games as well as the lack of long-term monitoring of the intended educational outcomes. Herein, there are gaps in our understanding of the impact of serious games on the public, and how this might be modulated by prior knowledge and computer savviness. Understanding these gaps can provide better insight into designing future games to be more learners friendly and focused on educational aims. Key features of successful serious games in environmental education include immersion, real-world simulation, autonomy and a competent host. Indeed, newly developed games incorporate these features with the use of location-based technology, alternate reality, augmented reality and virtual reality. These technologies help bring the natural environment into the learning classroom or bring the learners to interact with nature, in turn improving our nature awareness and appreciation. This might be the way forward for the beneficial use of serious games in environmental education.

AUTHOR CONTRIBUTIONS

Cedric K. W. Tan: Investigation; supervision; writing—original draft; writing—review and editing. **Hidayah Nurul-Asna**: Investigation; writing—original draft; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no data sets were generated or analysed during the current study.

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