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Systematic Review

Game-Based Solutions and the Plastic Problem: A Systematic Review

Luca Piero Vecchio * and Alexia Del Greco

Psychology Department, Milano-Bicocca University, 20126 Milan, Italy; a.delgreco1@campus.unimib.it
* Correspondence: luca.vecchio@unimib.it

Abstract: Plastic pollution is an urgent worldwide environmental issue affecting marine, freshwater and terrestrial ecosystems. Half of the global plastic production is dedicated to items only used once: the so-defined single-use plastic (SUP) items. Different strategies have been implemented to reduce SUP consumption. Game-based solutions are an emerging strategy to favour behaviour change. The present systematic review aims at providing a synthesis of the current evidence about the use of game-based solutions to encourage sustainable behaviours concerning plastic (i.e., consumption, avoidance, waste management, pollution). Relevant studies were identified via three databases: Scopus, ProQuest and Web of Science for qualifying papers published between 2015 and 2021. Twenty-two studies that employed or designed game-based interventions to address the plastic problem were included. Results suggest that there is still little research exploring the use of game-based solutions to address the plastic issue. The studies included in this review mostly aim at changing behaviours and raising awareness towards plastic pollution among the general public. Although findings suggest that game-based intervention can be promising in terms of engagement and motivation and increasing knowledge of the issue, there is still little research focused on proving actual behaviour change, especially over time and in different settings.

Keywords: single-use plastic; sustainable consumption; plastic consumption; plastic pollution; recycling; plastic waste management; behaviour-change; game-based solution; serious game; simulator; meaningful game; teaching game; purposeful game; playful design

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1. Introduction

Plastic pollution is an environmental issue of global concern, degrading several ecosystems.

Plastic debris, in the form of both macro- and microplastic, represents a serious threat to marine, freshwater and terrestrial fauna and habitats. Moreover, due to its ingestion by organisms, plastic enters the food chain, potentially representing a health hazard for consumers as well [1].

A big source of plastic pollution is single-use plastics (SUPs), designed to be used once—yet representing 50% of total plastic production [2]. Various strategies are being implemented to address this environmental emergency, including international conventions, awareness campaigns, the production of documentaries, workshops in schools and nudge-based interventions.

This review aims to investigate the role of an innovative approach that uses game-based interventions to address serious issues, including sustainability-related behaviours.

Specifically, through a systematic review of the existing literature, we aim to explore two main themes: what game-based interventions have been implemented to tackle the plastic problem and whether they have been shown to be effective, relating to the outcomes identified by the authors, including awareness, behaviours and usability.

1.1. Plastic Pollution

Plastic is a synthetic material obtained from coal, petroleum or natural gas. Currently, its global annual production is approximately 35 kg annually for each of the 7 billion people on the planet [3].

Plastic has many advantages: it is lightweight, durable, inexpensive, tough and hydrophobic.

However, about half of the plastic produced is destined to be single-use items [4,5]: the paradox is that objects intended to be used once are made of a material that will persist from years to centuries in the natural environment [6]. Single-use plastics (SUPs) mainly include plastic bags, microbeads, throwaway cutlery, straws, water bottles, general packaging and polystyrene used for cups and food containers [4]. These items, once used, are often littered or dropped in nature. At the same time, they are also transported to landfills, polluting the surrounding natural environment and even reaching the sea through rivers, sewage systems or blown by wind [3].

Plastic pollution is damaging many ecosystems and represents a serious threat, particularly to marine environments. Approximately 60–80% of marine debris in the world's oceans is made of plastic: between 873 and 2576 tons of plastic debris are floating on the sea surface in the form of caps, spoons, sachets, paste tubes, straws, pens, plastic bits, beads, hair clips and nylon ropes [7,8].

Plastic marine pollution includes both macro-plastics (>5 mm) and microplastics (0.1 μm to <5 mm) [9]. Microplastics comprise primary microplastics (e.g., microbeads contained in cosmetic and healthcare products) and secondary microplastics deriving from macroplastics that are fragmented into small particles, often through mechanical abrasion but also due to biological and chemical degradation [5,10,11]. Microplastics have even been found in the deep sea and in the polar region.

The interaction with plastic exposes marine biota to many threats [3,11–13], such as

- Ingestion—leading to organisms suffering from reduced stomach capacity, reduced growth, infertility, internal injuries, intestinal blockage and the bioaccumulation of toxic substances.
- Entanglement in large plastic debris—leading to strangulation and reduction of mobility, thus resulting in feeding inefficiency, and, in some cases, drowning.
- Increased toxicity of the oceans due to chemical pollutants, such as hydrocarbons, dyes, and heavy metals, being rafted by plastic debris or released into the water.
- Habitat degradation due to non-native species being rafted by plastic fragments, and the physical abrasion of very delicate habitats, such as coral reefs, and reduced light penetration and oxygen exchange due to floating debris smothering the benthos.
- As a direct and indirect effect, marine plastic pollution also leads to a decline in species, thus resulting in a decline in biodiversity.

Research has revealed that plastic waste can have an equally serious impact on freshwater ecosystems [14]. Many organisms, including vertebrates and invertebrates, are at risk of ingesting microplastics. Given their crucial role in ecosystems, this phenomenon may alter important processes such as decomposition and nutrient cycling. Moreover, ingesting plastic debris can adversely affect terrestrial organisms' health and the trophic transfer to more mobile species, such as birds, could facilitate the dispersal of both the plastic and the pollutants that they carry into water basins and sediment.

Microplastics have also been found in tap water and seafood consumed by humans, including Atlantic cod, Atlantic horse mackerel, European sea bass and bivalves such as mussels, oysters and crustaceans [15]. Despite having only a little evidence available on the adverse effects, it is clear that microplastics have become a health hazard for human health, too [16,17]. Potential effects include enhanced inflammatory response and the disruption of the gut microbiome [18]. In particular, phthalates, widely used in SUP products to increase their flexibility, and bisphenol A are of great concern since they have been proven toxic in animal studies [4].

Additionally, microbes and other organisms can be transported by plastic debris, thus plastic dispersal can increase the global risk of contamination and infections [15].

Research has been investigating people's perceptions and attitudes towards plastic, given the increasing attention regarding the issue of plastic pollution. A recent Portuguese study [19] shows that people are highly aware and informed about plastic pollution and its effects on the natural environment and human health. However, despite a general awareness of the phenomenon of microplastics, plastic pollution is interestingly more commonly associated with images of macro-plastic debris floating, probably due to what the media presents. As also confirmed by Henderson and Green [20], the general public relies on the internet and tv shows rather than scientific reports to gain information about such topics. Participants in the study by Soares and colleagues (2021) [19] were, in fact, generally unaware of the presence of microplastics in most cosmetic products, and—regarding marine litter—people tend to attribute their causes to a direct release of trash into the sea, whereas, as explained before, most debris comes from land [21].

Despite the overall high concern about plastic pollution, the public has a low awareness of the available alternatives to plastic and little knowledge about their impact on organisms and the environment [19]. Such insights suggest how important it would be to raise awareness about sources and paths of plastic debris, besides discussing their effects and alternative options to plastic.

Regarding people's willingness to act to tackle the issue of plastic pollution, a review of public perception of marine litter across Europe by Hartley and colleagues (2018) [21] reveals that people seem more willing to engage in some solutions such as recycling, while they are more reluctant towards the idea of adopting other measures, such as cleaning up trash, avoiding straws, choosing items with the least plastic packaging or returning schemes. Similar findings have been shown in the UK population in a study by McNicholas and Cotton (2019) [22], whose participants report feelings of powerlessness in avoiding the purchase of plastic products, including single-use items such as plastic straws. The main barriers seem to be related to hygiene, health and social norms (i.e., social embarrassment). An important barrier could also be that individuals' perceived responsibility for the issue is limited, while governments, industry and retailers are considered the most responsible; people believe that retailers should be held more accountable through taxation rather than penalising individuals [20–22].

To summarise, limited cognition about the problem and alternatives' availability, the underestimation of personal action compared to behaviours of others, especially government and businesses, cultural practices and habits represent the main challenges to tackle plastic consumption at the individual level, underlining the importance of considering the cultural context, values, social practices and education when designing behaviour change interventions.

However, even if individuals play a pivotal role in plastic consumption and pollution, businesses also need to be targeted, as the sources of an enormous amount of plastic waste. The hospitality sector alone, e.g., hotels and restaurants, produces tons of plastic waste yearly. In this case, the main barriers to adhering to waste reduction programs have been identified as perceived high capital costs, doubts of return on investments, lack of time and too much management required and limited interest/knowledge in the issue [23].

Various pollution control measures on the sea, such as the UN Law of the Sea Convention (UNCLOS), and on land have been undertaken at national, regional and international levels to address this environmental issue. The European Commission has recently implemented measures to reduce the consumption of single-use items, including plates, cutlery, straws, balloon sticks, cotton buds, cups and other food containers as well the exclusion, from the 3 July 2021, of such products from the markets of the EU Member States. The EU directive also aims to promote the transition to a circular economy of more sustainable business models that prioritise non-toxic, re-usable products and re-use systems and promote public awareness about the issue [24].

However, plastic's durability, affordability and versatility make it very attractive for the market and reducing its use necessitates changes in the current economic system and in our everyday practices as well as strong international cooperation [25].

Furthermore, policies and bans may not be enough without educating and engaging the general population. Such effort requires not only the targeting of single consumers but also businesses and organisations.

Numerous interventions and approaches have recently been carried out in many countries with the aim of raising awareness about plastic pollution and changing people's behaviour. Some examples of interventions aiming at increasing knowledge and awareness are online courses and e-learning platforms to make information accessible from home and in developing countries [26]; these include artistic installations and workshops [27] and documentaries [28]. Some interventions targeting specific behaviours are worldwide campaigns, such as plastic-free July [29], and architectural changes in universities and public spaces [30,31].

Gamification for behaviour change represents a recent approach employed in education and health, as demonstrated by numerous studies (Koivisto and Hamari, 2019) [32].

Khodabandelou and colleagues [33] systematically reviewed all the studies that have implemented gamification in organisations to improve employee's capabilities, finding that the main outcomes of games could be grouped into business, psychological and educational. Business outcomes included, for instance, team building. Knowledge, engagement and performance are considered to be educational outcomes, whereas motivation, satisfaction, and enjoyment are psychological outcomes. Motivation and engagement are also shown to be the main functions of gamification for e-learning educational platforms, as recently reviewed by Sabri and colleagues [34] and by Khaldi and colleagues [35]. Lampropoulos and colleagues [36] and Oliveira and colleagues [37] conducted systematic literature reviews of gamification in education; the latter focused on tailored applications of gamification: overall positive behavioural, attitudinal and psychological changes were found in the reviewed studies. Aura, Hassan and Hamari (2022) [38] reviewed gamification within education with the specific aim of teaching civic education, finding a positive impact on cognitive and emotional dimensions and increasing social experiences and motivation. Increases in learners' engagement, participation and retention were found by Karsen and colleagues (2022) [39], who showed how gamification could increase the completion rate of massive open online courses (MOOC). Competence in medical education can also be enhanced by implementing game-design elements (Hamndi et al., 2022) [40]. Fu, Hu & Sundstedt (2022) [41] have shown that the increasing trend of using game-design, in particular augmented and virtual reality, could represent a promising tool for disease prevention, treatment and rehabilitation, and medical education.

Gamification within the sustainability field has also been implemented with the aim of environmental education, energy saving and biodiversity conservation [42–44]. A recent review by Miao, Saleh and Zolkepli (2022) [45] on gamification for pro-environmental behaviours showed that energy efficiency and reducing carbon emissions are the most commonly targeted behaviours. Literature about the use of game-based interventions dealing with the plastic crisis seems to be limited. Tackling plastic use and addressing its correct disposal or re-use is a set of behaviours that is difficult to operationalise and assess. It generally does not provide immediate and personal benefits to individuals. On the contrary, plastic is a material that is cheap, useful and difficult to avoid or even recognise. Therefore, exploring innovative approaches employing game elements to tackle plastic pollution may represent an innovative and promising field of research.

This paper's primary contribution is to discover current applications of game-based solutions for tackling the plastic problem among individuals and organisations and how and if these can be considered effective.

1.2. Game-Based Interventions

One of the first authors to describe the key elements that make educational games engaging was Malone (1980) [46], who identified the importance of (a) challenges of an appropriate level of difficulty whose achievement is uncertain but at the same time assuring a certain increase in the players' perceived self-efficacy; (b) a clear goal and prompt feedback; (c) a situation set in a fantasy world; and (d) an environment with an optimal level of information complexity that elicits players' curiosity. More recently, McGonigal (2011) [47] summarised the four defining traits of games as: goal, rules, a feedback system and voluntary participation. The goal, she explains, provides players with a sense of purpose; rules stimulate players' creativity and strategic thinking; and a feedback system informs players of the game's objectives and increases motivation, whereas voluntary participation makes the whole experience safe and pleasurable.

From a behaviourist perspective, in game-playing, the user's behaviour and motivation are altered by elements drawn from behavioural psychology, such as antecedents, consequences of behaviours and schedules of reinforcement [48].

From a cognitive–emotional perspective, positive emotional stimuli, such as rewards typical of gamified settings, may facilitate emotion-driven learning [49]. By eliciting specific emotions in the player, games can also promote the acquisition of knowledge and the recollection of memories and information associated with emotions within the realm of working and episodic memory. Moreover, stimuli evoking emotions can increase players' attention [49].

Gamified scenarios have been increasingly employed in many fields, especially in education, marketing, public health and customer care, with different goals, such as increasing attention and engagement, stimulating innovation, decisions making, facilitating learning processes and promoting behaviour change [48–51].

Gamification has been defined as applying game features into a non-game context to promote motivation and engagement in learning and reach behavioural outcomes [52,53]. Gamification can be of two types: structural gamification and content gamification. The former aims to motivate the learner to go through the content and engage them in the learning process through game-like elements, such as rewards and levels. In this case, the content does not change. The latter consists of applying game elements and game thinking to alter content, for instance, starting a course with a challenge instead of a list of objectives [54].

However, the original umbrella term "gamification" could be replaced by "game-based design solutions", to better cover all aspects of the game-related phenomena [55,56]. In fact, game-based solutions would include tools employed in many settings, namely playful designs, serious games and simulations [56].

Playful design refers to user interfaces that mimic those of games even though they do not contain mechanics or dynamics typical of a game.

Serious games are instead full games that have been developed for a goal other than entertainment, and these can be distinguished in:

- teaching games, when the player is taught to use something by playing a game;
- meaningful games are games employed to convey an important message and promote a potential change;
- purposeful games when, by playing, the user reaches a real-world outcome.

Simulations give players a virtual way of practising something from the real world by providing a safe environment.

These are all examples of game-thinking or game-based solutions, previously defined within the concept of "gamification".

In educational settings, research shows that gamified learning effectively causes students to reach learning achievements as learning becomes more attractive due to higher motivation and engagement. Additionally, certain game elements often employed, such as points schema, leader boards and badges, encourage peer-based feedback that, in turn, favours collaborative learning and social recognition and connection [44]. Points, leader

boards and badges are indeed the most commonly found game-elements and are shown to be effective in increasing both intrinsic and extrinsic motivation in students, especially when used in combination [57]. Games via apps and other technology-based solutions are also some of the most innovative approaches for promoting behaviour change related to sustainable consumption and pro-environmental choices. In particular, certain Sustainable Development Goals, including Responsible Consumption and Production (SDG 12) and Climate Action (SDG 13), Life Below Water and Life on Land (SDGs 13 and 14), could be specifically addressed through game-based intervention [42,43,58–60].

Our review focuses on Goal 12, Responsible Consumption and Production, whose aim is to make fundamental changes in how our societies produce and consume goods and services (United Nations, 2021) [61]. Since the plastic problem is an urgent matter that directly involves individual and organisational choices and behaviours, it could be relevant to investigate new engaging and funny approaches to tackle the problem, such as game-based interventions.

Specifically, this study explores the current literature in terms of how game-based solutions have been tailored to change single-use plastic consumption at individual and organisational levels. The main questions we explored are how game-based solutions have been employed in the literature to tackle plastic pollution caused by single-use items and whether such an approach has been found to be effective in reaching their goals.

1.3. Research Question(s)

(RQ 1) What is the current application of game-based solutions for tackling the plastic problem among individuals and organisations?

(RQ 2) Are game-based solutions effective in reducing the consumption of single-use plastic items among individuals and organisations?

2. Materials and Methods

A systematic review of the scientific literature was carried out to answer our research questions. The search and selection of studies were guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [62]. The systematic review protocol was recorded in the Open Science Foundation register (https://osf.io/79h5y, accessed on 17 September 2021).

2.1. Search and Identification of Studies

Three main inclusion criteria were considered for the research: (a) articles, including journal articles, conference papers and proceedings; (b) published in the English language; and (c) published in the last 6 years, i.e., between 2015 and 2021. After a preliminary exploration of the literature to identify the suitable terminology, we developed strings combining three groups of keywords related to the study (gamif* OR "serious game" OR technology OR app OR gam* OR virtual OR simulation OR smart OR online), to the target population (individuals OR consumer* OR retailer OR hotel OR restaurant OR school OR university OR canteen OR cafeteria OR store OR supermarket OR hospital OR office OR household OR "nursing home" OR department OR hospitality OR "food sector" OR corporation OR airport), and to the outcome (behav* OR use OR wast* OR consum* OR recycl* OR choose OR avoid* OR "reduc* plastic" OR "single use" OR disposable OR "one use" OR throwaway OR polystyrene OR styrofoam OR "plastic free").

We limited our search to specific research areas, including environmental science, business, sociology, computer science, economics, decision science, psychology and neuropsychology, education, biodiversity conservation and communication.

The systematic review was undertaken via an examination of the Web of Science, Scopus and ProQuest—specifically within ProQuest, we examined only the following databases: APA Psycinfo, Agricultural and Environmental Science Collection, Education Collection and Social Science Database.

The choice was guided by the fact that these databases are the largest ones available, and the goal of this review paper was to be as inclusive as possible of all the literature published on the subject. Moreover, our research topic could have been addressed in many different research fields, therefore our aim was to explore broad databases. Specifically, ProQuest is the largest, multidisciplinary, full-text database available in the market today. Scopus is one of the two big commercial bibliographic databases that cover scholarly literature from a vast majority of disciplines. Web of Science is the other larger bibliographic database, covering over 100 million items. We chose three databases to limit the location bias of a single, although extremely large, database.

2.2. Selection Process

All studies (n = 10,754) gathered from the above-mentioned databases through strings and keyword combinations were uploaded to the purpose-built screening platform Rayyan. Then, all the duplicates were identified and deleted (n = 1613). The remaining articles (n = 9141) were screened and assessed for relevance to the selection criteria through their titles and abstracts by two independent reviewers (LPV and ADG). Articles were then labelled "Included", "Excluded" or "Maybe". Articles coded by both reviewers as "Included" were included in the next stage of study selection. Articles coded "Excluded" by both reviewers were excluded. Those articles coded as "Maybe" by either of the reviewers proceeded to the next phase, in which reviewers discussed them and reached a consensus about whether these fell within the scope of our research. A third reviewer would have been consulted if a consensus had not been reached.

The vast majority of studies had to be excluded as irrelevant to the review's scope. Specifically, they were either research studies on plastic materials within other subjects related to chemical or mechanical properties and processes (e.g., chemistry, engineering, material science, biology), or about the application of gamification for other aims (e.g., medicine training, education, disabilities), or research studies in psychology but either on unrelated topics (e.g., gambling) or, alternatively, related to plastic but with no use of gamification (e.g., exploration of public attitudes, barriers, knowledge of single-use plastic and re-usable products). The number of appropriate articles was thus reduced to 24. Moreover, two studies were impossible to retrieve from the authors, so the final number of articles reviewed was twenty-two, two of which examine games and installations developed for the same awareness campaign [63,64] (see Figure 1).

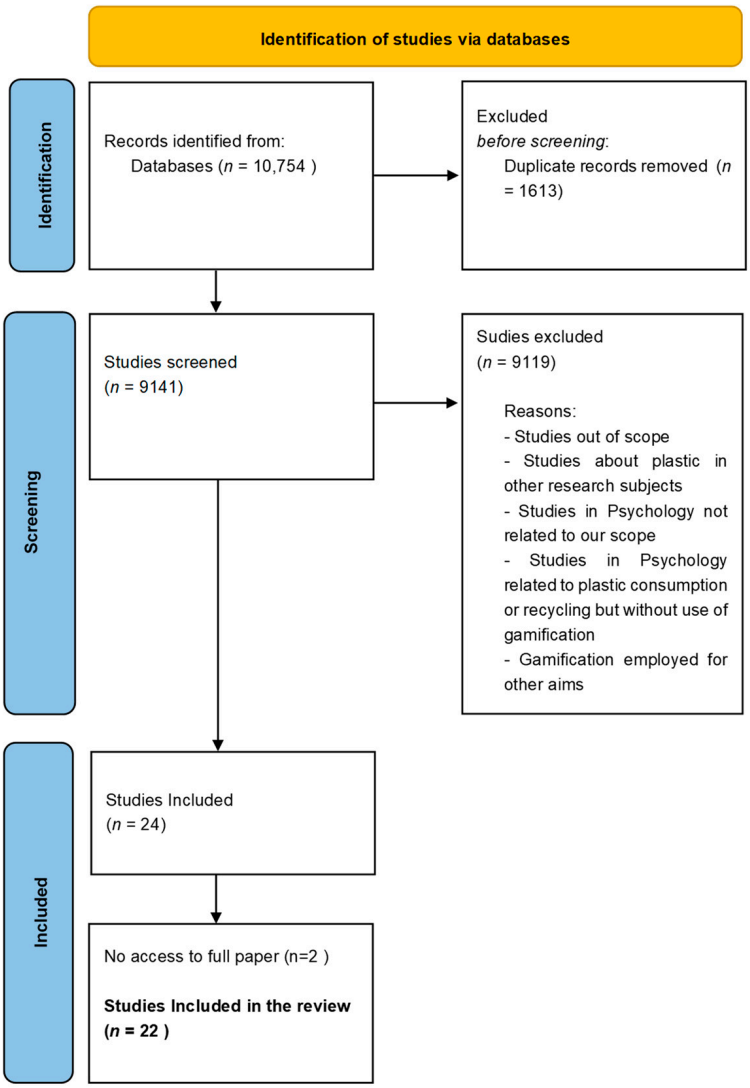

Figure 1. The number of publications included after each step. Flow chart based on the PRISMA guidelines.

3. Results

Articles were organised and analysed in a spreadsheet.

To answer our first research question, we identified some general characteristics for each of the 22 papers, such as geographical focus, target populations and how gamification was implemented, as shown in Table A1 (Appendix A). However, some papers only provided suggestions on implementing game-based interventions or analysed existent games.

To explore our second research question, we focused on the sample of the studies, the criteria employed by the authors to validate the effectiveness of the game-based interventions and the relative outcome(s) (Table A2, Appendix A).

The results are as follows.

3.1. (RQ 1) What Is the Current Application of Game-Based Solutions for Tackling the Plastic Problem among Individuals and Organisations?

The 22 papers included in the review were analysed to answer the RQ1; thus, to better understand how gamified approaches have been employed to address the plastic issue among individuals and organisations (Table A1, Appendix A).

3.1.1. Locations

First of all, most studies employing game-based interventions to tackle the plastic problem were carried out in Asia, especially Indonesia; although some studies are focussed multiple locations both within and outside Asia [65] and on different continents [66,67]. Table 1 provides a more detailed breakdown by country and shows that Asian countries (45%; n = 10) followed by European countries (32%; n = 7) are the most studied locations in terms of intervention implementation or intervention design.

Table 1. Locations of Studies.

Country/Region		Percentages	Total Percentage
Asia	Indonesia	14%	
	Singapore	9%	
	Hong Kong	9%	
	Thailand	4.5%	
	Malaysia	4.5%	
	Republic of Korea	4.5%	
	India	4.5%	
			Tot Asia 45.5%
Europe	Greece	14%	
	Germany	9%	
	Spain	4.5%	
	Denmark	4.5%	
			Tot Europe 32%
USA			14%
Africa			9%
South America			4.5%
Australia			4.5%

3.1.2. Target Populations

The majority of studies (41%; n = 9) design, analyse or implement interactive installations and serious games with the aim of engaging the general public at exhibitions, events or festivals, as shown in Table A1 (Appendix A). Nine studies (41%) design or employ games in educational settings involving primary school children or university students. One work targets both the general population and university students [67]. Two studies (9%) involve private households, and only one research work [68] aims at designing a game to improve the understanding of plastic waste management for the stakeholders involved. One study is a literature review about the role of games in engaging general users [69], whereas no studies engaging businesses or organisations were found to be included in the review. Table 2 summarises these findings, identifying the main target groups addressed in the studies, while a more specific overview is provided by Table A2 (Appendix A).

Table 2. Target Populations of Studies.

Target Population	Percentage
General Population	59%
Primary School Students	18%
University Students	23%
Plastic Management Stakeholders	4.5%

3.1.3. Game Design and Aims

In terms of how the principles of gamification have been used, as shown in Table 3, the majority of the studies designed, implemented or analysed at least one serious game (n = 20; 91%). One study did not specify the type of game to be developed [70], and one study employed a playful design in the form of a public installation [71]. The serious games analysed or implemented were mostly purposeful games (45%), meaning they aim

at achieving a result in the real world, followed by meaningful games (36%), simulators (14%) and teaching games (9%). Two studies [63,67] implement both meaningful and purposeful games.

Table 3. Gameful Solutions Employed.

Game-Based Design	Percentage
Serious Games	91%
Teaching Games	9%
Simulators	14%
Meaningful Games	36%
Purposeful Games	45%
Playful Design	4.5%
Not specified	4.5%

Many interventions have multiple aims (Table A1, Appendix A). Overall, the main objective of six studies (27%) is to raise awareness and inform about the effects of plastic pollution on the natural environment and human health, as well as to increase knowledge about possible solutions to deal with the plastic problem. Sixteen (73%) studies employ games specifically aimed at changing users' behaviours by reducing plastic consumption, teaching how to correctly sort waste and recycling or promoting cleaning-up. Table 4 synthesises these findings.

Table 4. Objectives of Studies.

Aim	Percentage
To only provide information	32%
To promote behaviour change	68%

Many studies also address multiple themes relative to plastic, however, efforts seem mostly focused on plastic end-of-life (n = 15 studies; 68%). Only seven studies (32%) address the theme of plastic reduction (Table 5).

Table 5. Focus on plastic lifecycle stage.

Theme		Percentage
End-of-life of Plastic		68%
	Pollution	45%
	Management (i.e., disposal and recycling)	50%
	Litter cleaning-up	9%
Prevention of plastic consumption		32%

More than half of the studies (n = 13; 59%) include a description of the design and development process for the games and installations. One study is a literature review aimed at identifying the most effective gamification platforms that encourage pro-environmental behaviours.

3.1.4. Game Elements

Multiple elements were employed in each study (see Table 6). The most employed element is progressing within the game given via specific challenges or levels required to pass in order to win, present in 54.5% (n = 12) of the studies. Following this, a recurring element is the presence of a ranking or score system (41% of the studies, n = 9) and badges (32%, n = 7), both allowing the participants to compete against each other and share their own achievements. Five games (23%) also provide rewards (monetary incentives, certificates or other kinds of advantages).

In 36% (n = 8) of the studies, graphic and audio elements also represent important features; this is the case for playful interactive installations in particular, where physical interaction also plays a major role (n = 5; 23%).

Table 6. Gamification Elements Employed in Studies.

Gamification Elements	Percentage
Challenges/Levels	54.5%
Ranking/Scores	41%
Audio/Visual Feedback	36%
Badges/Social Recognition	32%
Introduction/Tutorial	23%
Physical Interaction	23%
Information Delivery	23%

3.2. (RQ 2) Are Game-Based Interventions Effective in Reducing the Consumption of Single-Use Plastic Items among Individuals and Organisations?

To answer our RQ2, it was necessary to explore how game-based interventions were evaluated (Table A2, Appendix A) and, secondly, what the outcomes were; this information is summarised in Table 7.

Table 7. Outcomes assessed in the studies.

Outcome	Percentage
Awareness/knowledge	45%
Behaviours change/intention	41%
Enjoyment/engagement	41%
Usability	32%
Other psychological dimensions	18%

Most studies investigated multiple outcomes to assess the effectiveness of their gamified interventions, as they have, in fact, multiple aims.

The most common parameter researchers focus on when evaluating their game-based interventions' effectiveness is a behaviour change or at least the intention to change behaviour (n = 11; 50%). Ten studies measured an increase in (self-reported awareness, concern or knowledge related to the plastic problem before and after participation in the games or interactive playful designs (45%). Nine studies (41%) include users' engagement and enjoyment in the games' evaluation as these aspects may be considered as features able to increase people's motivation to play, as well as to learn or take practical actions. Seven studies (32%) tested games' design regarding approachability and usability. Four studies (18%) investigated attitudes or other psychological dimensions, such as self and collective efficacy or driving factors and barriers to participation in gamified activities [67,72–74], and five studies (22.7%) only described games' design, not their implementation, thus were not able to evaluate their effectiveness [66,68,70,75,76].

Once we examined what criteria were taken into account in order to establish the effectiveness of the reviewed studies, we can now consider their results.

Knowledge and awareness of the plastic problem, as well as of strategies to reduce, recycle and replace, seem to increase overall in all the studies examined. Therefore, gamification seems to be a promising educational tool within this field. One study highlights the importance of the game being played within contexts addressing environmental issues to increase participants' awareness about the plastic problem [77].

Regarding behaviours and intentions, game-based solutions seem effective in increasing participation in recycling programs, intentions to take actions to reduce plastic use and (self-reported) knowledge about how to correctly manage plastic waste. Two studies [67,78] showed limited results in increasing pro-environmental perceptions, personal responsibility and attitudes and intentions towards recycling.

In terms of engagement, game-based interventions seem promising given that all studies investigating this parameter report high enjoyment, motivation and focused attention in participants who also show high levels of social dimensions, such as collaboration and the sharing of achievements and information.

Other interesting findings suggest some conditions that are able to enhance game-based solutions' efficacy. Among these are the presence of a facilitator, peer recognition, a sense of belonging to a group and proposing tasks of medium difficulty.

Some studies include the design evaluation underlining the importance of testing games and installations to improve various aspects, including usability, aesthetic, title and the general experience.

4. Discussion

Our review highlights that the majority of studies employing game-based solutions to tackle the plastic problem have been carried out in Asia; however, our search did not retrieve any studies carried out in China. Some studies (32%) have been implemented in Europe and only a small amount in the USA. Studies conducted in Africa, South America and Australia are scarce. Regarding the targets of the studies included in our review, these are the general population, including private households, followed by students. It seems that gamified approaches for plastic management, education or reduction have not yet been designed in organisational settings.

Regarding the mentioned gamification mechanics and dynamics, we observed that studies employ a variety of elements. In particular, the most employed elements characterising gamification are challenges or levels to pass, a system of points and rankings, as well as badges or other systems to share one's own achievements with others.

The types of gamification most employed are purposeful games with a direct outcome in the real-world and meaningful games are mostly designed to increase positive intentions and behaviours, such as sorting waste correctly and recycling, and to raise awareness about plastic pollution. In fact, the majority of studies aimed at promoting behaviour change.

Overall, the majority of efforts seem directed towards the end of a plastic item's lifecycles in terms of correctly sorting plastic waste, recycling and cleaning up. However, some studies focus on preventing plastic pollution by informing and encouraging the reduction, replacement and re-use of plastic [63,64,72–74,78,79].

The main evaluation criteria of the quality of the studies are as follows: changing behavioural intentions, increase in awareness, users' enjoyment, motivation and games approachability, confirming findings by Kovisto and Hamari, 2019 [32]. Only a few studies evaluated actual user behaviour changes [67,72,73,80]. Most studies, rather than directly measuring the impact of gamification implementations through an evaluation of performed behaviours compared to a baseline, evaluated the efficacy of interventions in terms of self-reported or tested practical knowledge and intended behaviours.

This could be due to the early stage of research on this topic, which leads researchers to be more interested in designing and developing engaging and user-friendly serious games to make this new approach popular, as well as due to the difficulty of measuring pro-environmental behaviours directly.

Results are very promising regarding information conveyed through games, intentions and users' overall response in terms of the engagement, interaction and enjoyment of serious games, virtual reality experiences or installations (i.e., playful designs) [81–83].

Although a scarce number of studies focused on our research theme, several reasons emerged for choosing game-based solutions as an effective tool to convey knowledge and to change attitudes and behaviours towards the plastic problem.

Some authors underline the importance of raising awareness about the plastic issue in order to build more sustainable habits in individuals of a young age, and games can be a successful approach to reaching out to children [1,81]. Young people seem one of the most suitable targets for aiming at a change in consumption patterns and pro-environmental behaviours, also because they tend to spend much time in the natural environment, and

this has a role in building their identity [6]; games are promising to be an educational tool proved to be able to enhance knowledge and to present real-world problems while also being entertaining [14]. In fact, many studies employ gamification or virtual reality experiences and compare such approaches to traditional learning methods for their unique ability to effectively engage learners through emotions, empathy, fun, role-playing, physical play, interactivity, motivation and storytelling [2,3,5,7,9,11,12,14–19]. Games can involve people cognitively, behaviourally and emotionally [14,15].

Another feature that makes game-based solutions a promising and effective tool in the field of sustainability and thus in tackling the plastic problem is that they present complex issues with clearness [6] and provide the opportunity for players to explore different decisions and approaches to solve problems by testing multiple possible outcomes [10]. Serious games also allow us to better understand the interdisciplinarity of real-world issues and the interconnection between daily choices and consequences [11], as well as the interconnected nature of sustainability itself, which comprise environmental, social and economic dimensions [14] as opposed to monothematic and small-scale approaches [21]. Gamification can also be employed to improve the understanding of stakeholders in complex matters, such as waste management where the current system is ineffective [10], by providing a scenario based on real-life problems, actors involved and where to test decisions outcomes safely. Furthermore, games can also be a tool to investigate psychological predictors and dimensions related to plastic consumption and management [8].

The other advantages of gamified learning are its cost-effectiveness and the fact that it provides a time-compressed environment, meaning that players can see how actions interact with the environment over a short period. In contrast, in real life, such linkage would only become clear over a period of years. At the same time, players can make multiple attempts to understand an issue or behaviour without facing negative consequences [18].

Games and playful designs can also make some issues—otherwise invisible or unknown—visible, such as the microplastic problem [2]. They can become an accessible tool for those who cannot rely on a stable internet connection, as is the case for developing countries [19].

Some limitations and challenges have been highlighted as well. From our review, the first important aspect to reflect on is the little amount of evidence we were able to retrieve about the use of game-based solutions to address the plastic problem. As mentioned before, research employing gamification to solve the plastic crisis is still at a preliminary stage, especially because the problem may be particularly difficult to tackle; avoiding plastic is not always easy for private citizens due to the pervasiveness of plastic and the limited options to avoid it, unlike other sustainability-related issues, such as energy saving. Furthermore, measuring the outcomes of such interventions is difficult unless relying on self-reported data.

Hence, it is difficult to understand the actual learning or behavioural outcomes [82,83]; most studies used self-developed surveys or questionnaires, thus accurate comparisons between the results are difficult. Moreover, behaviours have mostly been measured regarding engagement with games or scores rather than actual behaviours. It is also difficult to assess the quality of the tasks performed to obtain incentives, for instance, plastic waste sorting.

Even more concerning, small samples were assessed, and not many studies with a control group or longitudinal studies have been conducted; this raises doubts about the effectiveness on a bigger scale and the degree of knowledge and awareness retained over time. The lack of validation tools and underlying theories were also highlighted by Lampropoulos and colleagues [36] and Oliveira and colleagues [37].

There is clearly a substantial need for monitoring these dimensions over time and over different settings and with bigger samples, as also suggested by Aura, Hassan and Hamari (2022) [38], related to gamification applied to teaching civic education.

One of the challenges for employing game-based solutions to tackle the plastic crisis is for teachers and educators who want to employ these strategies by acting as facilitators, as this will require new skills and approaches different from traditional teaching styles [14].

Furthermore, game-based solutions risk oversimplifying or destroying the serious message they are designed to convey; so, a well-designed game must find a balance between the medium and the content that cannot be too implicit or receive too little attention [4,5]. Additionally, concerning interactive installations (i.e., playful designs), the public's limited attention or unclear instructions can make them unsuccessful in delivering the message [5].

Presenting games outside a topic-related context can make them less effective in increasing players' knowledge [16]. Moreover, to make a game effective, content such as plot and tasks needs to be effectively designed, considering both intrinsic and extrinsic motivations as well as both short and long-term goals and motivating actions to be taken in real life [14]. Negative and positive emotions elicited by the game also need to be balanced [15].

Challenges also involve game mechanics and dynamics since levels and tasks need to be of an appropriate difficulty in order to be stimulating and fun at the same time [6,12], approachable and understandable by the target population [7,9].

Another challenge could be related to incentives provided by gamified strategies that should benefit both the individual and the change of society [21].

5. Conclusions

Plastic consumption and disposal is particularly difficult to tackle due to the overwhelming presence of plastic and its undeniable advantages. This paper aims to collect and review the current literature about using game-based solutions to tackle such issues.

Available research seems to be at an early stage; in fact, more effort is put into designing games than evaluating them following a systematic method. Our retrieved studies show great differences in methodological quality and choices concerning their content. The continents most interested in using game-based solutions are Asia and Europe. No studies have been conducted in organisational settings.

Preliminary evaluations, however, show great potential in terms of engagement and as a tool to deliver knowledge and awareness.

Recommendations for future research may include a more systematic development of game-solutions and playful designs following psychological theoretical models and their evaluations of actual behavioural outcomes in short and the long term. A need for greater samples and control groups is also suggested in order to strengthen results about how game-based solutions can affect people's awareness, intentions and behaviours. Organisations should represent a future relevant setting where game-based solutions can be tested.

Greater attention and effort should be given to plastic avoidance and the delivery of information about alternative materials and their benefits.

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Data Availability Statement: The data presented in this study is available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Overview of reviewed papers.

Reference Number	Title, Authors, Year	Country	Target Population	Aim of Intervention	Description and Elements	Info about Design Process	Game-Based Solution Implemented
[60]	Citizen-Based Litter and Marine Debris Data Collection and Mapping *(Jambeck, J. R. and Johnsen, K., 2015)*	US	General Public	To increase knowledge about plastic sources and deposition points To increase citizens' awareness of pollution To encourage cleaning up	Mobile application, database and website to collect data about debris. • Ranking Badges	Included	Serious game: purposeful game
[63]	A week without plastic bags: Creating games and interactive products for environmental awareness (*Gardeli, A., Vosinakis, S., Englezos, K., Mavroudi, D., Stratis, M., Stavrakis, M., 2018*)	Greece	General public	To reduce, replace and clean up plastic bags To increase knowledge and awareness about plastic waste consequences and management	2 Digital single-player videogames and 6 interactive public installations with practical challengesInstallations: • Rewards • Points • Ranking • Feedback (video/audio) • Interaction Computer games: • Mission • Progress • Rewards • Points Feedback (video/audio)	Included—PACT technique (analysing people, activities—actual, target behaviours, inhibitors of target behaviour, context and technologies involved) and Fogg's (2002) design process.	Serious game: • Meaningful games • Purposeful games
[64]	Design and Development of Games and Interactive Installations for Environmental Awareness (*Gardeli, A., Vosinakis, S., Englezos, K., Mavroudi, D., Stratis, M., Stavrakis, M., 2017*)	Greece	General Public	To reduce, replace and clean up plastic bags To increase knowledge and awareness about plastic waste consequences and management	2 Digital single-player videogamesand 6 interactive public installations with practical challengesInstallations: • Rewards • Points • Ranking • Feedback (video/audio) • Interaction Computer games: • Mission • Mission • Progress • Rewards • Points • Feedback (video/audio)	Included—User-driven design research based on PACT technique (analysing People, Activities—actual, target behaviours, inhibitors of target behaviour, Context and Technologies involved) and Fogg's (2002) design process	Serious game: • Meaningful games • Purposeful games

Table A1. *Cont.*

Reference Number	Title, Authors, Year	Country	Target Population	Aim of Intervention	Description and Elements	Info about Design Process	Game-Based Solution Implemented
[65]	Oceans We Make: Immersive VR Storytelling (*Thomas, A., Kumar, A., Krehel, R., Vasey, K., Khoo, E. T., Marsh, T., Li Junting, B., 2018.*)	Singapore, Thailand, US	General Public	To raise awareness about plastic waste (in the oceans) and potentially change attitudes and behaviours about plastic usage	Virtual and Augmented Reality Experience (immersive and multisensory)Objective: to collects plastic and trash, rewarding them with score. • Graphic elements • Narrative storyline • Physical interaction • Achievements, rewards • Scores • Levels of increasing difficulty	Not Included	Serious game: meaningful game
[66]	Eco champion: A transcultural educational eco game for children *(Speth, M., Müller, J., Rist, T., Seidl, J., Faschina, M., 2018)*	Morocco, Argentina and Germany	Elementary students	To increase children's knowledge, skills and cooperation about environmental problems (including waste management)	6 single-player minigames, each one addressing a specific environmental challengeGarbage Patrol (waste)Harbour Master (oil slick)River Manager (river discharge) City Major (Transport)Park ranger (fires)Saviour of the seas (Nets pollution in marine environments) • Story • Hero • Real-world scenarios • Mission Challenges and cooperation	Included	Serious game: meaningful game

Table A1. *Cont.*

Reference Number	Title, Authors, Year	Country	Target Population	Aim of Intervention	Description and Elements	Info about Design Process	Game-Based Solution Implemented
[67]	Interactive Game-Content-Based Storytelling for the Environment *(Lee, Y., and Lee, J., 2020)*	US and Korea	General Population and University Students	To raise awareness about the plastic problem Behaviour change: donations for an environmental campaign, environment-related missions	Level 1 Art as mean of storytelling: piece of art as medium to make participants donate to an environmental campaign • Emotional engagement Level 3 storytelling: serious game with quizzes, levels (rooms), storyline not pre-determined mission (to prevent environmental disaster) • Quizzes • Challenges and Achievements • Interactive world • Different possible outcomes Level 5 Social aspects storytelling: an environmental mission unique experience, unique storyline, e.g., #trashtag challenge, forest stay focused application • Mission • Planning for the mission left to each player (uncertain scenario) • Social recognition	Not Included	Serious game: • meaningful game • purposeful game
[68]	Serious Simulation Gaming as Learning Media for Plastic Waste Recycling Management System in Indonesia: A Conceptual Model *(Putri Laksmi, M., Ardi, R. 2020)*	Indonesia	Stakeholders	To improve the understanding of plastic waste recycling management for stakeholders.	board game RECOPOLY • Clear goal (mission) • Uncertain scenario • Coordination and collaboration • Objectives/challenges • Levels • Decision making	Included—7 steps by Lukosch et al. (2018)	Serious game: simulator

Table A1. *Cont.*

Reference Number	Title, Authors, Year	Country	Target Population	Aim of Intervention	Description and Elements	Info about Design Process	Game-Based Solution Implemented
[69]	Gamification Approaches for Education and Engagement on Pro-Environmental Behaviors: Searching for Best Practices *(Ouariachi, T., Chih-Yen, L., Elving, Wim J L, 2020.)*	-	-	To search for best practices in the field pro-environmental gamification platforms for behavioural change	-	Octalysis framework focuses on motivation (white hat motivators VS black hat motivators and left-brain motivators or extrinsic and right brain motivators or intrinsic). Climate Change Engagement through Games Framework classifies 15 game attributes into three categories: cognitive involvement emotional involvement behavioural involvement	Literature Review
[70]	Producing and Communicating an Interactive Popular Science Video for New Media: Using as an Example the Theme of Marine Microplastics Spelling Big Problems for Future Generations (*Tsai, M., 2017*)	(Taiwan)	General Public	To raise awareness about microplastics	Game-based learning proposed methodology	Included	Not specified
[71]	Rayuela: Delivering serious information through playful interactive installations (*Chhikara, A., Hespanhol, L., 2020)*	Australia	General Public	To raise awareness about plastic use and waste, how this pollutes oceans and enters the food chain	Intuitive (game of hopscotch) public light installation that presents 11 light storytelling boxes illustrating, each step, the story of a plastic bottle through its lifecycle. By jumping participants would light the following box, until the end where the last box would show alternatives to plastic usage.	Included	Playful Design

Table A1. *Cont.*

Reference Number	Title, Authors, Year	Country	Target Population	Aim of Intervention	Description and Elements	Info about Design Process	Game-Based Solution Implemented
[72]	Keep on Rockin' in a Plastic-Free World: Collective Efficacy and Pro-Environmental Intentions as a Function of Task Difficulty *(Reese, G., and Junge, E. A., 2017)*	Germany	General Public Volunteers (Mean age:31.7, SD = 12.4)	Behaviour change: Plastic reduction challenges	Plastic reduction challenges printed on playing card distributed in German towns and cities -> low, medium and high difficulty challenges. • Challenges • Information delivery	Included	Serious game: purposeful game
[73]	Teaching Presence in Online Gamified Education for Sustainability Learning (*Diyana Mahmud, S., N., Husnin, H., Tuan Soh, T. M., 2020)*	Malaysia	University Students	To avoid waste, including plastic Awareness and knowledge of sustainable behaviours	Mobile app "Joulebug" combining gaming, social media and educational tools with practical activities/challenges • Challenges • Audio and visual feedback • Rewards and badges • Competition against other players in challenges • Leader board and social recognition • Sharing achievements and progress with others	Included—description of the app	Serious game: purposeful game
[74]	Comparing pedagogies for plastic waste management at university level (*Yeung, S.-K., So, W.-M.W., Cheng, N.-Y.I., Cheung, T.-Y., Chow, C.-F., 2017)*	Hong Kong	University Students	To increase knowledge about plastic reduction, reuse and recycling. To change plastic recycling attitudes and intended behaviour	Simulation of a dynamic system through a sequential decision-making process • Role playing • Free world • Levels • Tasks and challenges • Collaboration and competition • Social recognition (prestige level and academic level of each user shown on screen) • Achievements	Not included	Serious game: simulator

Table A1. *Cont.*

Reference Number	Title, Authors, Year	Country	Target Population	Aim of Intervention	Description and Elements	Info about Design Process	Game-Based Solution Implemented
[75]	A proposed technology IoT based ecosystem for tackling the marine beach litter problem *(Ponis, S. T, 2021)*	Greece	General Public	To raise awareness through technology that monitors pollution indicators To promote engagement, and behaviour change in recycling and cleaning up plastic	Wireless sensor network and gamified web platform • Ranking • Competition • Status and social recognition • Rewards (monetary incentives and certificates) • Information delivery	Not included	Serious game: Purposeful game
[76]	An On-Device Deep Learning Framework to Encourage the Recycling of Waste *(Ekundayo, O., Murphy, L., Pathak, P., Stynes, P., 2022)*	Africa	Households	To help and reward correct recycling of household trash	Gamified App "RecycliQ"develops inferences based on similarities between pictures/garbage items to help sorting waste correctly • Experience points • Achievements or Badges • Ranking • Rewards (virtual or monetary)	Included—Creation of a dataset of images of 7 categories of waste	Serious game: purposeful game
[77]	How can a serious game be designed to provide engagement with and awareness of the plastic crisis as part of UN's SDGs *(Bjorner, T., 2021)*	Denmark	University Students (17–21)	To raise awareness about the effects of plastic on the environment	Platform Action single-player videogame"EnvironMan": maintaining responsible production and consumption of plastic, informing what types of plastics have the worst impact on the environment move and jump the player character between points and avoid enemies. • Intro and tutorial • Graphics • Music • Levels	Included: emphasis on content, learning objectives and game's title	Serious game: meaningful game
[78]	Plastic waste problem and education for plastic waste management *(Chow, C.-F., So, W.-M.W.,Cheung, T.-Y., Yeung, S.-K.D., 2017)*	Hong Kong	Elementary school students	To increase knowledge of the 3Rs, and plastic waste problem/management To change recycling attitudes and intended recycling behaviours	Game: "plastic city", role as citizens to understand interconnection between daily life and environmental problem	Not included	Serious game: simulator

Table A1. *Cont.*

Reference Number	Title, Authors, Year	Country	Target Population	Aim of Intervention	Description and Elements	Info about Design Process	Game-Based Solution Implemented
[79]	Water bodies: VR interactive narrative and gameplay for social impact *(Vasey, K., Bos, O.; Nasser, F., Tan, A., JunTing, B.L., Khoo, E.T., Marsh, T, 2019)*	Singapore	General Public	To raise awareness about plastic and microplastic pollution in the oceans and related to human health	Interactive Virtual Reality ExperienceParticipants visit the human stomach where microscopic marine creatures are ingesting plastic microfibers; players can shoot microplastics and collect them • Narrative storyline • Graphics • Intro, tutorials • Challenges • Time • Feedback • Points Information	Not Included	Serious game: meaningful game
[80]	Incentives for Plastic Recycling: How to Engage Citizens in Active Collection. Empirical Evidence from Spain *(Gibovic, D., and Bikfalvi, A., 2021)*	Spain	Households	To increase plastic recycling	Web App and Social Community • Rewards • Social Recognition	Not included	Serious game: purposeful game
[81]	Designing Educational Game to Increase Environmental Awareness *(Huda A., N., Ramadhan, F, 2021)*	Indonesia	Elementary School Students	To raise awareness about plastic waste, reduction of SUP items (straws, bottles and bags) and replacement with reusables To raise knowledge about the dangers of plastic	Strategy Genre—Tower Defense single-player videogamePlayers will manage a boat team that has three colour variants with their respective functions (collecting plastic bags, plastic bottles, and plastic straws).Players are asked to complete the objectives. Different difficulty levels and two settings: sea (protect sea from plastic waste) and land (protect city from flooding) • Storyline • Tutorials • Challenges to complete • Levels • Animated cutscenes	Included-Game Development Life Cycle (GDLC), Production through the Gdevelop game engine.	Serious game: meaningful game

Table A1. *Cont.*

Reference Number	Title, Authors, Year	Country	Target Population	Aim of Intervention	Description and Elements	Info about Design Process	Game-Based Solution Implemented
[82]	Approachability Evaluation of Virtual Reality Educational Game: The Case of Keepin *(Siregar, R. M. P., Sudarmilah, E., Endah and Istiadi, 2021)*	Indonesia	Elementary school children	To increase awareness about environmental impact of waste To increase knowledge about waste handling and segregation	Virtual reality game for android smartphone: open world single-player game with a mission: waste handling • Intro • Tutorials • Levels • Challenges/goals	Not Included	Serious game: teaching game
[83]	Serious Game on Recognising Categories of Waste, to Support a Zero Waste Recycling Program *(Menon, B.M., Unnikrishnan, R., Muir, A., Bhavani, RR, 2017)*	India	University Students	To teach waste sorting and recycling	Virtual interfacecombined with a motion sensing input device Microsoft Kinect. • Introduction • immediate feedback, negative feedback • Score • Physical involvement • Timer	Included	Serious game: Teaching game

Table A2. Evaluation Criteria and Outcomes of Game-based Interventions.

Reference Number	Study	Sample and Study Design	Evaluation Criterion	Main Outcome	Other Evaluation Criterion	Other Outcomes
[60]	Citizen-Based Litter and Marine Debris Data Collection and Mapping (*Jambeck, J. R. and Johnsen, K., 2015*)	General user engagement in the app	**Behaviour** (App use)	Prior to the 31 October 2014, the app had nearly 11,000 downloads and 774 registered users, and the website had more than 137,640 page views from 159 countries, with approximately 30 visits per day.	**Engagement**	High user engagement and organisation of clean-ups.

Table A2. *Cont.*

Reference Number	Study	Sample and Study Design	Evaluation Criterion	Main Outcome	Other Evaluation Criterion	Other Outcomes
[63]	A week without plastic bags: Creating games and interactive products for environmental awareness *(Gardeli, A., Vosinakis, S., Englezos, K., Mavroudi, D., Stratis, M., Stavrakis, M., 2018)*	Primary evaluation—sample not specified In situ observation, video recording, questionnaires and interviews	-		**Enjoyment** and **Motivation** **Design** and **Usability**	Users were engaged, motivated, attracted, importance of immediate feedback and rewards. The social aspect on public installations was strong, enhancing collaboration and sharing achievements. Need for assistance with some tasks, some users diverged from the actual scenarios and tried to explore different features, most users preferred the tablet device rather than the laptop. Technical issues identified (e.g., ambient noise, sound, lighting conditions).
[64]	Design and Development of Games and Interactive Installations for Environmental Awareness (*Gardeli, A., Vosinakis, S., Englezos, K., Mavroudi, D., Stratis, M., Stavrakis, M., 2017*)	First evaluation Sample n = 5 children Second evaluation: Sample n = 8 participants (19–21 y.o.) Usability test in a lab pre-test and post-test, observation and qualitative feedback	**Knowledge** about collecting and recycling plastic waste	High degree of understanding the campaign's goals; games provided users with new ideas on how to replace plastic bags	**Usability** Nielsen's general principles for interaction design **Enjoyment** and **Motivation** **Engagement**	Users' confidence in interacting with installations, preference for interactive installation when compared to traditional means of information Digital games more suitable for younger players, overall games easy to understand despite some UI elements little confusing and in some cases not enough challenging to motivate a long-term engagement High degree of engagement and motivation; storytelling and introduction of digital games particularly engaging
[65]	Oceans We Make: Immersive VR Storytelling *(Thomas, A., Kumar, A., Krehel, R., Vasey, K., Khoo, E. T., Marsh, T., Li Junting, B., 2018)*	Sample n = 69 post-experience questionnaire rating their experience from 1 to 10 and open-ended feedback	**Concern** about ocean pollution	Mean rating 8.68; users did develop concern about ocean pollution, and they were compelled to take action	**Enjoyment**	Mean rating 8.94
[66]	Eco champion: A transcultural educational eco game for children *(Speth, M., Müller, J., Rist, T., Seidl, J., Faschina, M., 2018)*	Evaluation to be carried out	-	-	-	-

Table A2. *Cont.*

Reference Number	Study	Sample and Study Design	Evaluation Criterion	Main Outcome	Other Evaluation Criterion	Other Outcomes
[67]	Interactive Game-Content-Based Storytelling for the Environment *(Lee, Y., and Lee, J., 2020)*	Sample n = 9 to evaluate Level 3 intervention Sample n = 10 to evaluate Level 5 intervention Focused group interviews (FGI)	**Eco-friendly perceptions** and **behaviours**	Level 1: Change in attitudes regarding participation in a tree planting program. Level 3: interviewees increased their interest in acting pro-environmentally; Limited achievement of promoting eco-friendly perceptions, limited perceived personal responsibility compared to societal one, and small change in beliefs about concern for environmental problems. Level 5: Many students reported they had already experience in participating in environmental campaigns/interest in the topic. All interviewees reported an increased environmental perception and intentions to take more practical actions for the environment.	**Engagement/Interest** **Cognition**	Level 3: the worldview and storyline were, however, neglected because the main focus was on emotions between the main character and the robot. Level 5: The game increased participants' motivation in playing. Affection to the trees. Level 3: Focus on the quizzes rather than recognition of the aim of increasing eco-friendly perceptions. Level 5: Many users recognised and understood the environmental message.
[68]	Serious Simulation Gaming as Learning Media for Plastic Waste Recycling Management System in Indonesia: A Conceptual Model *(Putri Laksmi, M., Ardi, R. 2020)*	Testing and evaluation still to be performed	-	-	-	-

Table A2. *Cont.*

Reference Number	Study	Sample and Study Design	Evaluation Criterion	Main Outcome	Other Evaluation Criterion	Other Outcomes
[69]	Gamification Approaches for Education and Engagement on Pro-Environmental Behaviors: Searching for Best Practices *(Ouariachi, T., Chih-Yen, L., Elving, Wim J L, 2020)*	Analysis of 6 game-based solutions through *Octalysis framework* and the *Climate Change Engagement through Games Framework*	**Behaviour change drivers**	Gamification approaches have the potential to educate and encourage pro-environmental behavioural change, as long as they combine in their design extrinsic and intrinsic motivational elements, short-term and long-term drivers and game attributes that encourage taking action in real life.	Recurrent **strategies** and **aims** of gamification	The most recurrent strategy is competition through simulations, strategic games and news games; The issues addressed are mostly energy saving, waste management and recycling; aim of games are behaviour change and raising awareness.
[70]	Producing and Communicating an Interactive Popular Science Video for New Media: Using as an Example the Theme of Marine Microplastics Spelling Big Problems for Future Generations *(Tsai, M., 2017)*	No evaluation yet	-	-	-	-
[71]	Rayuela: Delivering serious information through playful interactive installations (*Chhikara, A., Hespanhol, L., 2020)*	Direct observation, comments of visitors	-	-	**Engagement, enjoyment** **Usability**	Excitement, familiarity, nostalgia, social **engagement** reported Unidirectional in contrast to traditional hopscotch, images are thus upside down and need to redirect people, sometimes scarce attention to information

Table A2. *Cont.*

Reference Number	Study	Sample and Study Design	Evaluation Criterion	Main Outcome	Other Evaluation Criterion	Other Outcomes
[72]	Keep on Rockin' in a Plastic-Free World: Collective Efficacy and Pro-Environmental Intentions as a Function of Task Difficulty *(Reese, G., and Junge, E. A., 2017)*	Sample n = 165 Online survey with 7-point Likert scales	Behavioural **intentions**	Medium difficulty task leads to stronger collective efficacy beliefs which in turn are predictors of pro-environmental behaviours. An easy task can lead to a higher response rate but lower efficacy beliefs, thus resulting in lower future intentions and behaviours. At the same time, effects of collective efficacy should be considered as depending on changes in self-efficacy. Self-efficacy beliefs leading to an increased collective efficacy were significant for plastic-specific behaviours.	**Psychological dimensions**: self-efficacy, collective efficacy, descriptive norms, injunctive norms, attitudes	Collective efficacy beliefs may increase self-efficacy beliefs as well, which both lead to sustainable choices.
[73]	Teaching Presence in Online Gamified Education for Sustainability Learning (*Diyana Mahmud, S., N., Husnin, H., Tuan Soh, T. M., 2020)*	Quasi-experimental design. Control group sample n = 20; Tratment group sample n = 28 Questionnaires Pre-test and post-test	**Knowledge** of Sustainability	Sustainability knowledge higher in the treatment group		
			Pro-environmental behaviour	Pro-environmental behaviours higher in the treatment group:		
		Points in the App (mean value, between groups)			**Role of teacher** presence in the performance in gamification activities	Students' performances of the group with presence of a teacher were higher and higher participation was seen.
		Semi-structured interviews			**Driving factors** and **Barriers** in participation in the gamified activities	Driving factors: recognition by teachers and peers, competition, sense of belonging to a group; Barriers: time constraint, boredom due to lack of social interaction, activity repetition and inappropriate level of difficulty of tasks.

Table A2. *Cont.*

Reference Number	Study	Sample and Study Design	Evaluation Criterion	Main Outcome	Other Evaluation Criterion	Other Outcomes
[74]	Comparing pedagogies for plastic waste management at university level (*Yeung, S.-K., So, W.-M.W., Cheng, N.-Y.I., Cheung, T.-Y., Chow, C.-F., 2017)*	Experimental design Sample: n = 60 randomly assigned to Control group and Treament group; Questionnaires	**Knowledge** of local waste management, 3Rs, plastic waste classification	**Both groups increased significantly in** knowledge about local waste management, Rs concept, plastic waste classification		
			Attitude towards sustainable use of resources	A **positive attitudinal change** was **only** observed **in the gaming simulation group**.		
			Intended behaviour	Both groups increased their intended behaviour of recycling plastic waste		
		Semi-structured interviews			**Psychological dimensions** making the programs effective	Active learning (both groups),elevating difficulty levels (GS group), gaming was effective in triggering reflections on cognitive dissonance that induced attitude changes.
[75]	A proposed technology IoT based ecosystem for tackling the marine beach litter problem *(Ponis, S. T, 2021)*	Not evaluated yet	-	-	-	-
[76]	An On-Device Deep Learning Framework to Encourage the Recycling of Waste *(Ekundayo, O., Murphy, L., Pathak, P., Stynes, P., 2022)*	**Comparison** of five deep learning image classification **models**			**Design effectiveness(not tested with participants)**	InceptionResNetV2 shows promise if the motivation is for accuracy, and accuracy and loss; MobileNetV2 and DenseNet201 show promise for accuracy and latency; and MobileNetV2 and DenseNet201 show promise for accuracy and size.
[77]	How can a serious game be designed to provide engagement with and awareness of the plastic crisis as part of UN's SDGs *(Bjorner, T., 2021)*	2 evaluations: sample 1 n = 10; sample 2 n = 22 User Engagement Scale (UES-SF) questionnaire and semi-structured interviews	**Awareness** of plastic crisis	Not effective when played out of context: only 20% were made aware when game played out of context, whereas 60% participants reported to have been made aware of plastic crisis when played within a project-specific theme about plastic overproduction.	Immersion and **engagement**	Most participants were engaged and motivated in the game, focused attention, overall positive feedback on aesthetics
					Usability	The game can be improved in its usability, aesthetic appeal, game title and balance between challenges and skills.

Table A2. *Cont.*

Reference Number	Study	Sample and Study Design	Evaluation Criterion	Main Outcome	Other Evaluation Criterion	Other Outcomes
[78]	Plastic waste problem and education for plastic waste management *(Chow, C.-F., So, W.-M.W.,Cheung, T.-Y., Yeung, S.-K.D., 2017)*	Sample *n* = 61 children divided into three groups (1 game-based teaching; 2 control groups: direct teaching and hands-on teaching) Pre and post-test	**Knowledge** about plastic and waste, recycle, reuse, and reduce.	Pupils who participated in the simulation game attained the most significant improvement in their knowledge when compared with those of the control groups.		
			ecological worldview and Recycling **Attitudes**	No significant differences in pupils' ecological **attitudes** before and after the program for each strategy; slight improvement in recycling attitudes in the hands-on and in the simulation game-based groups.		
			Intentions about recycling and plastic waste management	No significant changes in **intended behaviour** of plastic waste recycling and management in neither of the three groups		
[79]	Water bodies: VR interactive narrative and gameplay for social impact *(Vasey, K., Bos, O.; Nasser, F., Tan, A., JunTing, B.L., Khoo, E.T., Marsh, T, 2019)*	Sample *n* = 20 Feedback on a scale of 1 to 10	**Awareness** about microplastic pollution	Average pre-test: 5.05, average post-test: 9.2	**Enjoyment** level	Mean rating 8.7
[80]	Incentives for Plastic Recycling: How to Engage Citizens in Active Collection. Empirical Evidence from Spain *(Gibovic, D., and Bikfalvi, A., 2021)*	At the end of the studies sample *n* = 1053 households 6-week period	**Behaviour** (recycling)	The **project increased the number of population points that actively recycled** to 20 (from 60% to 80% of the population), with those who already recycled improving their waste selection by 10 points along with the corresponding reduction of improper waste.		

Table A2. *Cont.*

Reference Number	Study	Sample and Study Design	Evaluation Criterion	Main Outcome	Other Evaluation Criterion	Other Outcomes
[81]	Designing Educational Game to Increase Environmental Awareness *(Huda A., N., Ramadhan, F, 2021)*	Sample: n = 45 Pre-test and post-test: 10 multiple choice questions	**Knowledge** and **awareness** of danger of plastic waste	71.11% of the students increased their environmental and plastic waste understanding.		
[82]	Approachability Evaluation of Virtual Reality Educational Game: The Case of Keepin *(Siregar, R. M. P., Sudarmilah, E., Endah and Istiadi, 2021)*	Sample n = 35 Pre-test Empirical evaluation Follow-up	**Knowledge** of waste handling	28 respondents achieved the goal of the game by responding correctly to the questions—5 could were able to achieve the goal of the game despite reporting a negative experience, 7 ended the game without finishing it.	**Usability**	23 respondents had a positive experience; 12 reported a negative experience
[83]	Serious Game on Recognising Categories of Waste, to Support a Zero Waste Recycling Program *(Menon, B.M., Unnikrishnan, R., Muir, A., Bhavani, RR, 2017)*	Sample: n = 9 Questionnaires (pre and post training)	**Knowledge** of correct waste sorting	All of the trainees reported that they **increased their confidence** in sorting the waste into the four different categories	**Engagement**	The majority of the trainees also showed a keen interest in playing the game more often and learning more
					Design and **usability**	Suggestions about the design, overall positive experience thanks to virtual interface with a motion sensing input device Microsoft Kinect

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