Research Article

Utilizing Gamification in Smart Waste Management: A Participatory Approach Integrating Green Schools, the Internet of Things (IoT), and Social Marketing

Ruhollah Rezaei Shandiz[1], Faezeh Alizadeh[2], AmirHossein Ahmadi[3], Shirin Naderi[3], Klodian Dhoska[4], Mohammad Eftekhari[5], Saeed Kamranfar[6], Aamir Mahmood[7], Mohammad Gheibi[7*]

[1]Kavian Institute of Higher Education, Mashhad, Iran

[2] Marketing Management Department, Imam Reza University, Mashhad, Iran

[3]Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Torino, Italy

[4]Faculty of Mechanical Engineering, Polytechnic University of Tirana, Tirana, Albania

[5]Department of Chemistry, University of Neyshabur, Neyshabur, Iran

[6]Department of Architecture, Built Environment and Construction Engineering, Polytechnic Milan, Italy

[7]Institute for Nanomaterials, Advanced Technologies and Innovation, Technical University of Liberec, Czechia

*mohammad.gheibi@tul.cz

Abstract

Urban and rural life heavily depends on the movement and collection of waste. A weak and inefficient waste collection system increases costs and poses significant risks to public health. Conventional waste collection methods are neither the most effective nor the most efficient. Enabling smart, sufficient, and self-sustaining Internet of Things (IoT) solutions is crucial for enhancing human welfare. In recent years, many countries have faced increasing pressure to meet legally binding targets related to recycling and waste management, with a growing focus on sustainability from policymakers and consumers alike. From this perspective, recycling plays a crucial role in reducing the amount of waste disposed of while simultaneously decreasing the demand for raw materials. The waste management process consists of six main stages: waste generation; handling, segregation, storage, and processing at the source; collection; sorting, processing, transformation, and conversion; transportation; and disposal. In this proposal, we first explore foundational studies on creating incentive systems to attract public participation. The next phase focuses on the implementation of participatory systems. The third step involves the development and construction of waste management applications, followed by the fourth step, which is dedicated to educating all stakeholders involved.

Keywords: Waste Management; Smart Systems; Green Schools; Gamification; Internet of Things (IoT); Social Marketing

INTRODUCTION

Given the inevitability of waste production by humans, the focus on controlling and organizing it becomes a national responsibility [1]. In this regard, the first priority should be to address how to collect the vast and scattered volume of waste, and then focus on recycling it. Waste collection is essentially an effort to reduce entropy (disorder). The various components that make up urban waste are scattered over large distances, and the role of the collector is to gather these materials in one place [2]. In Iran (as in many other parts of the world), waste collection systems typically rely on a person/truck system. With few exceptions, urban solid waste collection worldwide is carried out by individuals accompanying a truck that travels through the city. The collected waste is then transported to a disposal site. This site could either be the final disposal point or a temporary station where the waste is deposited into larger containers, trailers, ships, or railcars, which are then transported to a landfill, composting site, or recycling plant. A significant portion of the costs related to urban waste collection (around 60%) is associated with the collection phase. Therefore, efforts to optimize and improve this process have been underway for years [1]. Past waste management experiences indicate that increasing the waste collection facilities in a specific area or region only imposes additional costs on waste management systems. Meanwhile, in today's smart waste management systems, the collection process should incorporate gamification elements to enhance user interaction and promote sustainable practices [3]. This approach effectively motivates individuals to adopt better waste management behaviours such as recycling and proper waste classification [4]. Key aspects of gamification in this context can be outlined as follows: Scoring and Rewards: Citizens earn points for desirable behaviours such as proper waste sorting, using waste management apps, or participating in clean-up programs. These points can be exchanged for various rewards like discounts on municipal services, movie tickets, or cash prizes [5]. Challenges and Badges: Implementing challenges and awarding badges for achievements can further increase user participation and commitment to waste management methods [6]. Badges and Rankings: Granting honour badges to individuals who perform well in waste management and displaying user rankings on a leader board can foster healthy competition and motivation for improvement [3]. Storytelling and Narratives: Using engaging stories and narratives about the importance of recycling and its impact on the environment can raise citizens' awareness and encourage their participation [6]. Additionally, from a technological integration perspective, mechanisms such as: Internet of Things (IoT) and Mobile Apps: The integration of IoT with mobile apps enables real-time tracking of waste management activities, improves the user experience, and facilitates data collection [6]. Machine Learning: Apps like ScanBage use machine learning to assist users in waste sorting, making the process more visual and efficient [7]. From a user acceptance and behavioural change mechanism perspective, the focus can be placed on: Social Influence and Trust: Gamification can influence the relationship between user intent and system use, especially in contexts where trust in the system is crucial [8]. Feedback Mechanisms: Providing immediate feedback to users about their recycling efforts can bridge the gap between knowledge and behaviour, leading to improved recycling rates [5]. Gamification has been recognized as a valuable feature that not only increases user engagement but also moderates the relationship between behavioural intention and system usage. This means that when gamification elements are present, users are more likely to use the system, especially if they initially have little motivation. Innovative tools,

including blockchain, economic incentives, and gamification, encourage consumers to adopt a new household waste management system [8]. Their results show that gamification can be valuable for increasing adoption among users with low behavioural intention. While gamification offers a promising way to improve waste management, it is important to consider potential limitations such as the need for continuous user participation and the risk of diminishing returns [6]. In the traditional waste collection system, machines, accompanied by human collectors, travel to the nearest point to households and perform the collection process. However, this method does not involve any direct participation from citizens. Global urban management meetings have shown that controlling the future of cities will be far more costly and complex than what current administrators face. In other words, as demand levels rise and urbanization develops, the economic, cultural, and environmental costs imposed on cities will become uncontrollable. Given these challenges, forward-thinking managers have begun to seek out participatory systems in cities. To achieve these goals, waste collection stations are gradually moving away from household locations, and these distances are covered through transformative citizen participation. To attract citizen participation, managers should promote the development and use of models that include IoT-based components integrated with mobile and web applications, using a semantic web and gamification approach. This would encourage users to reduce, reuse, and recycle waste [9]. For example, smart bins equipped with IoT sensors can be used. These smart bins, with specific sensors such as humidity, infrared, and ultrasonic sensors, form an IoT-based waste sorting system. These sensors can be used to detect the type and size of waste [10]. With the use of triggers in smart bins, automated processes such as opening and closing lids and compressing waste can be facilitated. This automation not only increases the efficiency of waste management but also helps improve hygiene by minimizing human contact with waste. The presence of these sensors enables real-time data collection, optimizing waste collection routes, reducing operational costs, and minimizing carbon emissions [11]. This optimization can be used to refine waste management strategies. Thus, it can be concluded that an IoT-based waste management system not only enhances the efficiency and effectiveness of waste sorting but also plays a crucial role in promoting environmental sustainability and resource conservation. The integration of various sensors and automation technologies makes this system a forward-looking solution to modern waste management challenges [10]. Through the stimulation of emotional intelligence, incentive systems have been established at the city level to guide audiences toward participation in urban management. Waste management systems in major cities like Tehran, Mashhad, Tabriz, and Isfahan have faced repeated failures. However, source separation of waste is a much more complex and specific goal compared to regular urban waste collection. In this study, an operational method for creating a transformative participation system in the studied county will be presented, along with a vision for the implementation of the transformative participation system.

The Level of Participation

In the previous discussions, participation is classified according to the interests of the designers and promoters of participation, who focus on the issue of participation from the top, as well as the participants, whose interests are pursued from the bottom [12] [13]. This classification is presented in Tables 1 and 2 in both traditional and modern formats.

Table 1. Levels of Participation in Traditional Local Governance Systems.

Function	Top-Down Goals	Bottom-Up Goals	Levels of Participation
Symbolic	Population entry	Legitimacy	Nominal
Instrumental	Cost management	Efficiency	Instrumental
Expressive	Influence on the public	Sustainability	Symbolic
Instrumental-Goal	Empowerment	Empowerment	Transformational

However, now, considering modern approaches such as the Internet of Things, social marketing, and green schools, the table of levels of participation should be expressed as follows:

Table 2. Levels of Participation in Modern and Smart Urban Waste Management Systems with a Green Schools Approach and Emerging Technologies.

Function	Top-Down Goals	Bottom-Up Goals	Levels of Participation
Symbolic	Initial and motivational participation	Creation of social legitimacy	Nominal and limited participation [13]
Instrumental	Cost reduction through technology and culture	Operational efficiency enhancement with technological monitoring	Instrumental and functional participation [14]
Expressive	Encouragement of community-driven initiatives	Promotion of sustainability and environmental focus	Encouraging and symbolic participation [15]
Instrumental-Goal	Empowerment of students and citizens	Structural behavior changes	Transformational and deep participation [16]

Intelligent	Collection and analysis of participatory data	Data-driven decision making	Data-driven participation [17]
Interactive	Enhanced community interaction through gamification	Promotion of solidarity and responsibility	Interactive and innovative participation [18]

Nominal and Limited Participation (Symbolic): A level of participation where individuals or groups are only symbolically present in the system, with no real influence on decision-making or implementation. For example: organizing waste separation programs in schools merely to showcase achievements without real participation from students [19]. Instrumental and Functional Participation (Instrumental): Participation aimed at utilizing human or social resources to achieve economic or operational goals, without a strong focus on fundamental changes. For example: using students for waste collection and separation to reduce the costs of urban waste management [20]. Encouraging and Symbolic Participation (Expressive): A level of participation where individuals engage to attract attention or exercise social influence, but no deep structural changes occur. For example: organizing gamification competitions in schools to encourage students to separate waste, without precise monitoring of its long-term effectiveness [15]. Transformational and Deep Participation (Instrumental-Goal): Participation aimed at empowering individuals and groups to create sustainable changes in behaviours and social structures. For example: environmental education in schools that transforms students into local leaders of change in waste management [21]. Data-Driven Participation (Intelligent): A level where the collection, analysis, and use of participatory data is facilitated by emerging technologies like IoT for precise decision-making and predictions. For example: using smart sensors to track the level of participation in waste separation by each school and analysing data to improve processes [22]. Interactive and Innovative Participation (Interactive): Participation based on continuous interaction between the community and urban management, using creative technologies and tools to increase trust and responsibility within the community. For example: designing a gamification app where schools and students can view their scores and interact with others to strengthen a sense of competition and solidarity [23]. Based on this, the present plan aims to create empowered systems in the field of smart urban waste management, alongside the establishment of transformational participatory systems. However, it should be noted that achieving this goal requires attention to the city's branding components, the creation of a virtual city environment, the implementation of resistance economy elements, the establishment of environmental schools, and planning for the future management of the city in question. The management of future cities increasingly relies on citizen participation, as their involvement is crucial for sustainable urban development.

Integrating citizens into the planning processes not only enhances the acceptance of initiatives but also creates an essential collaborative environment to address urban challenges. This dependency on citizen participation is evident in several key areas: A. Public Participation: Public participation has become a fundamental aspect of urban planning, significantly influencing project outcomes [24]. Additionally, citizen participation in energy transition projects leads to better acceptance and implementation of sustainable strategies [25] and, as a result, collaborative efforts between citizens, local authorities, and businesses to address environmental issues in densely populated areas have become vital [26]. B. Technology Integration: The use of smart sensors and open technologies facilitates citizen participation in urban monitoring, increasing the understanding of urban dynamics [27]. Additionally, digital tools and platforms provide real-time feedback and interaction between citizens and planners, promoting active participation in urban development [28]. C. Challenges and Opportunities: Despite the importance of citizen participation, the level of actual involvement often remains low, requiring innovative approaches to incorporate diverse stakeholders. Projects such as co-creating urban futures aim to solve these challenges by fostering inclusive public discussions and urban planning processes [28]. While emphasis on citizen participation is critical, it is also necessary to recognize that not all citizens may have equal access to participate, potentially leading to inequality in urban development outcomes. In light of these points, management must consider decision-making as one of the essential parameters in reflecting people's participation. In fact, the people's decisions on public affairs are one of the main solutions for creating public acceptance and fostering consensus in urban management. However, the question arises: how should the management of these decisions be carried out? It seems that an intelligent system should have the capability to receive, evaluate, categorize, and apply opinions in specific areas. This intelligent planning and control system should be directly accessible to decision-making levers and allow for citizen input to be implemented by determining a place for these decisions. Among the cities that have developed processes to involve people in decision-making, the reports in Table 3 below provide insight into their efforts.

Table 3. Reports on Citizen Participation Mechanisms

Report	City	Mechanisms of Citizen Participation and Public Oversight	Details and Programs	Source
1	Zurich	Public participation and oversight mechanisms in Zurich	1. Voting in municipal elections 2. Direct communication with the mayor 3. Participation in idea competitions and online engagement 4. Direct connection with the Urban Development Center 5. Membership in	[29]

			mayor rating systems 6. Welcome Desk 7. Production of informational packages "Zurich for You"	
2	London	Public participation and oversight mechanisms in London	1. Meeting with the mayor 2. Opportunity for public questions 3. Talk London program 4. Live mayor broadcasts on Twitter 5. Ask the mayor and city council questions	[30]
3	Ottawa	Public participation and oversight mechanisms in Ottawa	1. Communication tools with the mayor 2. Transparency and annual municipal financial reports 3. Satisfaction surveys of municipal services 4. Online interaction and citizen request registration 5. Online city services platform 6. Special hotline for fraud and waste reports	[31]
4	Munich	Public participation and oversight mechanisms in Munich	1. Publishing magazine in Munich 2. Creating a "Citizens' Club"	[32]
5	Tokyo	Public participation and oversight mechanisms in Tokyo	1. Tokyo Virtual Reality Project 2. Citizen advisory services (Ohta Citizen's Network) 3. Formation of social networks for citizens 4. Direct communication with municipal centers	[33]
6	Barcelona	Public participation and oversight mechanisms in Barcelona	1. Use of participatory apps for urban issues management 2. Barcelona Digital City online platform for citizen-municipality communication 3. Gamification in waste management with points for urban service discounts 4. School-based communities for environmental education and promotion 5. Citizen network and transparency of information through smart systems	[34]
7	Singapore	Public participation and	1. Use of IoT and smart technologies in urban management 2. Smart Waste	[35]

oversight mechanisms in Singapore	Management app for waste separation with financial and social rewards 3. Green schools and educational programs including gamification and student competitions 4. Social marketing campaigns to increase awareness and citizen motivation 5. Real-time reporting system for monitoring citizen participation impact

provides a comprehensive overview of various cities' efforts to integrate citizen participation and oversight in urban management through various mechanisms, ranging from online platforms to real-time feedback systems and gamification. These initiatives highlight the importance of involving citizens in decision-making and urban development processes. We introduce the cities of Barcelona and Singapore as advanced examples that have adopted innovative approaches combining technology, education, and gamification for waste management and increasing social participation in schools and the community. Achieving this in the urban management system, in order to establish democracy at the city level, encourages citizens to feel responsible for the city's overall decisions. This, in turn, leads to continuous improvement in urban management systems.

Overall Plan

In this project, urban management software will be designed and developed based on an application platform. Additionally, citizens' accounts will be linked to the application information [36]. For the collection of sorted waste, each household will be assigned an account under the name of the head of the household. However, children in lower age groups within the household will be considered the driving force behind this initiative. To make the process more engaging, gamification will be integrated into the app's structure, allowing children to directly participate by earning badges, progress levels, and rewards associated with green schools. The experience of basic cultural programs at the national level, such as the "Cooperative Police Officer Program," indicates that planning for children and early-age groups can lead to the continuation of long-term programs [37]. To this end, the initial step of the project will involve consultations with the Ministry of Education to encourage and stimulate emotional intelligence among school children at the primary level. In this way, urban needs will be addressed, and the objectives of environmental schools (EcoSchool) will be strengthened [38]. At this stage, the Internet of Things (IoT) will be used to intelligently monitor the performance of households and schools [39]. Sensors embedded in the sorted waste bags or collection stations will transmit data related to the amount of sorted waste to the application, and points will be instantly added to the household and school accounts. During the implementation of this plan, through coordination between the Ministry of Education and the project managers, students will

be rewarded based on the waste sorting performance in their homes or the points earned by their households. Schools can also use social marketing tools to encourage families and establish effective communication with the local community. These educational and urban management intersections will provide the framework for guiding, controlling, and institutionalizing many civic education initiatives within the community. At the same time, households will segregate waste into bags of different colours according to their type and transfer them to the collection stations [40]. Subsequently, the household head's account will be credited based on the weight of the collected waste, and the total points will be visible and reportable within the application. Additionally, gamification features such as regional rankings, the introduction of top-performing households, and the ability to share achievements on social media will help encourage and increase family participation. In this way, several motivational potentials are categorized and considered in this plan. Initially, recreational and attractive outlets in the city will be identified, and permanent discounts will be offered to create conditions for engagement [41]. The integration of social marketing campaigns and incentive systems in urban waste management can significantly enhance community participation and environmental awareness. For example, five prominent restaurants in the city will be considered as participating outlets. Since the population of the city is introduced as customers for these restaurants, it is known that cooperation between restaurants and local governments can increase customer loyalty, thus guaranteeing a number of permanent customers for them [42]. Furthermore, due to the advertising done for restaurants or other urban outlets, there will always be permanent discounts for holders of the urban management green cards, which will further motivate them. To increase participation, social marketing campaigns will be conducted at the neighbourhood level, and educational and motivational messages about waste segregation and its role in the environment will be shared through the app and social media. In addition to this incentive system, special rewards and benefits such as recreational, pilgrimage, and tourist trips will be offered to top point earners in the program[42]. At the same time, the think tank for this project will add a new motivational proposal to the services basket obtained from waste segregation at the source every three months. To accomplish this, brainstorming sessions will be held at universities across the city. Furthermore, artificial intelligence technology will be used to analyse data and provide personalized suggestions to households to improve performance in waste management [43]. Additionally, the city's universities can be useful in generating new, profitable, and beneficial ideas [44] [45]. It should be noted that the current plan establishes a strong communication network between schools (as the driving force behind the plan and follow-up), universities (for generating innovative ideas in urban management as research projects and ideation), participating outlets (as the city's economic pillars), citizens (the governing population of the city), and the urban management system (the central hub and control room), strengthening and organizing it. This program does not require adding physical burdens or incurring heavy costs for the city. In other words, due to its high flexibility, the system can adapt to current urban management conditions, and only in the absence of independent systems for segregated waste collection, mobile containers should

be deployed at specific locations in the city. Finally, this plan will be introduced as a model for other cities in the country and can be adapted to different conditions, including smaller cities or areas with limited resources.

Branding in the Case Study

For example, Neyshabur is one of the most important and central cities in the Razavi Khorasan province. Despite having numerous cultural, tourist, and religious attractions, it has not been prominently recognized on a national or global level. This project aims to position Neyshabur as a city brand at the national level, using the name " Neyshabur, the Green City" as its urban management brand. If successful, this project will be introduced as a national pilot in Neyshabur. To achieve this goal, the proposed new plan (using gamification in smart waste management with a school-participation approach, the Internet of Things, and social marketing) is introduced as an innovative strategy in urban management. In this regard: Green Schools as the Core of Participation: By using educational programs and gamification in schools, students and families will be encouraged to actively participate in waste segregation and waste reduction processes [46]. Use of the Internet of Things: The installation of sensors and smart devices at waste collection stations for monitoring performance and providing accurate information to citizens and city managers [47]. Social Marketing: Advertising and promotional campaigns to emphasize the importance of waste management and the role of citizens in creating a green city. Using modern communication tools like social media to enhance public participation [47]. Incentive System and Gamification: Developing gamification-based applications that encourage citizens to separate waste and reduce waste production. Rating households and offering attractive rewards like discounts at local stores, cash prizes, or recreational trips [48]. In this project, Neyshabur will be introduced as Iran's first pilot smart and green city, utilizing new technologies and citizen participation. The goal is to make Neyshabur a national and international model for smart waste management and sustainable development. Additionally, the project will be implemented at both cultural and operational levels by creating a communication network between schools, urban management, universities, and citizens. This network will be strengthened through smart technologies and digital platforms to showcase participatory urban management in practice.

Virtual City

Virtual cities can serve as vital tools for emergency preparedness, providing simulations that assist in training and planning for various urban scenarios [49]. IBM recently established a centre in Toronto called Business Analytics Solutions, adopting integrated strategies aligned with digital city initiatives to improve public policies and urban sustainability [50]. This centre provides solutions for the development of virtual cities and addresses the related challenges. The management approach based on creating a virtual city through the Smart Commute TORONTO strategy is designed to reduce the city's dependence on carbon and fossil fuels significantly while enhancing productivity and

environmental sustainability [51]. Additionally, it has ensured that public urban services are distributed equally among all citizens. Smart urbanization strategies, using intelligent control systems and tools, have led the governance system to base most of its services on this approach. Therefore, the implementation of information systems in urban services has increased management control and operational efficiency, ensuring that services are tailored to social needs [52]. The government of Singapore, as one of the pioneers in smart urbanization, has implemented a project called 'Virtual Singapore.' This project is an advanced three-dimensional platform that allows urban managers, citizens, and businesses to view and analyse data and information related to urban infrastructure, traffic, energy consumption, and waste in a virtual and interactive environment [53]. The platform uses technologies such as the Internet of Things (IoT), smart sensors, and Artificial Intelligence (AI), providing advanced tools for analysis and prediction. One of the key innovations of this project is simulating the environmental behaviours of citizens [54]. This capability helps urban planners assess and analyse the impacts of different policies on the environment and quality of life before implementation. This plan also aims to lay the groundwork for creating a virtual city and, by completing the existing features of this software package, to enable the virtual management of cities.

Environmental Issues in Iran

Soil erosion and ecosystem changes: Air pollution in major cities of the country - the phenomenon of dust and fine particles - water scarcity - plundering and destruction of forests and pastures - land grabbing and mountain grabbing [55]. Key solutions for addressing environmental problems in the country: Preparation of a national document - serious collaboration among all agencies - preparing an environmental appendix for all programs - criminalization of environmental destruction - raising awareness among the public [56] [57] [58]. In addition to the mentioned problems, the lack of smart waste management has become one of the serious environmental issues in the country. The absence of waste separation at the source, inefficient urban waste management, and excessive use of non-renewable resources have placed additional pressure on the country's ecosystem. Main solutions for sustainable development and smart waste management: Preparation of a national smart waste management document - inter-agency collaboration - preparing an environmental appendix for all projects - criminalizing environmental destruction - raising awareness among the public through gamification and turning adolescents into environmental ambassadors. One of the initiatives that could be part of these solutions is the creation of an interactive platform called 'Green Citizen of Iran.' This platform could encourage citizens to collect and separate waste, focusing on green schools and family cooperation. Through online games and daily challenges, points are awarded for eco-friendly behaviours. These points can be used in public transportation systems, city discounts, and even national prizes [59]. Eco-Schools is an organization that encourages young people to participate in and protect the environment by creating opportunities for them. Through this program, young people can get involved in environmental management policies at their schools, ultimately leading to certifications and accreditation.

This program contributes to improving the environment in the community. For over two decades, environmental schools have started and developed with the help of European educational programs in four countries, based on the global model for education, environment, management, sustainability, and international certification [60]. Currently, 59 countries worldwide and over 20 million students are participating in this program. In the context of smart waste management and using gamification, these schools have taken new steps, including using Internet of Things (IoT) technology for optimal resource management and social marketing to create motivation and sustainable participation among students and teachers [61], [62]. This new approach has not only increased student participation but also improved public awareness of environmental issues and recycling [60], [63]. Important milestones in the evolution of environmental schools and concrete examples related to their developments in this model are presented in Table 4.

Table 4. Evolution of Environmental Schools and Practical Examples

Year	Public participation and monitoring mechanisms	Practical Example	Details	Description of Event
2024	Creating international networks for knowledge exchange, using digital tools and virtual conferences, participation in joint projects between schools.	Iranian schools connected to the global eco-school network and, in a joint project with schools from Japan and Finland, developed an educational app for learning waste segregation principles. Students competed online.	Involved creating an international network of eco-schools to share knowledge and experiences in smart waste management and environmental education using digital tools and virtual conferences.	Connection of eco-schools to a global network for knowledge exchange in waste management and smart technologies.
2022	Using technology for monitoring and managing waste, providing feedback to students and teachers based on collected data.	In the UAE, a project in Dubai schools was launched where sensors were installed to monitor waste levels in recycling bins. Data was automatically reported to teachers and students.	Use of sensors and connected devices to monitor resource consumption and waste management in schools began. These systems provided real-time data and identified energy wastage.	Expansion of the Internet of Things (IoT) for monitoring and managing waste resources in schools in Asian and Middle Eastern countries.

2020	Using scoring and competitive systems to encourage student participation in environmental activities, motivating through games.	In Finland, the "Eco Challenge" program was launched to encourage students to segregate waste, save energy, and reduce food waste. Students earned points based on their activities.	This program developed using gaming elements in environmental education, including scoring, badges, and leaderboards for participation in environmental activities.	Use of gamification systems to encourage student participation in waste management.
2015	Teaching sustainable agriculture techniques to students, participating in local agricultural projects.	In Madagascar, a program was implemented in schools to teach sustainable agriculture, where students learned techniques for growing drought-resistant plants and managing water resources.	This initiative aimed to support island countries facing challenges such as rising sea levels and water shortages. The goal was to teach students how to cope with these challenges.	Launch of eco-schools in the Indian Ocean islands with EU financial support.
1999	Student participation in environmental projects such as visiting recycling plants and holding exhibitions, raising public awareness through exhibitions.	In the UK, a school in Liverpool received this award for supporting the "Eco Warriors" project. Students visited recycling plants and held environmental exhibitions.	This award was given to eco-schools for promoting international education and globalizing environmental issues. The goal was to create social and cultural changes in environmental protection.	Eco-schools received the "World Aware Global Education" award.
1994	Student participation in practical projects such as waste segregation and creating recycling stations,	In Germany, the "Schüler für die Umwelt" project was launched, which included plastic and paper waste segregation in schools	The European Commission provided funding for the development of eco-schools in European countries. Education on waste	Eco-schools in Denmark, Germany, Greece, and the UK were launched with support from the European Commission.

environmental education in schools.	and the establishment of recycling stations in small towns.	recycling, energy saving, and water conservation was offered.	
1992	Student and teacher participation in practical activities like tree planting, raising awareness through environmental education.	In Denmark, a program was designed for tree planting in schoolyards, where students, along with teachers, planted trees and learned about plant life cycles and carbon dioxide reduction.	This initiative was presented at the Earth Summit in Rio de Janeiro, Brazil, addressing global issues like climate change and biodiversity loss, and emphasizing environmental education for children.	The eco-school initiative aimed to address needs identified at the United Nations Conference (UM).

It should also be noted that this proposed model aims to encourage and empower children, develop a sense of responsibility, enhance self-confidence and motivation, increase participation in environmental activities, develop individual skills and knowledge, and improve physical and mental health. To achieve these objectives, various continuous scenarios must be implemented at the school level and in the everyday lives of younger age groups. An overview of the components of the environmental school operational plan is presented in Table 5, adapted from [65], [66], [67].

Table 5. General Framework for the Operational Plan for an Eco-School

Stage	Description
Operational Plan Setup	Design a comprehensive program using smart waste management systems and online platforms to facilitate implementation stages.
Environmental Reviews	Use IoT sensors to analyze waste and environmental data in schools.
Formation of Participatory Committees	Create student and parent teams and encourage them to participate in educational and monitoring activities through gamification tools.
Creation of Environmental Codes	Develop operational protocols based on sustainability standards and monitor them using IoT.
Awareness and Participation	Implement social marketing campaigns for public awareness and promote recycling culture.

87

Utilizing Gamification in Smart Waste Management: A Participatory Approach Integrating Green Schools, the Internet of Things (IoT), and Social Marketing

Integration with Curriculum	Incorporate smart waste management concepts into the curriculum through practical and game-based activities.
Monitoring and Evaluation	Use smart dashboards for performance monitoring and continuous improvement.

The Environmental Schools Program began in 2010 with the aim of education and awareness-raising in Europe. By 2015, it expanded to over 40 countries, with environmental certifications granted to active schools. In 2020, with the introduction of new technologies, the training programs transitioned to digital and online formats, focusing on climate change mitigation [68]. Starting in 2023, the approach of gamification was integrated into smart waste management, with online competitions held in schools. Finally, in 2024, smart technologies such as Internet of Things (IoT) sensors for precise waste monitoring and gamification-based social marketing campaigns like "Green Scoring" were implemented to encourage sustainable behaviors among students [69].

The eco-school program was first presented based on the ISO 14001/EMAS environmental management project control standards to the country's educational management system. In this comprehensive program, a large number of managers, teachers, students, and their parents undergo an educational process. Additionally, the Environmental Protection Organization provided guidelines for implementing the eco-school program in the summer of 2013. The aim of this approach is to promote sustainability practices in schools and cultivate an environmental responsibility culture among students and staff [70]. This program is primarily based on the principles of Article 50 of the Iranian Constitution, the Vision 2025 document of the Islamic Republic of Iran, the Comprehensive National Scientific Map, the National Environmental Document, and the National Fundamental Transformation Document of Education. However, no unified model has been provided for the lower-level implementation, and the absence of this operational program is noticeable. The main issue is that the environmental program must appeal to younger age groups as an engaging activity, leading to a mental habit within the target society. In this way, over time, a clear mental map can be established in the minds of younger generations. Programs lacking creativity, innovation, and new attractions can result in a negative impact on the target audience. Therefore, new brainstorming sessions must be created to generate fresh ideas and continuously surprise audiences at every stage of the process. The emotional intelligence of students should be stimulated to internalize new perspectives. Given the necessity of implementing this program, many schools worldwide and in Iran have been striving to establish environmental schools and have experienced significant achievements. On the other hand, the need for active participation from the younger generation in this area leads to the exploration of ways to enhance the environmental school program using modern approaches. These approaches may include: Gamification: The use of game elements such as scoring, challenges, competitions, and

rewards to create motivation and encourage greater student participation in waste management. This can lead to transforming desirable environmental behaviors into a sustainable habit for them [71]. Smart Waste Management: Leveraging modern technologies such as Internet of Things (IoT) sensors to collect accurate data on waste generation, segregation, and recycling. This data can be used to optimize waste management processes and provide feedback to students[72]. Participation-Centered Approach: Creating an environment for active participation of students, teachers, parents, and the local community in waste management programs. This can be done through the formation of environmental committees, conducting workshops, and implementing collaborative projects [73]. Green Schools: Emphasizing the role of schools as centers for education and promotion of environmental culture. Green schools, by creating a healthy and sustainable environment, can help students learn environmental concepts and develop responsible behaviors [74]. Social Marketing: Utilizing social marketing techniques to promote desirable environmental behaviors and raise public awareness about the importance of waste management. This can be done through the implementation of advertising campaigns, organizing events, and using social media [75]. This research aims to provide a comprehensive model for implementing smart waste management in schools using gamification and participation-centered approaches, by examining successful global experiences and offering practical solutions. One of the final goals of this paper is to create a generation that is aware and responsible for the environment and to promote sustainability of culture in society. Examples of the performance of environmental schools inside and outside the country are summarized in Tables 6 and 7.

Table 6. Experience of Implementing Environmental School Program in Foreign Countries

Country	Sources	Approaches and Tools Used	City
Scotland	[76]	Most of the accredited schools in this country have joined the global environmental school program. The program encourages students, staff, and officials to collaborate through incentive systems such as rewards and certificates. Use of basic gamification incentive systems (such as rewards and certificates) to encourage participation.	Edinburgh
USA	[77]	The Academy for Global Citizenship acts as a pioneer in environmental schools in the USA. Special attention is given to environmental programs based on individual and group activities.	Chicago

		Group activities can incorporate gamification elements such as team competition or collaboration to achieve a common goal. More details are needed about the programs.	
USA	[78]	Focus on incentive systems indicates the use of gamification approaches. More information is needed on the types of incentive systems used.	New York
Japan	[79]	Smart management and control could involve the use of IoT sensors to monitor waste and provide feedback to students. This approach can be combined with gamification elements such as displaying data graphically or creating data-driven challenges.	Tokyo
Sweden	[80]	Use of smart energy management systems (IoT) and providing feedback to students through digital displays in classrooms. This system can be combined with gamification elements like energy consumption reduction challenges between classes and awarding prizes to the best class. School social networks are used for notifications and encouraging participation (social marketing).	Stockholm
UK	[81]	Implementation of mobile recycling programs using mobile apps (gamification) that reward students for submitting old phones. These points can be used for purchases from specific stores or participation in raffles (gamification and social marketing).	London

Table 7. Experience of Implementing Environmental School Program in Iran

Country	City	Environmental School Program	Approaches and Tools (Focusing on Gamification, IoT, and Social Marketing)
Iran	Hajar Girls High School	The Environmental Committee of Hajar Girls High School started in Mehr 1390 under the supervision of the Green Star Institute (exclusive representative of FEE Environmental Foundation) with the aim of familiarizing students with environmental issues and the benefits of conservation. Activities included: - Reducing energy costs at school and home while preserving the environment. - Organized, purposeful, and beneficial group activities. - Promoting enthusiasm, discovering nature, and building confidence. - Training future managers aware of environmental issues. - Practical, hands-on research in nature. - Creating a sense of friendship with the environment. - Integrating environmental topics into all subjects through theoretical and practical lessons.	Direct and practical education focusing on reducing energy consumption at school and home, group activities, confidence-building, and training environmentally conscious leaders. These activities can be combined with gamification elements such as energy-saving challenges at home and school, group competitions on environmental topics, and a point-based system for sustainable behaviors. School exhibitions and events can showcase students' achievements and encourage others (social marketing).

Iran	Shahid Mahdavi Educational Complex	Shahid Mahdavi Educational Complex has aimed to revive environmental school objectives through conferences and cohesive activities. Strategies include: - Reviewing global environmental changes. - Highlighting major environmental constraints. - Addressing environmental issues in Iran. - Emphasizing children's role in preservation.	Organizing conferences and cohesive activities focusing on global environmental changes, environmental constraints, environmental issues in Iran, and the role of children in preservation. Online platforms and social media can host competitions, surveys, and share relevant information (gamification and social marketing).
Iran	Haj Ahmad Behnam Nia Elementary School, Musk Village	Last autumn, students were provided seeds (mainly acorns) which were planted in disposable containers and nurtured at home until they grew into saplings, later brought back to school. The event included environmental songs, slogans on walls, and decorations made from recycled materials, creating an inspiring atmosphere.	Practical seed planting by students and nurturing at home with parental collaboration, accompanied by environmental songs and decorations made from recycled materials at school. This can be gamified using mobile apps to track plant growth, provide educational content, and organize photography contests. School exhibitions and local events can showcase achievements and raise awareness (social marketing).
Iran	Shahid Keshavarz High School, Bardkhun, Bushehr	This high school implements an indirect environmental education system for older students.	Implementing indirect environmental education for older students. Simulation games, group challenges, and research projects can be used for indirect learning. Online platforms can deliver engaging educational content and host quizzes and competitions (gamification).

Iran	Tehran	A school in Tehran focusing on waste segregation in collaboration with the municipality.	Using the "Recycling" mobile app developed by Tehran Municipality to teach waste segregation and provide information on recycling station locations. Gamification features like competitions, point scoring, and rewards can enhance engagement (gamification and social marketing). Example: Schools in Tehran's District 6 collaborate with the municipality in the "Green School" initiative using this app and other methods.
Iran	Isfahan	A school in Isfahan focusing on smart waste management.	Some schools in Isfahan collaborate with the municipality's waste management organization to use smart bins with weight and volume sensors. Data is shared online with school administrators and students for waste reduction challenges and feedback to classes. Educational workshops and exhibitions raise awareness about waste management (IoT, gamification, and social marketing). Example: Farzanegan Amin Girls High School in Isfahan uses these approaches in the "Green School" initiative in collaboration with the municipality.

The Environmental Comprehensive Schools Charter (GEM) can be considered the primary guiding document on this topic. This document was created through the

collaboration and expert opinions of two governmental entities: the Ministry of Education and the Department of Environment. The charter provides a general framework for the creation and development of Green Schools and emphasizes the importance of student education and participation in environmental issues. In line with the goals of this charter, the use of modern approaches such as gamification, the Internet of Things (IoT), and social marketing can play an effective role in smart waste management and increasing student participation. For example, mobile apps and educational games can encourage students to separate waste and reduce waste production. Furthermore, the use of smart bins equipped with IoT sensors can provide accurate data on the amount and type of waste generated in the school, which can be utilized in educational programs and gamification challenges. Additionally, the use of social marketing techniques such as awareness campaigns and creating social networks within the school can promote waste management culture and increase participation from students and their families. These approaches not only align with the goals of the GEM Charter but also contribute to their more effective implementation [82]. A general overview of the charter document's outlook is displayed in Figure 1.
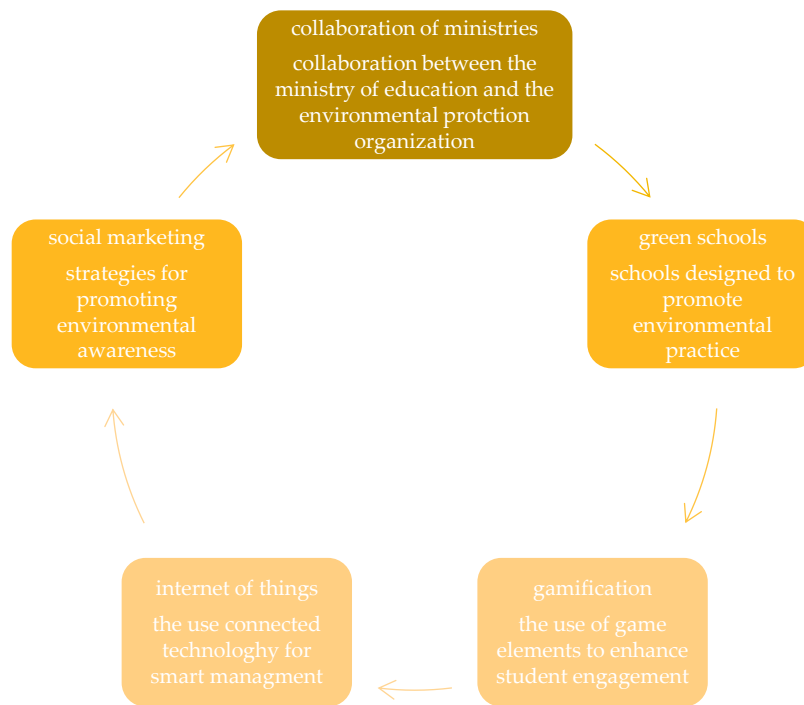

Figure 1. Components of the Charter for Comprehensive Environmental Schools

Institutionalizing the Concept of Protection and Responsibility: Through gamification and the creation of challenges and competitions related to waste segregation and reducing waste production, students' sense of responsibility can be strengthened. Additionally, showing waste-related data using IoT can make the impact of their actions tangible. Engaging Family Participation: Through social marketing and providing information about school programs and the results they yield, families can also be engaged in these

activities. Moreover, mobile apps can be used for communication between the school and families, offering educational tips and information. Promoting Efficiency and Optimal Resource Use: The use of smart bins and IoT-based waste monitoring systems can help optimize resource management and reduce the costs related to waste collection and disposal. Enhancing Students' Knowledge as Environmental Ambassadors: By teaching concepts related to waste management and the environment through engaging games and activities, students can become environmental ambassadors in their families and communities. Improving School Environment Structure and Conditions: Implementing waste management programs and using appropriate equipment can create a healthier and more sustainable environment in schools. Increasing the Knowledge and Awareness of Teachers and Educators: Holding workshops and providing educational resources on gamification, IoT, and social marketing can help increase teachers' and educators' knowledge and awareness in these areas. The goals outlined in the aforementioned document are categorized into two main groups: macro goals and policy-making and executive goals. With a focus on gamification, IoT, and social marketing, the executive goals are extended to strengthen student participation and awareness through gaming mechanisms and the use of modern technologies. These approaches, emphasizing smart processes and interactive learning, contribute to developing environmental sustainability. The summary of these goals is provided in Table 8.

Table 8. Goals and Executive Objectives in the Comprehensive Environmental Schools Charter:

Executive Objectives	Macro Goals and Policy-making
Create gamification mechanisms to encourage student participation in environmental programs	Foster self-motivation, enthusiasm, interest, awareness, and sensitivity in students
Participate in creating healthy and standard educational spaces by utilizing IoT for air quality and energy consumption monitoring	Transfer sensitivity and responsibility towards the environment, family, and society
Develop interactive online platforms to inform and advertise green school programs	Enhance environmental knowledge, literacy, and understanding through digital and smart tools
Work to prevent the supply of unhealthy and non-standard foods and educate on healthy nutrition through gamification	Generate positive behavioral and attitudinal changes in students and staff regarding the environment
Smartly link educational tools to recycling and resource-saving programs	Transfer awareness and information from educators to students and families

Facilitate the use of stationery and educational materials by designing smart resource management software	Transmit environmental values to future generations
Partially fund school expenses through social marketing and revenue from recycling product sales	
Participate in environmental information dissemination and advertising via digital platforms and social media	

This high-level document for implementing the comprehensive environmental schools program utilizes a specific process, and this execution algorithm is detailed in Table 9 [83].

Table 9. Structure of the Comprehensive Environmental Schools Program Implementation in Iran

Row No.	Connection with Other Elements	New Role	Old Roles
1	Control center, data reception, and processing from all elements	Smart Waste Management Platform	Permanent Secretariat of Schools of JAM
2	Design games, interact with the platform for data reception and feedback	Gamification and Motivation Expert	Advisor of Schools of JAM
3	Exchange of information and experiences with other schools, receive data from platform	Exchange of information and experiences with other schools, receive data from platform Green Schools Network of the Province	Provincial Council of Schools of JAM
4	Provide financial resources, interact with the platform to receive reports	Business Partner and Investor	Financial Supporters of Schools of JAM

5	Generate data, receive training, interact with the platform	Pilot Schools	Selected Schools for Program Implementation
6	Communicate with other stakeholders, receive feedback, provide reports	Community Liaison Manager	Schools of JAM Liaison
7	Operational project implementation at school level, data collection	Project Implementation Team	Environmental Group of Schools of JAM
8	Train students, teachers, and others, interact with platform to receive content	User Training	JAM Schools Training Role
9	Collaborate in project implementation, receive reports	Social Partners	NGOs
10	Support the project, create policies	Supervisory and Supportive Institution	Ministry of Education
11	Data Collection	Send data to the platform Data Collection	IoT Sensors
12	Send data to the platform, receive information from the platform	User Interaction	Mobile Applications
13	Send data to the platform	Data Completion	Data Input from Other Systems
14	Receive data from the platform	Report Delivery	Information Displays
15	Generated by the platform, used in decision-making	Performance Evaluation	Reports

16	Designed by the gamification expert, use of platform	data Motivation Enhancement	Gamification Games
17	Based on platform data and decisions	Process Improvement	Executive Actions
18	Use platform data and reports	Continuous Improvement	Performance Evaluation
19	Use the platform to provide content	Awareness Enhancement	User Training
20	Use the platform to communicate with stakeholders	Collaboration and Partnership	Stakeholder Interaction

This table outlines the execution structure of the Comprehensive Environmental Schools Program in Iran, showing the transition from old roles to new roles and how they connect with other elements involved in the process.

Evaluation and Enhancement Process for Comprehensive Environmental Schools

The program, particularly in the context of using gamification in smart waste management with a participatory approach to green schools, the Internet of Things (IoT), and social marketing, must have a clear process for evaluating different schools. This evaluation not only examines the overall performance of schools in waste management but also specifically assesses the effectiveness of gamification elements, the implementation of IoT-based smart systems, and the success of social marketing campaigns. This multidimensional evaluation enables continuous improvement and optimization of the program, helping schools take more effective steps toward becoming sustainable green schools [84]. This process, with an emphasis on the involvement of students, teachers, and the local community, aims to foster a culture of environmental responsibility. Additionally, the use of data collected by IoT systems allows for more accurate monitoring and performance analysis of schools. This data can be made available through management dashboards for schools and authorities, assisting them in making more informed decisions. Furthermore, evaluations can be periodically conducted using Key Performance Indicators (KPIs) to track schools' progress over time. These KPIs could include measures such as waste reduction levels, student participation rates in recycling programs, the local community's awareness of the school's programs, and the use of smart systems [85]. The evaluation and enhancement framework for the Comprehensive Environmental Schools program is outlined in Table 10 below.

Table 10. Operational Phases for the Comprehensive Environmental Schools Program

Number	Phase	Expanded Explanation	Connection to Article
1	Identification of pilot schools	Selection of schools based on criteria such as technological readiness, commitment to the environment, and participation in the program.	Designing the foundation for implementing gamification and installing IoT sensors.
2	Formation of the central secretariat	Creating an intelligent platform for data collection and processing.	Managing school information and coordination with all elements.
3	Assessment of the current status	Analyzing initial data from sensors, gamification games, and applications.	Identifying strengths and weaknesses in processes.
4	Designing the operational program	Developing educational, motivational, and operational programs for students, teachers, and other stakeholders.	Aligning with participatory goals and social marketing.
5	Initial program implementation	Using gamification to encourage students to separate waste and reduce consumption.	Collecting feedback for continuous improvement.
6	Performance evaluation	Analyzing reports provided by the platform and sensors.	Evaluating the impact of programs and decision-making for improvement.
7	Feedback to schools	Presenting graphical reports and analyzed information to schools.	Increasing awareness and motivation of students and teachers.

8	Continuous improvement	Implementing changes based on feedback and evaluated data.	Evolving and optimizing the system for new schools.
9	Expansion to other schools	Expanding the program to other schools after pilot success.	Sustainable development and widespread impact.

In line with the execution of the Comprehensive Environmental Schools Charter, the strategies outlined in the document needed to be transformed into actionable guidelines for operational and tactical stages. As a result, a Comprehensive Environmental Schools Instruction Manual was developed to operationalize the plan, and its general algorithm is presented in Figure 2 [86].

Figure 2. Process and Implementation Phases for the Environmental Schools Program

This structured approach ensures that all elements of the program are executed systematically, beginning with the pilot schools, moving through continuous assessment and refinement, and ultimately scaling to broader educational institutions. The program emphasizes the importance of feedback loops, data analysis, and gamified engagement, ensuring long-term sustainability and broad participation [86].

Sustainable Practices: Greening Our Schools for the Future

According to Figure 3(a), Education accessibility is a fundamental pillar of societal development, yet disparities persist across the world. While developed nations ensure widespread school availability with robust infrastructure and digital learning facilities, many developing regions face significant barriers, including long travel distances, financial constraints, and insufficient resources. Addressing these disparities through investments in school construction, transportation systems, and policy-driven initiatives is crucial to achieving universal education. However, merely providing access to education is insufficient if complementary factors, such as school nutrition and environmental sustainability, are not integrated into the learning environment [87]. Likewise, Figure 3(b) demonstrated that one of the critical aspects of school functionality beyond accessibility is its ability to sustain students through proper nutrition and waste management. School cafeterias, while ensuring food provision, contribute significantly to food waste. A study from three Florida schools highlighted that food waste accounts for 47% to 58% of total cafeteria waste, with an average generation of 52.2 g·student^{-1}·day^{-1}. Addressing this issue requires behavioral interventions through student education and structured waste recycling initiatives such as composting and anaerobic digestion. Reducing cafeteria food waste directly ties back to school accessibility, as food security within schools plays a vital role in ensuring that students, particularly in underserved regions, receive adequate nourishment. Schools with poor access to food resources may struggle with student attendance and performance, reinforcing the need for integrated waste management and food distribution systems [88]. Finally, according to Figure 3(c), Sustainability in schools extends beyond accessibility and food waste management to broader environmental responsibility. The Eco-Schools Wales initiative demonstrates how schools can leverage data from the School Health Research Network (SHRN) to monitor and evaluate their environmental impact. By using SHRN data, schools can track active travel rates, assess sustainability efforts, and engage students and staff in discussions on eco-friendly practices. This approach bridges the gap between food waste management and environmental education by promoting a data-driven framework for sustainable actions. If integrated globally, such data-driven initiatives could enhance waste reduction strategies in school cafeterias while fostering environmental responsibility among students [89]. Figure 3(a) establishes the foundation of education accessibility, ensuring that students have physical and financial access to schooling. However, access alone is insufficient if schools do not address sustainability challenges such as food security and waste management, as depicted in Figure 3(b). The analysis of cafeteria food waste highlights the inefficiencies in school resource utilization and the potential for integrating sustainable waste management strategies. Figure 3(c) extends this discussion by demonstrating how schools can systematically track and improve their environmental impact using SHRN data, aligning educational access with sustainability initiatives. Together, these figures emphasize the need for a holistic approach to education—one that encompasses accessibility, resource efficiency, and environmental stewardship. By integrating school accessibility, sustainable food management, and environmental

monitoring, educational institutions can create a comprehensive model for fostering a resilient, efficient, and eco-conscious learning environment. This interconnected approach ensures that schools not only provide education but also cultivate responsible global citizens who contribute to sustainability and environmental preservation.
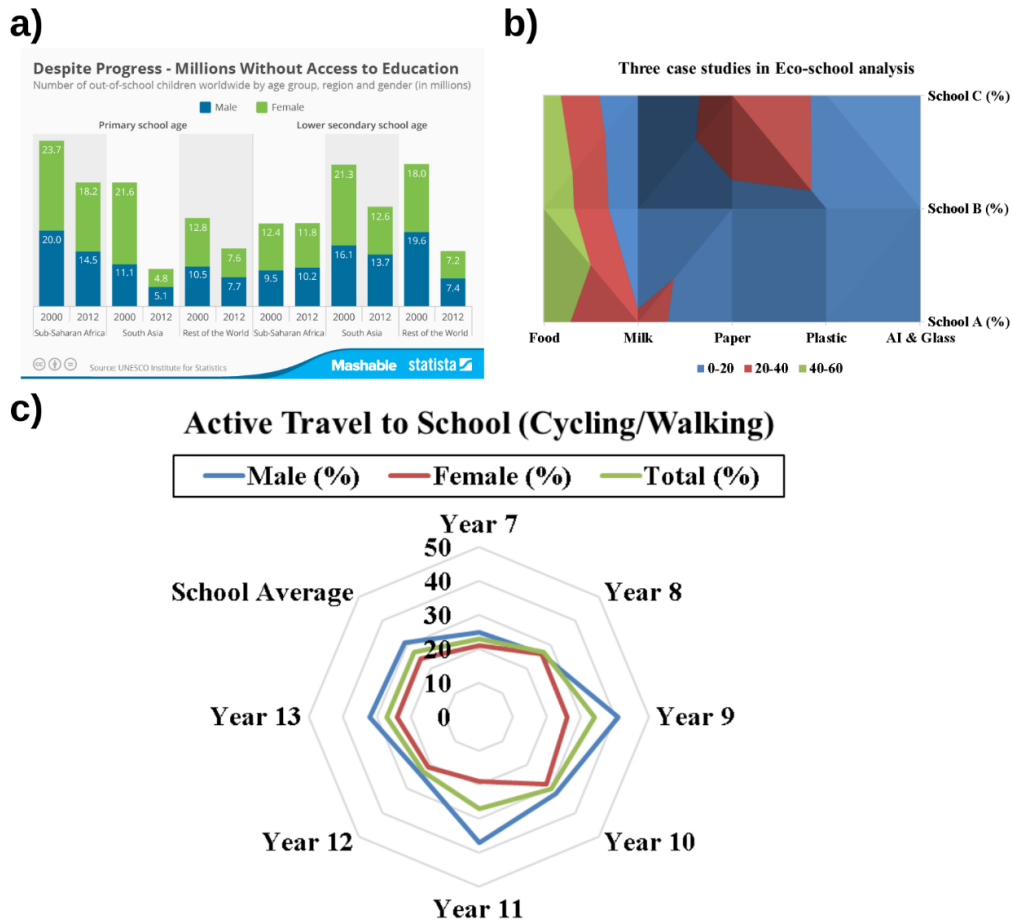

Figure 3. The data analysis of (a): School Accessibility and Provision Worldwide [87], (b): Case Study Analysis of School Cafeteria Food Waste [88], and (c): Eco-Schools Wales and the Use of SHRN Data for Environmental Education [89].

The outcomes of Eco-Schools implementations are evident in their contribution to sustainability, as demonstrated in Figure 4. Recycling initiatives within schools significantly reduce resource consumption and landfill waste. For instance, recycling one ton of plastic conserves 2,544 liters of oil, up to 7,571 liters of gasoline, and 23.3 cubic meters of landfill space, directly decreasing environmental pollution. Similarly, recycling one ton of office paper saves 26,498 liters of water, 1,753 liters of oil, and 17 trees, minimizing deforestation and excessive resource depletion. By integrating these eco-friendly practices, schools educate students on sustainability while promoting waste reduction, efficient resource use, and climate impact mitigation. Implementing structured recycling programs within schools aligns with broader environmental goals by fostering responsible

behaviour, reducing ecological footprints, and creating long-term benefits for communities and ecosystems. Eco-Schools play a vital role in shaping future generations to adopt sustainable lifestyles [90].
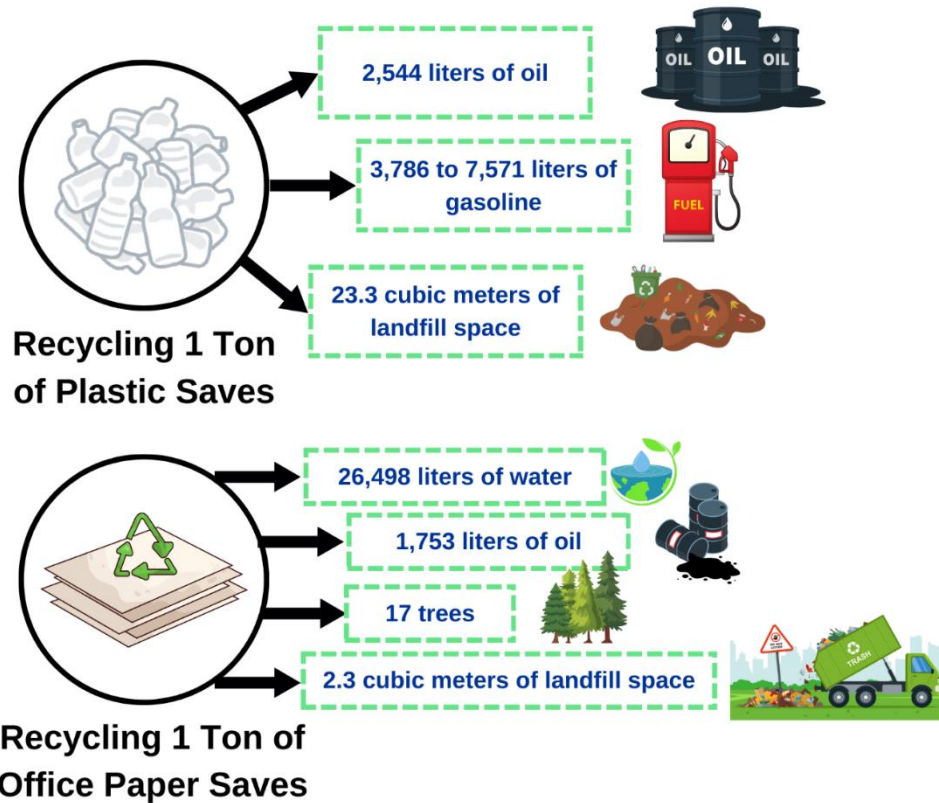

Figure 4. The concept of Eco-Schools drive sustainability by reducing waste, conserving resources, and energy [90].

Gamification and Eco-schools

The implementation of gamification in Eco-Schools follows a structured five-stage approach to enhance environmental awareness and engagement among students. The first stage, awareness and engagement, introduces ecological issues through interactive digital content, storytelling, and gamified challenges such as quizzes and simulations focused on climate change and waste management. The second stage, incentivized learning, integrates a reward system with badges, points, and leader boards to encourage participation while providing incentives for eco-friendly actions like proper waste disposal and reduced water consumption. The third stage, interactive problem-solving, involves team-based activities using digital games and online platforms to simulate real-world environmental challenges, including waste management strategies and sustainability planning. Moving into real-world application, students participate in hands-on projects such as recycling competitions and innovation challenges, tracking their progress through digital diaries and mobile apps. Finally, sustained engagement and community impact establishes long-term gamified

programs where students apply their knowledge beyond the classroom, supported by an eco-monitoring system that allows students and teachers to collaboratively track environmental improvements. This structured gamification model fosters engagement, motivation, and long-term sustainable behaviours among students [91].

According to Figure 5, Supervision in the study was implemented through a structured six-stage process to ensure the effectiveness of the environmental education program. It began with the design and planning of intervention, aligning ecological objectives with digital literacy goals. During implementation and monitoring, teachers and external facilitators guided students through digital tools, gamified tasks, and ecological exercises. Student progress tracking was conducted using e-diaries, teacher logs, and gamification-based performance metrics to assess engagement and learning outcomes. The evaluation of learning and behaviour changes involved assessing students' acquisition of ecological habits and digital competencies through structured feedback, discussions, and project presentations. Parent and community involvement played a crucial role, with families reinforcing environmental habits at home and providing insights into behavioural changes. Finally, post-intervention analysis and improvement ensured continuous program evaluation, identifying obstacles, and refining strategies for future implementation based on observed student engagement and impact [91].
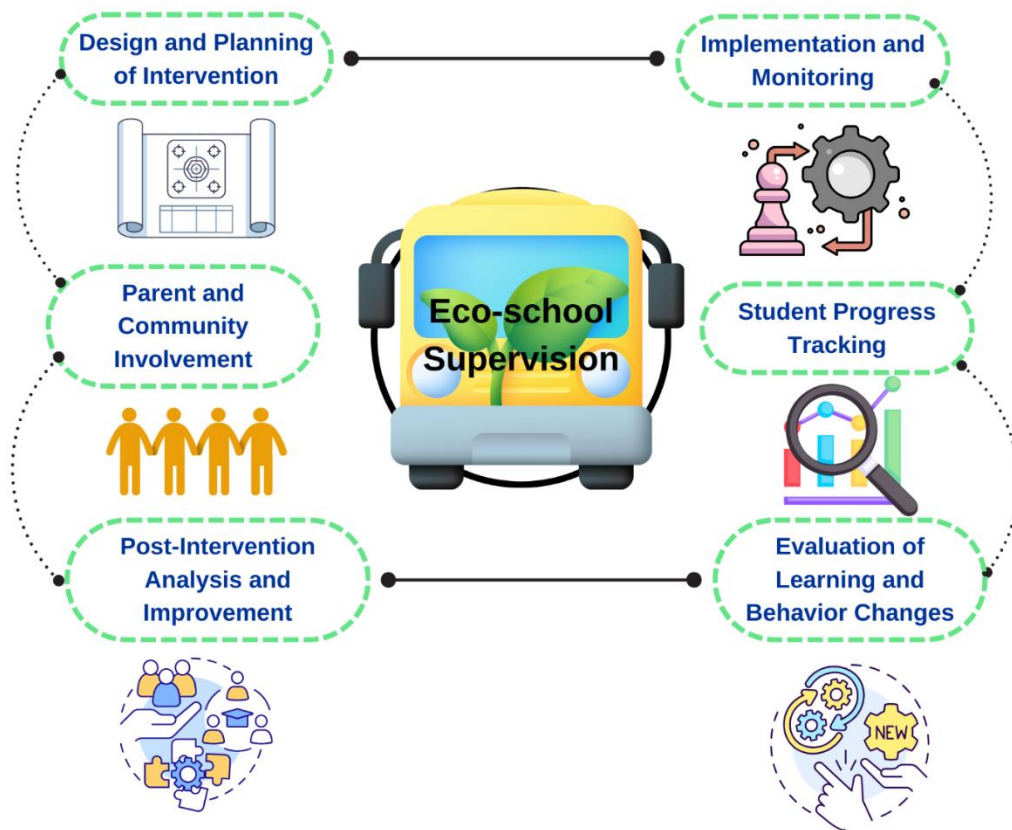

Figure 5. The concept of gamification supervision in Eco-schools.

CONSLUSION

The integration of gamification in Eco-Schools represents a transformative approach to fostering environmental awareness, digital literacy, and sustainable behaviours among students. By engaging students through interactive digital content, reward-based learning, and real-world applications, gamification not only enhances educational experiences but also instils long-term ecological responsibility. The study demonstrated that structured interventions—ranging from awareness-building activities to hands-on waste management projects—can effectively promote behavioural change. Additionally, the supervision process played a critical role in ensuring program effectiveness, with continuous tracking of student progress, parental involvement, and post-intervention evaluations helping refine strategies for future implementations. The application of gamification within Eco-Schools has proven to be instrumental in waste reduction, resource conservation, and fostering an environmentally conscious student body. The data highlights that the use of digital tools, competitive elements, and community-based challenges significantly enhances motivation and engagement. Moreover, the integration of real-time data monitoring and feedback systems ensures that both students and educators can assess and optimize their environmental efforts. Parental and community participation further reinforces the success of such programs, creating a collaborative ecosystem for sustainable development. Ultimately, Eco-Schools provide a model for integrating environmental education with innovative pedagogical strategies. The findings underscore the need for continued investment in gamified learning, real-world application of sustainability principles, and active participation from multiple stakeholders. Future efforts should focus on expanding the scope of gamification in education, integrating advanced technological tools such as the Internet of Things (IoT) for waste tracking, and enhancing data-driven decision-making for long-term sustainability. By institutionalizing these strategies, Eco-Schools can serve as a global blueprint for creating environmentally responsible citizens while addressing contemporary ecological challenges.

CONFLICT OF INTERESTS

The author declares that they have no conflicts of interest.

REFERENCES

1. M. Ram and E. Bracci, "Waste Management, Waste Indicators and the Relationship with Sustainable Development Goals (SDGs): A Systematic Literature Review," Sustainability, vol. 16, no. 19, p. 8486, Sep. 2024, doi: 10.3390/su16198486.
2. D. C. Wilson and C. A. Velis, "Waste management – still a global challenge in the 21st century: An evidence-based call for action," Waste Manag Res, vol. 33, no. 12, pp. 1049–1051, Dec. 2015, doi: 10.1177/0734242X15616055.
3. M. Helmefalk and J. Rosenlund, "Make Waste Fun Again! A Gamification Approach to Recycling," in Interactivity, Game Creation, Design, Learning, and Innovation, vol. 328, A. Brooks and E. I. Brooks, Eds., in Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 328. , Cham: Springer International Publishing, 2020, pp. 415–426. doi: 10.1007/978-3-030-53294-9_30.

4. L. Aguiar-Castillo, A. Clavijo-Rodriguez, P. De Saa-Perez, and R. Perez-Jimenez, "Gamification as An Approach to Promote Tourist Recycling Behavior," Sustainability, vol. 11, no. 8, p. 2201, Apr. 2019, doi: 10.3390/su11082201.

5. J. Rosenlund, M. Helmefalk, S. Stenfelt, and A. Palmquist, "Levelling up the Recycling Experience: Gamification of Recycling through an Innovative Recycling Station," Circ.Econ.Sust., Feb. 2025, doi: 10.1007/s43615-025-00510-w.

6. V. Tundjungsari, B. P. D. Putranto, M. B. Ulum, and N. Anwar, "CIRCONOMY: An IoT-based Waste Management Model with Semantic Web and Gamification Approach (An Indonesia Case Study) (Preprint)," Sep. 24, 2024. doi: 10.2196/preprints.66781.

7. G. Delnevo, G. Aguzzi, S. Letizi, M. Luffarelli, A. Petreti, and S. Mirri, "Encouraging users in waste sorting using deep neural networks and gamification," in Proceedings of the Conference on Information Technology for Social Good, Roma Italy: ACM, Sep. 2021, pp. 230–235. doi: 10.1145/3462203.3477056.

8. D. Vorobeva, I. J. Scott, T. Oliveira, and M. Neto, "Leveraging technology for waste sustainability: understanding the adoption of a new waste management system," Sustain Environ Res, vol. 33, no. 1, p. 12, Apr. 2023, doi: 10.1186/s42834-023-00174-x.

9. L. Beutelspacher, A. Mainka, and T. Siebenlist, "Citizen Participation via Mobile Applications: A Case Study on Apps in Germany," in Research Anthology on Citizen Engagement and Activism for Social Change, I. R. Management Association, Ed., IGI Global, 2022, pp. 988–996. doi: 10.4018/978-1-6684-3706-3.ch053.

10. Deeraj C, Dr. T Subburaj, and Neelesh B.U, "IOT based Waste Management System," IJARSCT, pp. 107–111, Jun. 2024, doi: 10.48175/IJARSCT-19020.

11. S. Mehta and A. Rathour, "Innovative Waste Management: The Efficiency of IoT-Enabled Smart Bins," in 2024 7th International Conference on Circuit Power and Computing Technologies (ICCPCT), Kollam, India: IEEE, Aug. 2024, pp. 467–471. doi: 10.1109/ICCPCT61902.2024.10672653.

12. J. N. Pretty, "Participatory learning for sustainable agriculture," World Development, vol. 23, no. 8, pp. 1247–1263, Aug. 1995, doi: 10.1016/0305-750X(95)00046-F.

13. R. T. LeGates and F. Stout, Eds., The city reader, Seventh edition. in Routledge urban reader series. London ; New York: Routledge, 2020.

14. M. S. Reed et al., "Who's in and why? A typology of stakeholder analysis methods for natural resource management," Journal of Environmental Management, vol. 90, no. 5, pp. 1933–1949, Apr. 2009, doi: 10.1016/j.jenvman.2009.01.001.

15. A. E. J. Wals, "Learning Our Way to Sustainability," Journal of Education for Sustainable Development, vol. 5, no. 2, pp. 177–186, Sep. 2011, doi: 10.1177/097340821100500208.

16. S. Sterling, Sustainable education: re-visioning learning and change, Reprint. in Schumacher briefing, no. 6. Foxhole: Green Books for the Schumacher Society, 2004.

17. M. Batty, The new science of cities, First paperback edition. Cambridge, Massachusetts London, England: The MIT Press, 2017.

18. J. McGonigal, Reality is broken: why games make us better and how they can change the world, Ed. with a new, 2. appendix. New York: Penguin Press, 2011.

19. C. Liao and H. Li, "Environmental Education, Knowledge, and High School Students' Intention toward Separation of Solid Waste on Campus," IJERPH, vol. 16, no. 9, p. 1659, May 2019, doi: 10.3390/ijerph16091659.

20. A. Cornwall, "Unpacking 'Participation': models, meanings and practices," Community Development Journal, vol. 43, no. 3, pp. 269–283, Jun. 2008, doi: 10.1093/cdj/bsn010.

21. J. Gaventa, "Finding the Spaces for Change: A Power Analysis," IDS Bulletin, vol. 37, no. 6, pp. 23–33, Nov. 2006, doi: 10.1111/j.1759-5436.2006.tb00320.x.

22. S. Malik, "Data-Driven Decision-Making: Leveraging the IoT for Real-Time Sustainability in Organizational Behavior," Sustainability, vol. 16, no. 15, p. 6302, Jul. 2024, doi: 10.3390/su16156302.

23. A. Galassi, L. Petríková, and M. Scacchi, "Digital Technologies for Community Engagement in Decision-Making and Planning Process," in Smart and Sustainable Planning for Cities and Regions, A. Bisello, D. Vettorato, H. Haarstad, and J. Borsboom-van Beurden, Eds., in Green Energy and Technology. , Cham: Springer International Publishing, 2021, pp. 387–397. doi: 10.1007/978-3-030-57332-4_27.

24. J. Michalska, J. Turek-Szytow, A. Dudło, and J. Surmacz-Górska, "Characterization of humic substances recovered from the sewage sludge and validity of their removal from this waste," EFB Bioeconomy Journal, vol. 2, p. 100026, Nov. 2022, doi: 10.1016/J.BIOECO.2022.100026.

25. M. Hajduk, M. Jaššo, M. Husár, and V. Ondrejička, "Citizen engagement within the process of realisation of the city energy transition projects," presented at the PROCEEDINGS OF THE 10TH WORKSHOP ON METALLIZATION AND INTERCONNECTION FOR CRYSTALLINE SILICON SOLAR CELLS, Genk, Belgium, 2022, p. 160004. doi: 10.1063/5.0105174.

26. S. Kalyazina, A. Borremans, and A. Dubgorn, "Participation of citizens in sustainable development of big cities," MATEC Web Conf., vol. 193, p. 01029, 2018, doi: 10.1051/matecconf/201819301029.

27. R. Schima, M. Paschen, P. Dietrich, J. Bumberger, and T. Goblirsch, "City of the Future: Urban Monitoring based on Smart Sensors and Open Technologies:," in Proceedings of the 8th International Conference on Sensor Networks, Prague, Czech Republic: SCITEPRESS - Science and Technology Publications, 2019, pp. 116–120. doi: 10.5220/0007484501160120.

28. B. Stelzle, A. Jannack, T. Holmer, F. Naumann, A. Wilde, and J. R. Noennig, "Smart Citizens for Smart Cities –: A User Engagement Protocol for Citizen Participation," in Internet of Things, Infrastructures and Mobile Applications, vol. 1192, M. E. Auer and T. Tsiatsos, Eds., in Advances in Intelligent Systems and Computing, vol. 1192. , Cham: Springer International Publishing, 2021, pp. 571–581. doi: 10.1007/978-3-030-49932-7_54.

29. M. Sicilia, A. Sancino, T. Nabatchi, and E. Guarini, "Facilitating co-production in public services: management implications from a systematic literature review," Public Money & Management, vol. 39, no. 4, pp. 233–240, May 2019, doi: 10.1080/09540962.2019.1592904.

30. "People's Question Time | London City Hall." Accessed: Mar. 04, 2025. [Online]. Available: https://www.london.gov.uk/events/peoples-question-time-0

31. "Audit Reports," Auditor General of Ottawa. Accessed: Mar. 04, 2025. [Online]. Available: https://www.oagottawa.ca/reports/audit-reports/

32. "Science and Sustainability through Outdoor Learning".

33. T. Yigitcanlar et al., "Understanding 'smart cities': Intertwining development drivers with desired outcomes in a multidimensional framework," Cities, vol. 81, pp. 145–160, Nov. 2018, doi: 10.1016/j.cities.2018.04.003.

34. "Decidim Barcelona | Barcelona Digital City | Barcelona City Council." Accessed: Mar. 04, 2025. [Online]. Available: https://ajuntament.barcelona.cat/digital/en/technology-accessible-everyone/accessible-and-participatory/accessible-and-participatory-5

35. J. Lopes, "Virtual Singapore – Singapore's virtual twin - Observatory of Public Sector Innovation." Accessed: Mar. 04, 2025. [Online]. Available: https://oecd-opsi.org/innovations/virtual-twin-singapore/, https://oecd-opsi.org/innovations/virtual-twin-singapore/

36. A. González-Briones et al., "RETRACTED CHAPTER: GarbMAS: Simulation of the Application of Gamification Techniques to Increase the Amount of Recycled Waste Through a Multi-agent System," in Distributed Computing and Artificial Intelligence, 15th International Conference, vol. 800, F. De La Prieta, S. Omatu, and A. Fernández-Caballero, Eds., in Advances in Intelligent

Systems and Computing, vol. 800. , Cham: Springer International Publishing, 2019, pp. 332–343. doi: 10.1007/978-3-319-94649-8_40.

37. L. Aguiar-Castillo and R. Perez-Jimenez, "Gamification or How to Make a 'Green' Behavior Become a Habit:," in Advances in Business Strategy and Competitive Advantage, O. Bernardes, V. Amorim, and A. C. Moreira, Eds., IGI Global, 2022, pp. 314–333. doi: 10.4018/978-1-7998-9223-6.ch015.

38. G. K. Shyam, S. S. Manvi, and P. Bharti, "Smart waste management using Internet-of-Things (IoT)," in 2017 2nd International Conference on Computing and Communications Technologies (ICCCT), Chennai, India: IEEE, Feb. 2017, pp. 199–203. doi: 10.1109/ICCCT2.2017.7972276.

39. M. P. Varghese, V. S. Anooja, R. Akhila, M. Krishnakumar, and A. Xavier, "IoT-Based Smart Waste Management System with Level Indicators for Effective Garbage Waste Segregation," in 2024 Third International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE), Ballari, India: IEEE, Apr. 2024, pp. 1–5. doi: 10.1109/ICDCECE60827.2024.10548589.

40. W.-E. Chen, Y.-H. Wang, P.-C. Huang, Y.-Y. Huang, and M.-Y. Tsai, "A Smart IoT System for Waste Management," in 2018 1st International Cognitive Cities Conference (IC3), Okinawa, Japan: IEEE, Aug. 2018, pp. 202–203. doi: 10.1109/IC3.2018.00-24.

41. L. Guedes Da Silva, L. Otavio Pereira Da Silva, J. Mark Lobo De Oliveira, and G. Vieira Da Silva, "GAMIFIED APP THAT MAPS COLLECTION POINTS AND PLACES OF ACCUMULATING SOLID WASTE IN THE URBAN ENVIRONMENT OF THE CITY OF MANAUS (AMAZONAS)," IJAR, vol. 10, no. 12, pp. 758–768, Dec. 2022, doi: 10.21474/IJAR01/15901.

42. D. Setiawan and R. Fabriansyah, "A study of Playscape approach for Eco-School at South Jakarta," IOP Conf. Ser.: Earth Environ. Sci., vol. 794, no. 1, p. 012223, Jul. 2021, doi: 10.1088/1755-1315/794/1/012223.

43. D. Czyżewska-Misztal, "Wykorzystanie sztucznej inteligencji na rzecz rozwoju miast i regionów," in Droga do zrównoważonej gospodarki światowej, 1st ed., J. Cabańska, D. Czyżewska-Misztal, and G. Mazur, Eds., Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu, 2024, pp. 43–52. doi: 10.18559/978-83-8211-245-0/3.

44. M. Gindert and M. L. Müller, "The Impact of Generative Artificial Intelligence on Ideation and the performance of Innovation Teams (Preprint)," 2024, arXiv. doi: 10.48550/ARXIV.2410.18357.

45. C. Kakatkar, V. Bilgram, and J. Füller, "Innovation analytics: Leveraging artificial intelligence in the innovation process," Business Horizons, vol. 63, no. 2, pp. 171–181, Mar. 2020, doi: 10.1016/j.bushor.2019.10.006.

46. P. Nnonyelu and N. Dongjie, "Strategies for Enhancing Solid Waste Management Practices in Urban Secondary Schools in Developing Countries," ejtas, vol. 2, no. 4, pp. 770–786, Jul. 2024, doi: 10.59324/ejtas.2024.2(4).66.

47. V. A. Bijlani, "Sustainable Cities With Gamification: How Gamification Can Help Improve Citizen Health and Reduce the Carbon Footprint," in Advances in Religious and Cultural Studies, R. A. González-Lezcano, Ed., IGI Global, 2023, pp. 205–226. doi: 10.4018/978-1-6684-6924-8.ch010.

48. B. Nikolov et al., "METHODOLOGICAL MODEL FOR ENHANCEMENT OF THE ECOLOGICAL COMPETENCES OF STUDENTS THROUGH SUSTAINABLE WASTE MANAGEMENT," PNS, vol. 1, pp. 73–77, Nov. 2020, doi: 10.12955/pns.v1.125.

49. S. Graham and A. Aurigi, "Virtual cities, social polarization, and the crisis in urban public space," Journal of Urban Technology, Apr. 1997, doi: 10.1080/10630739708724546.

50. G. G. F. Almeida, D. A. Rezende, R. D. C. D. Santos, and S. Czajkowski Júnior, "Estratégias urbanas e cidade digital estratégica como política pública: caso de Toronto," Cuad. Ed. Desar., vol. 16, no. 7, p. e4747, Jul. 2024, doi: 10.55905/cuadv16n7-046.

51. A. Nishu, "E-Toronto: Building a Digital Society," masters, OCAD University, 2022. Accessed: Mar. 14, 2025. [Online]. Available: https://www.abhisheknishu.com/projects-8

52. A. Van der Meer and W. Van Winden, "E-governance in Cities: A Comparison of Urban Information and Communication Technology Policies," Regional Studies, vol. 37, no. 4, pp. 407–419, Jun. 2003, doi: 10.1080/0034340032000074433.

53. R. Ferro-Escobar, H. Vacca-González, and H. Gómez-Castillo, "Smart and Sustainable Cities in Collaboration with IoT: The Singapore Success Case," in Machine Learning for Smart Environments/Cities: An IoT Approach, G. Marques, A. González-Briones, and J. M. Molina López, Eds., Cham: Springer International Publishing, 2022, pp. 213–243. doi: 10.1007/978-3-030-97516-6_12.

54. I. Aigner, M. Garai-Fodor, and T. P. Szemere, "Singapore's Journey as a Digit-all-ized and Innovative Smart Nation Toward Sustainability," in 2022 IEEE 10th Jubilee International Conference on Computational Cybernetics and Cyber-Medical Systems (ICCC), Reykjavík, Iceland: IEEE, Jul. 2022, pp. 000259–000264. doi: 10.1109/ICCC202255925.2022.9922714.

55. A. Ebadi, M. Toughani, A. Najafi, and M. Babaee, "A brief overview on current environmental issues in Iran," Cent. Asian J. Environ. Sci. Technol. Innov., vol. 1, no. 1, Feb. 2020, doi: 10.22034/CAJESTI.2020.01.08.

56. Koretsky Institute of state and law of the National Academy of Sciences of Ukraine, Kyiv, Ukraine. E-mail: kovalenko.v.v@gmail.com et al., "International and National Mechanisms Combating Ecosystems' Damage and Environmental Crimes to Foster Sustainable Development," GJNR, vol. 7, no. 2, pp. 63–82, Aug. 2024, doi: 10.33002/nr2581.6853.070203.

57. F. Balkau, "International Frameworks for Environmental Solutions," in Environmental Solutions, Elsevier, 2005, pp. 401–434. doi: 10.1016/B978-012088441-4/50016-2.

58. H. Haryono, S. Anggraini, and G. Iswahyudi, "Tinjauan Yuridis Perizinan dalam Pengelolaan Lingkungan Hidup Sebagai Sarana Pencegahan Pencemaran dan Kerusakan Lingkungan Hidup," almanhaj, vol. 4, no. 2, pp. 319–324, Oct. 2022, doi: 10.37680/almanhaj.v4i2.1806.

59. S. Chowdhury et al., "Sustainable Waste Management Using Deep Learning and Smart Bins," BJES, vol. 12, no. 6, pp. 36–47, Jun. 2024, doi: 10.37745/bjes.2013/vol12n63647.

60. J. Boeve-de Pauw and P. Van Petegem, "Eco-school evaluation beyond labels: the impact of environmental policy, didactics and nature at school on student outcomes," Environmental Education Research, vol. 24, no. 9, pp. 1250–1267, Sep. 2018, doi: 10.1080/13504622.2017.1307327.

61. L. F. Rahayu, "PENINGKATAN PENDIDIKAN DAN PENGELOLAAN LINGKUNGAN HIDUP MELALUI GERAKAN PEDULI DAN BERBUDAYA LINGKUNGAN HIDUP DI SEKOLAH," COM SERV EDU, vol. 1, no. 3, pp. 279–283, Sep. 2022, doi: 10.57254/eka.v1i3.42.

62. M. Zilincikova and J. Stofkova, "INTEGRATION OF SUSTAINABLE DEVELOPMENT MEASURES IN THE FIELD OF ECO-SCHOOLS," presented at the 16th International Technology, Education and Development Conference, Online Conference, Mar. 2022, pp. 7380–7387. doi: 10.21125/inted.2022.1863.

63. C. Chotimah, "Pengembangan Sekolah Berbasis Go Green dan Waste Management untuk Mewujudkan Green School di SDI Miftahul Huda Plosokandang Kabupaten Tulungagung," engagement, vol. 3, no. 2, Oct. 2019, doi: 10.29062/engagement.v3i2.78.

64. H. Qudsi, "GAMIFICATION IN EDUCATION: BOOSTING STUDENT ENGAGEMENT AND LEARNING OUTCOMES," ShodhKosh J. Vis. Per. Arts, vol. 5, no. 4, Apr. 2024, doi: 10.29121/shodhkosh.v5.i4.2024.2542.

65. G. Mannion, S. Johnson, A. Peacock, and W. Scott, "BOOK REVIEWS," Environmental Education Research, vol. 12, no. 5, pp. 637–645, Nov. 2006, doi: 10.1080/13504620601054090.

66. S. Özsoy, H. Ertepınar, and N. Sağlam, "Can eco-schools improve elementary school students' environmental literacy levels?," 2012, Accessed: Mar. 14, 2025. [Online]. Available: http://acikerisim.aksaray.edu.tr/xmlui/handle/20.500.12451/2721

67. S. Hallfreðsdóttir, "Comparison of Environmental Knowledge, Attitude and Actions between Students in Environmentally Certified Schools and Traditional Schools in Iceland".

68. A. Khalil, "Electronic Learning as an Entry Point for Promoting Environmental Awareness in Modern Curriculums," International Journal of Childhood and Women's Studies, vol. 3, no. 1, pp. 1–9, Jun. 2023, doi: 10.21608/ijcws.2023.329313.

69. Dr. D. Aggarwal, "Green Education for a Sustainable Future," JEIMP, no. 34, pp. 27–30, Jul. 2023, doi: 10.55529/jeimp.34.27.30.

70. H. A. Ghafaria, A. Karbassi, and A. A. Rajabi, "Green Schools based on Environmental, Health, Safety and Energy Strategy," Environmental Energy and Economic Research, vol. 1, no. 2, May 2017, doi: 10.22097/eeer.2017.47250.

71. A. M. Toda, P. H. D. Valle, and S. Isotani, "The Dark Side of Gamification: An Overview of Negative Effects of Gamification in Education," in Higher Education for All. From Challenges to Novel Technology-Enhanced Solutions, A. I. Cristea, I. I. Bittencourt, and F. Lima, Eds., Cham: Springer International Publishing, 2018, pp. 143–156. doi: 10.1007/978-3-319-97934-2_9.

72. M. Aazam, M. St-Hilaire, C.-H. Lung, and I. Lambadaris, "Cloud-based smart waste management for smart cities," in 2016 IEEE 21st International Workshop on Computer Aided Modelling and Design of Communication Links and Networks (CAMAD), Oct. 2016, pp. 188–193. doi: 10.1109/CAMAD.2016.7790356.

73. W. Wagner, "The Participation-Centered Model Meets Administrative Process," Wis. L. Rev., vol. 2013, p. 671, 2013, [Online]. Available: https://heinonline.org/HOL/Page?handle=hein.journals/wlr2013&id=681&div=&collection=

74. Ştefan Boncu, O.-S. Candel, and N. L. Popa, "Gameful Green: A Systematic Review on the Use of Serious Computer Games and Gamified Mobile Apps to Foster Pro-Environmental Information, Attitudes and Behaviors," Sustainability, vol. 14, no. 16, p. 10400, Aug. 2022, doi: 10.3390/su141610400.

75. R. N. Sukmana, A. J. Pradinda, T. N. Suharsono, Gunawan, and R. H. Laluma, "Gamification Implementation in The Learning Media for Waste Separation," in 2022 16th International Conference on Telecommunication Systems, Services, and Applications (TSSA), Lombok, Indonesia: IEEE, Oct. 2022, pp. 1–5. doi: 10.1109/TSSA56819.2022.10063908.

76. L. Addison and D. Boyd, "Early childhood education for sustainability within Scotland," in Understanding Sustainability in Early Childhood Education, Routledge, 2017.

77. L. J. Young and M. Subramaniam, "Eco-critical Consciousness Meets Oppositional Consciousness: Reading Early Chicago Housing Activism Through an Environmental Lens," Sociological Focus, vol. 50, no. 2, pp. 198–212, Apr. 2017, doi: 10.1080/00380237.2017.1251764.

78. B. L. Bruyere, M. Wesson, and T. Teel, "Incorporating Environmental Education into an Urban After-School Program in New York City," International Journal of Environmental and Science Education, vol. 7, no. 2, pp. 327–341, Apr. 2012, Accessed: Mar. 14, 2025. [Online]. Available: https://eric.ed.gov/?id=EJ990523

79. G. Trencher, T. Terada, and M. Yarime, "Student participation in the co-creation of knowledge and social experiments for advancing sustainability: experiences from the University of Tokyo," Current Opinion in Environmental Sustainability, vol. 16, pp. 56–63, Oct. 2015, doi: 10.1016/j.cosust.2015.08.001.

80. S. Breiting and P. Wickenberg, "The progressive development of environmental education in Sweden and Denmark," Environmental Education Research, vol. 16, no. 1, pp. 9–37, Feb. 2010, doi: 10.1080/13504620903533221.

81. "A Study on Eco-School Design for Sustainable Education Environment in the UK - Focused on BREEAM Certification Projects - -Journal of the Architectural Institute of Korea Planning & Design | Korea Science." Accessed: Mar. 14, 2025. [Online]. Available: https://koreascience.kr/article/JAKO201916842430196.page

82. A. Ayyanagoudar, A. Mohankar, J. Gharte, P. Pasnsare, B. Ainapure, and B. Appasani, "A Smart Bin with Real-Time Monitoring and Garbage Level Tracking Using IoT," in 2024 11th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), Noida, India: IEEE, Mar. 2024, pp. 1–7. doi: 10.1109/ICRITO61523.2024.10522263.

83. H. Meiboudi, A. Lahijanian, S. M. Shobeiri, S. A. Jozi, and R. Azizinezhad, "Creating an integrative assessment system for green schools in Iran," Journal of Cleaner Production, vol. 119, pp. 236–246, Apr. 2016, doi: 10.1016/j.jclepro.2016.02.004.

84. M. Dliyaul Haq, N. Hanif, A. Y. Rokhman, and K. Sukinawan, "Enhancing School Waste Management with EcoViber Using the Waterfall Approach," JIMAT, vol. 1, no. 2, pp. 19–29, Jul. 2024, doi: 10.62411/jimat.v1i2.11108.

85. A. Zivelonghi and A. Giuseppi, "Smart Healthy Schools: An IoT-enabled concept for multi-room dynamic air quality control," Internet of Things and Cyber-Physical Systems, vol. 4, pp. 24–31, 2024, doi: 10.1016/j.iotcps.2023.05.005.

86. A. Saeidi and H. Meiboudi, "Challenges of Evaluating Environmental Education in Iran's Green Schools and Strategies to Improve the Current Situation," Journals of Environmental Education and Sustainable Development, vol. 11, no. 2, pp. 107–117, Jan. 2023, doi: 10.30473/ee.2023.63265.2493.

87. "Infographic: Despite Progress - Millions Without Access to Education," Statista Daily Data. Accessed: Mar. 16, 2025. [Online]. Available: https://www.statista.com/chart/3180/out-of-school-children

88. A. C. Wilkie, R. E. Graunke, and C. Cornejo, "Food Waste Auditing at Three Florida Schools," Sustainability, vol. 7, no. 2, Art. no. 2, Feb. 2015, doi: 10.3390/su7021370.

89. C. Olson, "SHRN data to support Eco-Schools monitoring," DECIPHer. Accessed: Mar. 16, 2025. [Online]. Available: https://decipher.uk.net/news/shrn-data-to-support-eco-schools-monitoring/

90. "Green Growth Statistics." Accessed: Mar. 16, 2025. [Online]. Available: https://www.gemseducation.com/Our Promise/Sustainable Development/Green Growth Statistics

91. M.-C. Ricoy and C. Sánchez-Martínez, "Raising Ecological Awareness and Digital Literacy in Primary School Children through Gamification," International Journal of Environmental Research and Public Health, vol. 19, no. 3, Art. no. 3, Jan. 2022, doi: 10.3390/ijerph19031149.