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Gaming for change - exploring systems thinking and sustainable practices through complexity-inspired game mechanics

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This study examines how a serious game—Tipping Point—can improve systems thinking and sustainable decision-making. Building on earlier research in sustainability education, it addresses gaps in linking theory with hands-on practice by testing whether game-based learning can shift players from short-term, individual goals to long-term, collective strategies. An inductive, phenomenological approach was used with 70 participants from three academic programs in Belgium. Data were gathered via written reflections, focus group discussions, and facilitator observations during multiple game sessions. In Tipping Point, players made decisions on resource management, house construction, renovation, and waste removal, simulating real-world sustainability challenges. The game sessions showed that participants initially pursued immediate, self-centered actions but gradually shifted toward cooperative, future-focused strategies. Repeated gameplay and debriefings helped players recognize the benefits of resource sharing and adaptive planning, leading to a clearer understanding of the trade-offs between short-term gains and sustainable outcomes. This work demonstrates the potential of game-based learning to build essential skills in systems thinking and sustainable decision-making. The results support the inclusion of serious games in educational programs as a way to better prepare individuals for addressing complex social, economic, and environmental challenges, while suggesting useful avenues for further research.

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Introduction

The integrative perspective of sustainability necessitates, for the involved professionals, particular competencies for effective solving of ill-structured and value-laden problems (Clark and Dickson 2003; Kates et al. 2001; Komiyama and Takeuchi 2006; Swart et al. 2004). As outlined by Wiek and coworkers (Wiek et al. 2016; Wiek and Redman 2022), six (or seven) key competencies can be proposed as central to sustainability, namely systems thinking, anticipatory, normative, strategic, interpersonal/collaborative thinking, and integrated problem-solving competencies (plus critical thinking, as a possible seventh competency).

The role of education in addressing the sustainability crisis is substantial. However, its efficacy in yielding positive outcomes has faced criticism (Jickling and Wals 2008). Recent studies exploring the implementation of key competencies in sustainability education have uncovered significant obstacles (Redman et al. 2021; Trencher et al. 2018). These hurdles include disciplinary divisions, difficulties translating competencies into practical applications, a lack of alignment between desired competencies and teaching methods, inadequate resources in terms of time, materials, and collaboration opportunities, and insufficient attention given to emotional, social, and ethical dimensions (Idoiaga Mondragon et al. 2023; Parry and Metzger 2023).

This study is based on the working hypothesis that, to help students acquire skills in systems thinking, educational approaches need to be designed along systems thinking principles. Therefore it recognizes that the challenges faced by sustainable education and subsequent interventions are systemic in nature (Abson et al. 2017). Systems thinking, as defined by Arnold and Wade (2015), encompasses a cohesive set of analytical skills that enhance an individual's ability to recognize, understand, predict system behaviors, and utilize this knowledge to achieve desired changes. Lack of covering all key competencies and conveying how to best combine them inevitably leads to deficits in sustainability problem-solving (Wiek and Redman 2022).

Research in sustainability education design suggests an approach advocating for active learner engagement, exposing individuals to complex systems, and nurturing a sustainability-aligned mindset. This philosophy emphasizes addressing real-world problems connected to core sustainability values and concepts (Dieleman and Huisingh 2006; Tilbury 2004) while employing adaptive learning strategies to respond adeptly to evolving environmental challenges. Acquiring skills in this context necessitates experiential learning linked to tangible issues and activating methodologies (Backman et al. 2019).

In this context, environments like serious games offer promising opportunities to address educational gaps by offering immersive and engaging learning settings (Schell 2008b; Zeitz 2007). These games seamlessly integrate objectives, information, settings, themes, and storylines, thereby aiding players' comprehension of the significance of various activities and fostering a shared context (Gee 2007; Schell 2008a). This experiential and participative learning approach links enjoyment with educational outcomes, creating emotionally impactful learning experiences that engage players on multiple levels (Fabricatore 2007; Fabricatore and Lopez 2012; Gee 2007; Irabor et al. 2023; Lopez 2010). Experts advocate for a unique approach in educational gaming literature, emphasizing the deliberate fusion of game mechanics with clearly defined educational objectives within the game's structure, a concept currently lacking practical examples (Denham et al. 2016; Habgood and Ainsworth 2011). This distinctive approach might be crucial for improving sustainability competency development through serious games, by deliberately integrating complexity traits outlined by Fabricatore and Lopez (2012). These traits – emergence, uncertainty, non-linearity, self-organized adaptive evolution, and dynamic coupling – mirror fundamental aspects of sustainability challenges and effectively depict the complex interactions within sustainability challenges and their encompassing systems (Davis and Sumara 2009; Espinosa and Porter 2011; Fabricatore andd Lopez 2012; McDaniel and Driebe 2005; Miller and Page 2007; Salen 2008; Sweetser 2008; Tekinbaş and Zimmerman 2003).

Recognizing these sustainability traits as essential elements and characteristics of complex systems underscores the importance of systems thinking in sustainability game design to create environments that deepen understanding of systems and enable learners to apply this knowledge in comprehending and addressing sustainability challenges for behavioral change (Arnold and Wade 2015). However, existing research in serious games for sustainability often compartmentalizes experiences in either social, economic or environmental dimensions rather than considering their interconnectedness thus failing to capture the interactions effectively (Hallinger and Nguyen 2020; Stanitsas et al. 2019). This underscores the need for further empirical research to integrate these dimensions in learning scenarios, emphasizing their interplay (Stanitsas et al. 2019). Moreover, the scope of research on game-based systems thinking also remains limited, indicating a necessity for further exploration and integration of these complexities within serious games. Explicitly incorporating systems thinking as a pedagogical objective within serious games remains a crucial avenue for further development (DeVane et al. 2010).

To address the fragmented approach in many sustainability games, Tipping Point was intentionally designed to place participants in a situation where they must navigate limited land and growing waste, juggle scarce resource tokens and consider the costs or benefits of different actions, negotiate, share information, and collaborate to prevent collective collapse.

Research objectives

This study explores how participants engage with decision-making through their interactions with the Tipping Point game. The game requires players to navigate economic, social, and environmental dimensions within a shared system where individual actions contribute to collective outcomes.

The research objectives are aimed at exploring:

1. how participants engage with sustainability-related trade-offs in the game. This includes examining how they approach decisions involving resource use, collaboration, and waste management.
2. how participants' decision-making processes unfold over successive rounds of play. The study investigates how players respond to constraints, understand the game mechanics, and adjust their strategies over time based on this understanding.
3. how participants experience uncertainty in resource availability and its influence on their decision-making. This includes understanding how unpredictability in resource allocation shapes planning and adaptation.

By focusing on participants' experiences through an iterative process of repeated practice and reflection., this study seeks to provide insights into how serious games can facilitate engagement with sustainability challenges by simulating complex, interdependent systems. We chose an inductive, phenomenological approach because it was ideal for the dynamic environment, where predefined hypotheses might not capture the full range of participant insights. This method helped us understand their lived experiences and gain deeper insights into their perceptions and interactions. By focusing on their perspectives, we could explore the complexity of their decision-making processes within and beyond the game context. This approach was crucial for capturing the richness and diversity of their interactions, which might have been overlooked with a more rigid method.

Materials and Methods

Programs and study context. The University of Liège in Belgium offers several programs focused on sustainability. While the Tipping Point game has been used in various contexts, this research was specifically conducted in three of these programs. This selection was based on the presence of an introductory course on complexity, systems thinking, and sustainability management in these programs, as well as a balanced gender ratio among participants and the timing of ethical approval. The three programs are: an international post-graduate masters, entitled "Integrated Management of Health Risks" (IManHR) (Antoine-Moussiaux, Leyens (2023); Sidikou et al. 2022), a 4-month certificate titled "Understanding and managing the human dimensions of change for sustainability projects" (Accompanying Change), and an Environmental Health program with an ecosystem approach, constituting a minor within the Public Health master's program at the university.

The IManHR program focuses on developing a range of transversal skills in practitioners and executives from various sectors for field applications of the One Health concept, through constant back and forth between conceptualization and practice analysis (Antoine-Moussiaux, Leyens (2023)). It aims to address a broad scope of disease prevention and control situations, including crisis management, within public, private, or non-governmental sectors. The Certificate "Accompanying Change" aims to develop skills in professionals encountering difficulties in managing human-based dimensions in change-orientated projects, emphasizing aspects such as gaining support and engagement, building participative dynamics, leveraging collective intelligence, and addressing psychosocial obstacles. The Environmental Health program adopts an ecosystem approach, focusing on the intricate interactions between human activities, environmental factors, and public health outcomes. Through a comprehensive curriculum, students gain a nuanced understanding of the complexities involved in safeguarding human health within the broader context of environmental dynamics.

Study period

The study spanned from October 2022 to October 2023, accommodating five cohorts of participants, comprising two cohorts in the IManHR master's programs (October 2022 and October 2023), two in the certificate program "Accompanying Change" (March 2023 and October 2023), and one cohort in the minor in Ecosystem health, as part of the master's in public health (October 2023).

Description of the game. Tipping Point is a strategic game played on a board composed of 36 hexagons, initially covered by forest. This forest tiles can be replaced by houses, be cut down to express resource extraction (needed to build houses), or be covered by waste (produced by houses). Each turn, players must choose to build a house, renovate an existing one, or remove waste. A core rule is that players are compelled to act every turn; passing is not allowed. Players aim to score the most points by building houses – larger houses yield more points but require more resources and generate more waste, while smaller houses are less rewarding but generate less waste. Unpredictability intervenes at each turn as players draw two random resource tokens (R1 or R3) from a bag, constraining their possible actions. Waste is produced by all houses each round, gradually filling the board and reducing usable space. At the end of each turn, remaining forest tiles naturally absorb waste, meaning that this capacity diminishes as more forest is replaced by buildings. If the board fills completely with houses, cut-down forest, and waste before round six, everyone loses collectively. This means individual success is tied to the shared need to keep the island habitable.

Players constantly face trade-offs. Building more houses quickly boosts points but accelerates waste production. Renovating to smaller houses reduces waste but costs valuable resources. Removing waste manually is expensive (R3 token) and takes up a crucial turn that could be used for building or scoring. Also, the only way to obtain new resources in the course of the game is to build houses that are connected to other houses (mimicking economic benefits from urbanization). This dynamic—balancing building, renovation, and waste removal with limited, random resources—forces players to consider both immediate gains and the risk of overwhelming the island with waste. Repeated plays, failures and discussion help players learn to time their building and manage waste cooperatively, highlighting the tension between personal ambition and preventing system-wide collapse.

Resource management is central to success in Tipping Point in three ways. First, players must perform an action every turn using their resources. Second, to even be eligible to win, a player must have at least one resource token in hand at the end of the game. Running out of resources entirely means automatic defeat, regardless of points. Finally, any resource tokens held at the end of the sixth round are added directly to a player's score as shown in Fig. 1.

Initial design, intention and iteration. Developed as part of a research initiative, this game aims to explore how serious games can cultivate experiential learning and systems thinking skills. The design process specifically sought to embed systems thinking principles within the game mechanics, enabling players to actively engage with uncertainty, negotiation, and resource management.

A key design emphasis was placed on achieving accessibility and ease of learning through a fundamentally simple game structure. At its core, the game is built upon just three elements: land, shelter, and resources. Land is the finite island board. Shelter is represented by houses, providing both points and resources. Resources are tokens required to perform construction and waste management actions. This deliberately straightforward design—land, shelter, and resources—ensures rapid player uptake, yet it simultaneously gives rise to significant complexity. While the game's components are readily grasped, the inherent complexity emerges as players themselves begin to identify, understand, and strategically leverage the relationships between these core elements, as well as understand that the constrains of the game require them to revise their goals and mode of interaction between players.

Initial testing utilized an online format via Google Slides, facilitating remote playtesting with larger participant groups. Feedback gathered from these online sessions directly informed iterative design refinements. This process culminated in the creation of a physical 3D-printed prototype for research study. This prototype preserved the established core mechanics while enhancing tactile engagement, allowing participants to physically interact with the game components and more intuitively grasp the spatial and systemic relationships at play.

The game as part of a learning activity. The game was employed for approximately 3 to 4 hours during full-day introductory courses on systems thinking and complexity. These courses

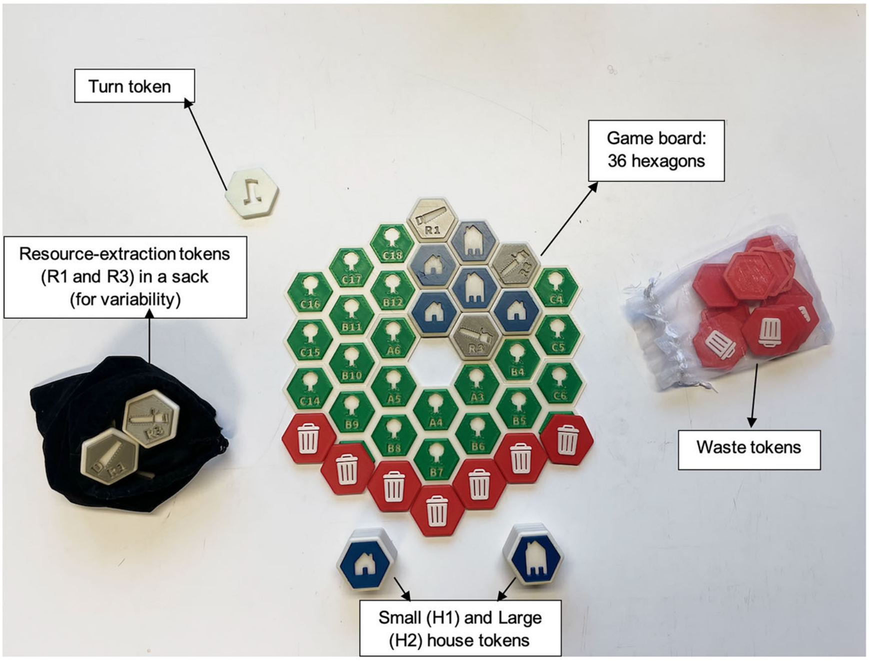

Fig. 1 Tipping point 3D prototype. The Tipping Point prototype presents a game board composed of green tiles depicting trees and bearing an alphanumeric identifier. The other tokens can be superposed to these green tiles to progressively cover the surface. Grey resource-extraction tokens (R1 and R3), symbolized by a saw, represent the process of converting raw materials to build the houses, figured by blue tokens of two sizes (H1 and H2). At the end of each turn, each house will generate red waste tokens (1 or 2), symbolized by small bins, which will also be added on the board and contribute to filling the space.

introduced key concepts, emphasizing the significance of uncertainty, diverse perspectives, and diverse knowledge in making decisions about complex issues.

The first 45 min were devoted to explaining the fundamentals of complex adaptive systems, exploring how independent elements or agents interact, leading to emergent outcomes that cannot be predicted from the individual interactions or elements. Following this introduction, the game was grouped into three sessions. Each session included six rounds of gameplay and a debriefing immediately after. Facilitation during gameplay ensured the game instructions were clearly presented (in French) and applied, with the facilitator aiming at limiting his influence on the dynamics of the game-participant interaction. Hence, the facilitator mediated or intervened only when necessary, aiming to enhance participants' autonomy (Kortmann and Peters 2017; Sitzmann 2011). During the debriefing sessions, a focus group guide was followed in a semi-structured manner (Appendix I) encouraging participant-led discussions. Adopting the same facilitation attitude as during the gameplay, the facilitator paid here particular attention to encourage the sharing of their thoughts by all participants. This was accomplished by soliciting feedback from other participants regarding their understanding or perspectives on the discussions presented by the previous speaker.

As depicted in Fig. 2, the configuration of each game session involved four teams, each consisting of 2–5 members, gathered around a single game board with a facilitator. Although designed as a four-player game, the format was adapted due to the number of students per program, allowing a team to reflect collectively and make decisions as a single player. This adjustment resulted in between 8 to 20 participants in 4 teams depending on the number of students present. The teams were formed based on simple criteria like proximity or similar birth months, and each team chose a nickname. The rapid pace of the gameplay ensured there was sufficient time for an extensive debriefing after each session.

The configuration of the learning activity was aligned with Kolb's four stages of experiential learning: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Konak 2014; Stice 1987). Participants engaged in reflection upon their decisions and actions during debriefing sessions, assessing the rationale behind their choices and their impact on the game's outcome, representing the "concrete experience" phase. Following this, the reflective observation phase involved analyzing performance and considering alternative approaches and strategies for subsequent gameplay. The abstract conceptualization phase, guided by a facilitator, focused on drawing general principles or lessons applicable beyond the game context. Finally, the active experimentation stage encouraged participants to implement new strategies based on insights gained, completing the experiential learning cycle, and guiding further decisions.

Participants. The inclusion criteria encompassed all participants enrolled in the selected programs, as the game was an integral part of their courses on systems thinking and complexity. There was an equal number of male and female candidates, ensuring a balanced gender distribution, consistent across all courses in the program as part of the selection criteria at the University of Liège. Additionally, two of the three programs recruited participants from various African countries, while the third program included participants from European countries. This diverse cultural and contextual background provided a varied sample population.

Initially unfamiliar with the concept of "systems thinking," participants began to understand the concept through discussions about their gameplay experiences, connecting it to the introductory theory presented earlier in the course and to real-life situations from their professional backgrounds in health or sustainability projects.

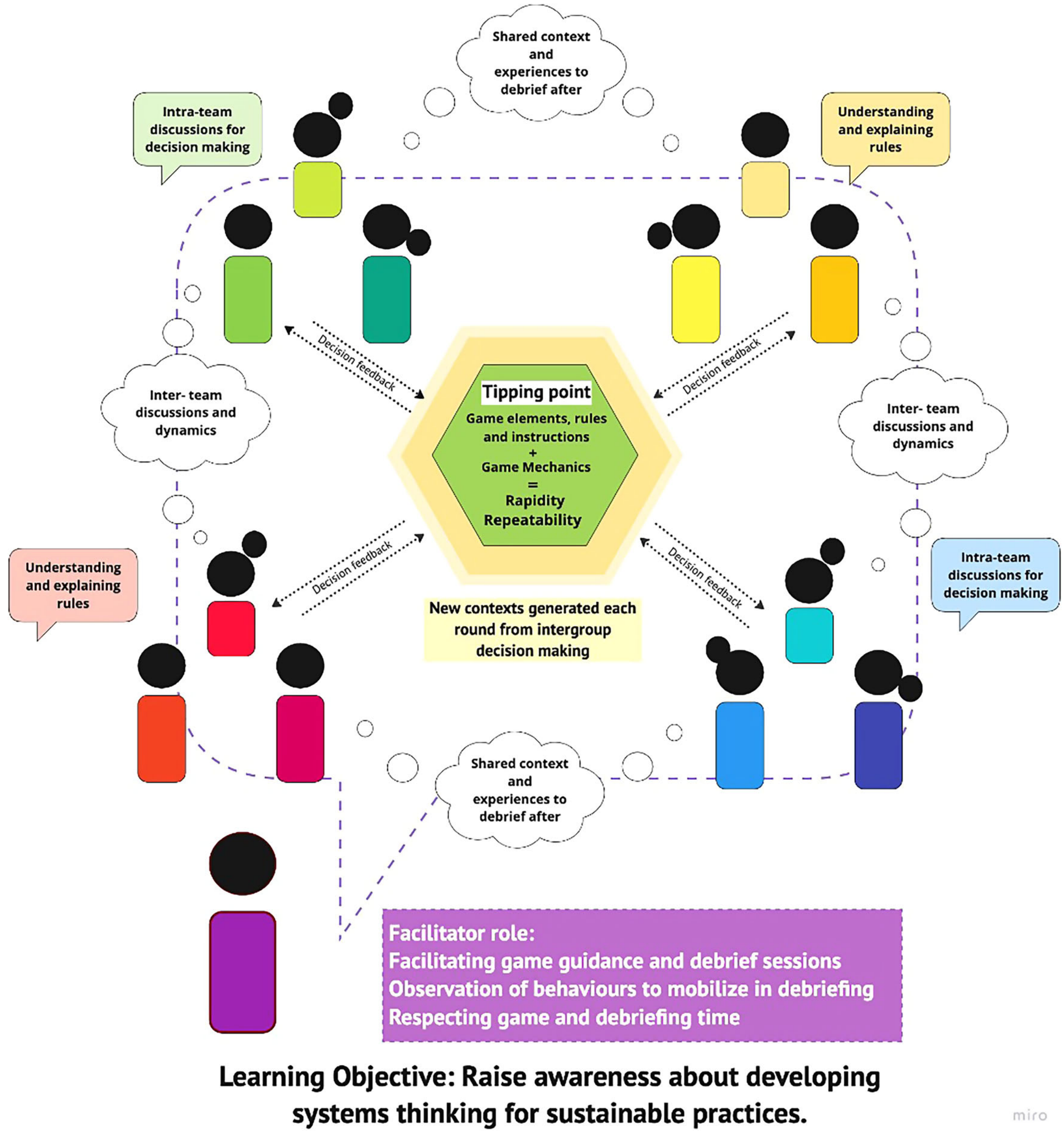

Fig. 2 Pedagogical framework for the tipping point game. The framework strategically coordinated interactions among the game as a repeatable and rapid shared experience for participant groups, guided by a facilitator to meet learning goals. Balancing structure with adaptability, time management was pivotal in shaping game cycles and debriefing sessions. The visual representation was created using Miro.com.

The study comprised an examination of 70 participants. Specifically, 27 from the first and second year of the Integrated Management of Health Risks master's program, 24 from the first and second year of the Certificate of Change program, and 19 from the minor in Ecosystem Health within the Public Health master's program. Participants represented a diverse array of academic disciplines, Including Public Health (26 participants), Medicine (17 participants), Veterinary Medicine (9 participants), Nursing (9 participants), Medical Imagery Technician (4 participants), Environmental Sciences (2 participants), Community Health (1 participant), Anthropology (1 participant), and Agronomy (1 participant).

The participants originated from countries such as Belgium (26 participants), Senegal (9 participants), Democratic Republic of Congo (8 participants), Cameroun (7 participants), Benin Republic (7 participants), Madagascar (6 participants), Burkina Faso (3 participants), Guinea (2 participants), Cuba (1 participant), and Niger (1 participant).The age range of participants varied from 24 to 54 years, contributing to a wide range of life experiences and perspectives within the participant cohort.

Data collection and analysis. Data collection for this study involved three primary methods: written reflections from participants, recorded focus group discussions, and facilitator observations during gameplay. Each participant provided written reflections after each of the three game sessions, either in hard copy immediately after the session or electronically via email within three to five days. These reflections were prompted by specific questions that encouraged participants to detail their experiences and evolving strategies throughout the game sessions.

For the focus group discussions, these were conducted immediately after each game session. The discussion was structured around a set of questions designed to elicit detailed responses about the participants' immediate reactions, any memorable moments, and connections they might draw between the game scenarios and their own life experiences. Both set of questions that nurtured the written reflections and focus group questions are available in appendix I.

Observations by the facilitators were documented after each game session during a debriefing with other facilitators of the master programs. This added an additional layer of data, capturing transversal patterns, unique instances, and non-verbal cues and dynamics across game sessions.

Data analysis began with an in-depth engagement with both the audio recordings and the written reflections. Each recording was listened three to four times, and the content was first transcribed with Microsoft Word®. The transcription, coding and initial themes were all conducted in French to preserve the authenticity of the participants' expressions. At the end, when themes were selected and being reported, the verbatim phrases chosen to support each theme were then translated to English by the author who is bilingual.

The identification of initial codes was conducted by systematically working through the data to highlight interesting features and recurring topics (Braun and Clarke 2006, 2012). To ensure that our coding was thorough and consistent, we employed a process of iterative refinement across two independent coders. This meant revisiting the data multiple times, each time with fresh eyes, to capture any additional nuances or overlooked details. Using an Excel spreadsheet allowed us to manage this large volume of data efficiently, adding comments and contextual notes to each coded segment separately, which we then cross-checked and compared to agree on a set number of codes (O'Connor and Joffe 2020). The high number of codes generated from both the focus group and written data reduced the need for intercoder reliability (O'Connor and Joffe 2020). An arborescent representation of the reviewed themes made it easier to reorganize categories, identifying commonalities, complementarities or overlaps. For example, there were similar codes that appeared in multiple areas and also appeared initially as potential themes. While some themes were expected based on the game's design, such as "systems thinking" we were open to emerging themes that we had not anticipated. This inductive approach ensured that the analysis remained grounded in the participants' actual experiences rather than being overly shaped by our preconceptions (Braun and Clarke 2006).

Once the themes were fully developed, we moved to the final stages of analysis: defining and naming themes and producing the final report (Braun and Clarke 2006). This involved clearly articulating what each theme represented and how it was supported by the data. For example, a theme like "adaptation and learning" was defined by how participants adjusted their strategies in response to the game's evolving challenges and feedback mechanisms. Producing the final report involved compiling our findings into a coherent narrative that accurately reflected the evolution of the participants' experiences from direct observation of gameplay.

Results

Regarding data collection and participant engagement, there was a response rate of 65.7%, with 46 participants submitting written reflections following the game or within several days after each session. All players participated in the debriefing sessions.

Thematic analysis and perspectives. The thematic findings are first presented along the three sessions of gameplay and debriefing, to show the evolving comprehension of the players and how it influences their thoughts, emotions, and behaviors over time. Then, an overview will consolidate the observed data to analyze the educational aspects reflected in the participant responses.

Session 1: initial decision-making and the impact of short-term thinking. The use of the 3D-printed board and tokens immediately captured participants' attention, with some commenting that the tangible elements reminded them of traditional board games. For many, this was their first experience with such a format, and the physical components helped shape their engagement with the session. Team nicknames further reinforced a competitive mindset, with one participant stating, "Groups were formed, each group had a nickname. This sparked in me the firm belief that our group would be the winner at the end of the game." This early emphasis on competition influenced how players approached their first decisions.

At the start of the game, most participants focused on individual point accumulation, treating construction as the primary means of success. Despite initial instructions emphasizing the need to sustain the board over six rounds, many players prioritized resource extraction without considering long-term implications. One participant reflected, "For me, the objective was simply to score the maximum points and win at all costs." This short-term perspective led to rapid depletion of available space and accelerated waste accumulation. Some participants showed early frustration as they realized the impact of their choices but hesitated to adjust strategies. The absence of immediate constraints in the first few rounds reinforced the belief that aggressive expansion was the best approach, delaying recognition of long-term consequences. As the board filled and options became more limited, participants began noticing the effects of their earlier choices. Some players attempted to slow construction, while others expressed frustration at their inability to reverse prior decisions. A participant remarked, "Even though it had been explained at the beginning, in my mind, it was still about winning more points." The facilitator observed that despite the game structure allowing multiple actions beyond construction, few participants initially considered alternative options, demonstrating how default strategies tend to focus on immediate gains rather than system-wide sustainability. Some players questioned the necessity of balancing expansion with preservation, recognizing that the game board functioned as a shared resource, much like the planet, where unchecked individual actions could lead to collective depletion when their available space ran out. One participant remarked, 'If we favor competition, we will end up losing the entire real resource… the real resource here is the island (game board), which is so limited.', reinforcing the difficulty of anticipating long-term risks without immediate consequences.

Session 2 results: expanding decision-making and recognizing resource constraints. By the second session, players became more aware of the constraints imposed by limited space and increasing waste. They began rethinking how construction impacted available resources, recognizing that every house built required placing both a house and a resource token, occupying two spaces. When constructing individually, teams consumed more space, which prevented the island's ecosystem from absorbing waste efficiently. As players continued to compete for resources, they also struggled with resource availability. Because resource tokens were the only currency to take actions, teams needed to generate them consistently. However, their competitive mindset led them to do so sparingly, which often resulted in shortages.

As waste accumulation increased, a turning point occurred when some teams began questioning whether resources could be shared. The game did not explicitly prohibit resource-sharing, but this option was not suggested to players, requiring them to recognize and ask for it themselves. When the unsustainable waste levels ultimately jeopardized any team's chance of reaching the sixth round and winning, some teams even contemplated deliberately depleting their resources to allow one team to advance. However, this strategy was not recognized as a win under the game's basic rules. It was only when teams prioritized collective survival over individual gains that resource-sharing emerged as a strategy. One participant reflected, "We were stuck with it because we were in the mindset of sacrificing ourselves, but we didn't know we could ask others to help us." Others later expressed frustration over the late realization that they had the option to redistribute resources, with one participant stating, "It greatly disturbed me not to have had that information from the start."

This shift in thinking also influenced house placement strategies. As participants increasingly acknowledged the potential for resource pooling and mutual benefit, their approach to house placement evolved. "The (house) placement is to produce resources so that they are made available to others," as one participant articulated. Teams began to coordinate house placement with the explicit aim of optimizing resource generation not just for individual gain, but to enhance resource availability for multiple teams. This fostered a more balanced capacity for essential actions like renovation and waste removal within the collective game. While the understanding of the necessity for collaboration grew, some players exhibited a reluctance to fully embrace collective strategies. As another participant noted, "players know and are aware that they still have to collaborate even if they don't want to." While the game experience illuminated the necessity of collaboration to win, the ingrained tendency towards individualistic play and a resistance to fully cooperative strategies persisted to some extent.

By the end of the session, participants demonstrated a greater awareness of how resource decisions influenced both individual and group success. The relationship between competition, resource allocation, and coordination became more apparent. A participant reflected on how individual decisions shaped team behavior, stating, "The behavior of each person in the game influences the behavior of their team; everything depends on their priorities."

As the session concluded, some teams recognized that long-term success required adjusting their approach earlier in the game. However, not all groups fully incorporated these insights into their strategies, and decision-making varied across teams.

Session 3: shifting paradigms – an adaptive learning process. During the third session, participants shifted from a focus on individual point maximization toward a shared goal of group survival, adopting a clear guiding principle: "Prioritize the survival of each group at all costs." This change was reflected in goal setting, action prioritization, and adapting to uncertainty within decision-making. For the first time, participants explicitly defined a collective objective, with a participant summarizing this realization: "Set our goals from the start. Yes, at no point did any group define the game's objective. It wasn't mentioned, but it also wasn't questioned, so if we had set the goal from the beginning, we might have been better at building collaboration right from the start." Establishing a shared purpose early in the game allowed teams to coordinate decisions more effectively, marking a shift from the previous sessions where decisions had been primarily reactive.

Teams also began visualizing the impact of their actions before making decisions, a departure from earlier rounds when strategies were largely short-term. One participant explained, "Before taking an action, we would already try to visualize its impact." This change was evident in how teams assessed future waste accumulation, reconsidered house placement for long-term efficiency, and balanced immediate versus future resource use.

As participants engaged in this process, they also became more aware of the uncertainty inherent in resource allocation. The unpredictability of drawing resources required teams to plan flexibly, adjusting their strategies in response to changing conditions. One participant described this, stating, "We clearly saw that as soon as we made a decision or took an action… there were sometimes consequences somewhere." Another participant compared this experience to real-world uncertainty, stating, "Drawing resources from the black sack reflects the unpredictability of everyday life." Some teams developed contingency plans, adapting their strategies based on possible resource distributions and house placement interactions.

During the debriefing, participants reflected on the necessity of adaptation, with some describing how observing other teams influenced their decision-making. One participant remarked, "I find that the game also taught us to adapt. Adaptation through observation of other players and teams. The initial phase was problematic, and gradually, we adjusted based on accrued knowledge." This learning process was also discussed in relation to why collaboration had not been prioritized earlier, with one participant noting, "It's a reflection of current society; initially, we were very individualistic, and later, when we see problems accumulating, etc., we start pooling ideas."

Several participants focused on the game's reinforcement of environmental consequences, particularly the impact of waste accumulation and the necessity of collective action. One participant highlighted, "There is an understanding that waste management and environmental concerns affect us universally, coupled with the realization that success hinges on collaboration." Others reconsidered the game's objective, shifting from an individual competition mindset to a more sustainability-focused perspective. A participant described this change, stating, "For me, the aim of the game was not just to win but to live well, not merely survive, meaning that each group lives with necessary resources while respecting the ecosystem." A key result from this was the emergent recognition of the island's limited self-regulating capacity for waste management. This was succinctly captured by a participant stating, "there is already a self-organizing system… but it's not enough; you have to think about waste management from the beginning." This insight revealed a crucial shift in understanding: participants recognized the necessity of proactive, player-driven interventions to maximize the game's inherent "ecosystemic services" (forest-based waste absorption).

Discussions also addressed the limitations of isolated decision-making. Some participants noted that team segmentation restricted early strategic development, creating barriers to coordinated long-term planning. A participant reflected, "Working in silos can never solve health problems; it only increases the risk of failure. Communication is crucial for an overall perspective." Another participant connected this to past health crises, describing how initial approaches to cholera prevention had been too narrowly focused, despite requiring a broader, interdisciplinary response.

Educational properties of the game. The game sessions revealed several important educational effects through the observations of facilitators and the reflections of participants. In the early rounds, most participants focused solely on building as many houses as possible to score high points. This short-term view led them to overlook the negative effects of rapid construction on land use and waste accumulation. Over time, many participants recognized that this approach was harming their group's success, prompting them to adapt their strategies by communicating more and sharing resources. One participant noted, "We realized we lacked mutual listening, so we decided to collaborate, listen to each other, and ensure our actions did not negatively affect the next team. That made the difference." Another explained, "We had to rethink our strategies completely. It wasn't just about building houses anymore…the number of houses we built and how we managed resources became critical." These reflections indicate that the game encouraged a process of continuous reassessment and adaptation in strategy.

A clear, common goal eventually emerged as an important element in guiding decision-making. One participant stated, "Representing a common understanding was very important to establish things in the same way for everyone." The emergence of a shared goal allowed teams to shift their focus from individual achievements to decisions that benefited the group as a whole.

The game also provided a safe space for discussing difficult topics such as environmental crises. Participants observed that the game environment reduced the stress around these heavy subjects. For instance, one participant remarked, "We 'killed' the planet three times, and we talk about it calmly." This suggests that the game helped lower the sense of intimidation typically associated with complex issues like governance and collective action.

In addition, many aspects of the game mirrored real-life challenges in sustainability and public health. The limited land and resource tokens required players to balance short-term gains with long-term well-being in a manner similar to how communities must weigh economic growth against environmental care. When teams shifted from competition to resource-sharing, it reflected the need for different groups in real life to work together and share limited supplies or budgets to address common challenges.

Finally, the debriefing sessions following gameplay were powerful in enhancing self-awareness and team building. One participant observed, "The game is the most powerful way to recognize yourself and your peers, because it creates a lot of enthusiasm. It is also a very effective tool for guiding behaviors toward goals." Many participants reported that the game helped them become better listeners, more open to different viewpoints, and more aware of their own behavior. As one participant summarized, "It was a valuable experience because I learned to listen, to consider external opinions, to see things differently, to trust, and to overcome some of my selfishness."

Discussion

Decision-making in a tragedy of the commons. Hardin's concept of the Tragedy of the Commons (Hardin 1968) describes how shared resources can fail when people focus on immediate self-interest rather than the long-term good. Although the first session of the game reflected the main ideas of the Tragedy of the Commons, it also shed light on the balance between logical thinking and social influences, as well as how delays in seeing outcomes complicate collective decisions.

One key observation was that the effects of the island (common good) use were not immediately obvious. This parallels real-world cases where environmental deterioration develops slowly, so people do not act until problems become serious (Devesh Rustagi, Engel (2010)). In the game, early signs of trouble were easy to ignore, causing players to respond too late (Thiault et al. (2018)).

Another finding was that not everyone worked together, even when shared effort seemed better. Many players held on to a competitive mindset, reflecting research that cooperation is more stable when there are strong ways to support collective rules (Lergetporer et al. (2014)). In the absence of formal structures, self-organization had inconsistent results, showing that success requires either internal social support or external regulation (Heyes 2023; Henrich, Boyd (2001); Zino et al. (2020)).

Many participants were also slow to invest in renovation and waste management. They saw these steps as an immediate expense rather than a future benefit, mirroring the tendency to focus on short-term costs over long-term advantages (Khairul Eahsun Fahim et al. (2023), p. 10; Ghufran et al. (2022)). The participants experience with the game's mechanics revealed an underlying tension between immediate resource use and the delayed benefits of proactive environmental management (Jayachandran 2021). This implies that effective policies might need to reframe early action, so it feels worthwhile and not just like a sacrifice (Kumar et al. (2022)).

Group interactions played a significant role in shaping behavior. Teams that engaged in open, supportive discussions tended to naturally adopt cooperative strategies, while groups where competitive norms prevailed were less likely to shift toward cooperation—even when the game's rules clearly made collaboration essential to avoid collective loss. This indicates that players' choices were not driven solely by logical, fact-based considerations, but were also heavily influenced by the surrounding social environment and peer dynamics. Research supports this by showing how cooperative behavior cascades through human social networks, highlighting the importance of a supportive group context for sustaining cooperation (Cooney 2019; Jacobs et al. (2010)).

Figure 3 shows a causal loop diagram that contrasts two pathways in the game. One loop shows how an individual, short-term strategy—focused on maximizing points through rapid house building—leads to increased resource use and waste, which reduces available island space and eventually causes the tragedy of the commons (game over). The other loop depicts a shift toward a collaborative, long-term strategy. Here, players respond to frustration by coordinating their actions: they build social trust, plan economically (optimizing house placement, coordinating resource generation and sharing), and engage in environmental care (using natural and manual waste removal, such as reinforcing ecosystem services with a 2:1 waste removal ratio). This collective approach reduces waste, frees up space, and sustains scoring potential.

While the game provided a view of how individuals respond to limited resources, it cannot be regarded as a mirror of reality, rather a caricatural perspective that helps the player and researcher live, observe and understand otherwise subtle phenomena. Indeed, real ecological and economic challenges stretch over much longer periods, in complex, multi-layered social settings, making them harder to track and address (Fernández-Giménez et al. 2019). In addition, real-world conditions involve deep-rooted interests and policy structures (Yang et al. 2023), that are obviously more powerful barriers to behavioral change compared to the mock setting of the game's rules and incentives. Since the game does not have an external authority to set or enforce rules, players must learn to manage shared resources and coordinate their actions on their own, relying on personal incentives, group discussions, and changing strategies. With no strict policies or penalties in place, participants depend on informal norms—such as mutual agreements, social pressure, and shared goals—to keep the system stable. This lack of a formal governing body reveals both the potential for self-organization and the risk that, without clear rules and oversight, short-term or individual interests may lead to resource depletion and social tension.

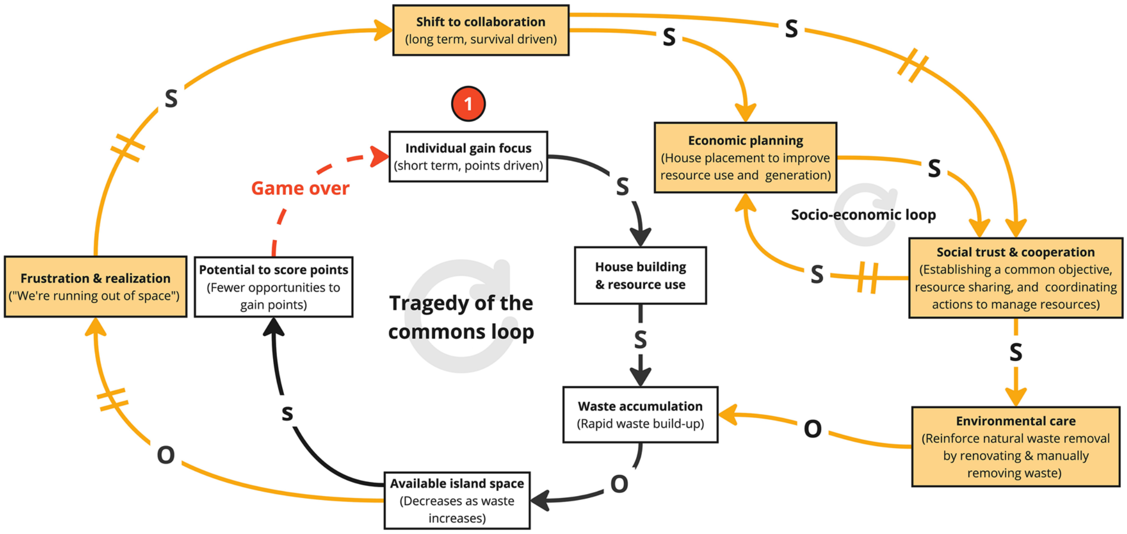

Fig. 3 Tipping Points' causal loop diagram. The diagram illustrates how a short-term focus on individual gain can lead to resource depletion over time. The arrows trace the flow of causes and effects, with double slashes (//) representing a delay between an action and its consequences. Arrows labeled "S" indicate that both connected elements move in the same direction (for instance, an increase in one leads to an increase in the other), while arrows labeled "O" indicate opposite changes. Following these arrows from the starting point (red #1) shows how rapid building and resource use escalate waste accumulation, reducing available space and increasing frustration. Recognizing these impacts prompt players to shift from an individual-centered strategy toward a more collaborative, sustainable approach. The diagram was created in www.miro.com.

Applying leverage points in a system. Leverage points are defined as elements within a system where the degree and manner of intervention can influence overall system behavior (Abson et al. 2017; Chan et al. 2020; Fischer and Riechers 2019; Linnér and Wibeck 2021). In Tipping Point, participants first act on weak levers (shallow) by trying to temper their pursuit of quick gains. Players see that every new house generates immediate waste—an effect so visible that many quickly realize they must adapt or risk saturating the board. However, their reaction is to question whether they will build small or big houses or try to connect houses in a different way but still on basis of individual reflections. This narrower focus on cause-and-effect relationships aligns with "forecasting" science, where outcomes are predicted by examining direct feedback loops (Abson et al. 2017; Fischer and Riechers 2019), with a system optimization that aims to adapt in terms of quantities or qualities of what is done.

However, as the game progresses into Session 2, it introduces more significant levers by shifting partly from short-term competition toward the broader goals of sustaining the board. This transition is accompanied by a more teleological perspective: instead of merely reacting to cause-and-effect cycles, participants explore the idea of defining a desired end state first and then working backward—a process known as backcasting (Dreborg 1996; Fischer and Riechers 2019). By doing so, teams identify the need to change rules and ways to interact between players. Several teams, for instance, moved beyond routine building and began sharing resources or coordinating house placement to ensure they had open spaces for future waste removal. These strategies showed how the game actively encouraged players to reconsider the purpose of their actions, rather than just the outcomes of any single turn. However, this shift still operated within a paradigm of competition, tempered by the recognition that a common good may justify some cooperation.

Through multiple rounds and failures, the synergy of causality (immediate feedback loops) and teleology (long-term goal setting) helps participants develop a more comprehensive understanding of system dynamics (Abson et al. 2017). By Session 3, many adopted a collective survival mindset, hence a radical shift in the paradigm, from a competition allowing cooperation to pure cooperation, where competition may have only held an annex and playful role (that often simply disappeared). Once this paradigm had shifted, teams had still to further reorganize both actions (e.g., anticipating waste production and absorption capacities) and rules (e.g., complete pooling of resources, simultaneous negotiation of all the actions of one round) in order to win (Fig. 4).

These results illustrate that even in systems with clearly defined goals, immediate feedback (causality) and long-term planning (teleology) interact to shape behavior (Abson et al. 2017; Fischer and Riechers 2019). Our findings support the need to move beyond short-term, parameter-focused fixes and to integrate immediate feedback with strategic, long-term interventions (Abson et al. 2017; Fischer and Riechers 2019; Meadows 2009). The hands-on experience of cycling between shallow adjustments and deeper paradigm shifts offered an accessible way to practice the core principles of systems thinking and sustainability, including both immediate problem-solving (forecasting) and purposeful, long-range planning (backcasting).

Reflections on sustainability competencies and disciplinary silos. The Tipping Point game offers an interactive way to foster the competencies needed for addressing complex sustainability issues. By encouraging participants to analyze a system and use those insights to guide collective change (Arnold and Wade 2017), it provides a problem-based environment that mobilizes a broad set of skills—from collaboration to strategic thinking (Brundiers et al. 2021; Brundiers and Wiek 2013). While the focus of this study was on decision-making in a constrained resource context, the real-time experience of forming strategies and negotiating outcomes mirrored the social dynamics of real-world group settings. This aligns with calls in sustainability education to emphasize interpersonal competencies, a gap often noted in the literature (Brundiers et al. 2021; Chen et al. 2018; Wiek and Redman 2022).

A central benefit of Tipping Point is its role as a boundary object—it allows participants from diverse fields to engage with a shared generic scenario, with which each player can engage

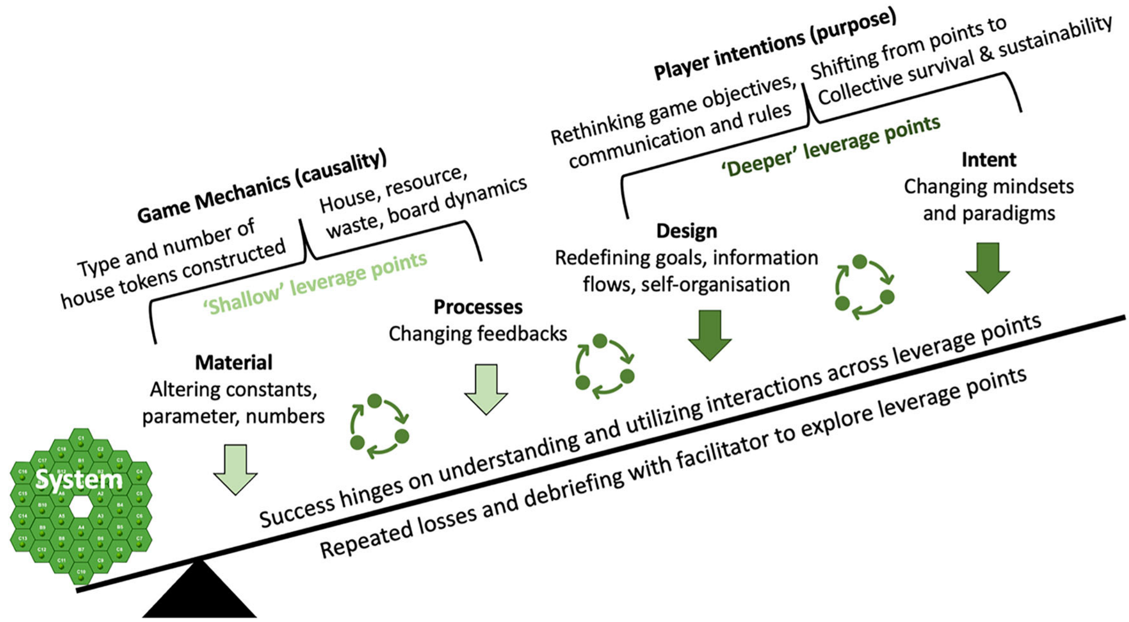

Fig. 4 Experiencing the leverage points in Tipping Point. Implementing Abson et al. (2017) model uncovers shallow (materials and processes) and deep (systems design and intent) leverage points influencing resource usage and waste dynamics on the limited board. Grasping these leverage points and their interactions is pivotal for success in tackling the sustainability challenges within the game. The feedback icons, featuring three arrows in a circular pattern, symbolize the interconnectedness among various leverage points.

through their own academic or professional lens (Akkerman and Bakker 2011; Black 2013). As a result, discussions in the sessions integrated a diversity of views, references, metaphors, and parallels to real life. Such diversity of viewpoints helps break down disciplinary silos, reinforcing the necessity of interdisciplinary collaboration for tackling multifaceted sustainability challenges (González-Pérez and Ramírez-Montoya 2022; Idoiaga Mondragon et al. 2023; Parry and Metzger 2023).

Interestingly, the facilitated discussions between participants tended to focus on ecological and social trade-offs. Hence, despite being central to the game mechanics, the economic dimension of the learning was less spontaneously discussed by participants. The lesser importance of economic dimensions in discussions may reveal biases due to participants' professional backgrounds (mainly pertaining to health-related professions), that can be corrected by a greater interdisciplinarity in the constitutions of the teams. The visual effect of the board saturation with red waste token and its direct relation to failure may also have contributed to attract attention to the environmental dimension. This partial focus, while reflective of how pressing environmental challenges can dominate sustainability debates, points to the need to more actively tackle economic trade-offs in debriefings to deepen the integration of all three dimensions of sustainability in the learning.

Facilitation, failure, and emergent learning outcomes. The educational framework for Tipping Point spanned three game sessions, yielding insights into how repeated failures and subsequent adjustments can strengthen sustainability learning. Observations suggest that setbacks, rather than hindering progress, captured participants' attention and led to deeper cognitive processing (Baumeister et al. 2001; Rozin and Royzman 2001; Taylor 1991). Notably, the collective nature of these failures reframed them from personal setbacks to group experiences, alleviating discouragement and fostering open, cross-disciplinary dialogue (Cochran and Tesser 1996; Eskreis-Winkler and Fishbach 2019; Hattie and Timperley 2007; Yeager and Dweck 2012). Facilitators played a pivotal role during the debriefings, providing enough structure to guide reflection while allowing spontaneous exchanges—thus underscoring how learning from collective failure can lead to improvements in approaching sustainability challenges (Hogan et al. 2023; Irabor et al. 2023; Lateef 2020; Pando-Garcia et al. 2016).

Within our broader teaching program on complex systems management, Tipping Point was developed as an integral part of formal pedagogical objectives formulated within a classical systems thinking framework. Rather than serving as the sole method for achieving these objectives, the game was designed to complement other instructional activities by offering a shared, experiential encounter with a pre-scripted complex problem. This approach enabled participants to practice their skills on a simplified, manageable model while engaging in discussions about key system elements, temporal dynamics, and emergent properties.

Through a retrospective analysis of the gameplay experience, we identified how specific design features of Tipping Point contribute to broader educational aims. Using established sustainability competencies as our foundation (Vare et al. 2022), Table 1 was created to retrospectively link core game design elements to specific learning outcomes. By mapping elements such as tool mechanics, rule structures, the facilitation method, the number of game plays, and the debriefing style to outcomes like ecological awareness, trade-off analysis, strategic decision-making, and cooperative problem-solving, the table demonstrates how the game fosters a progression from short-term, individualistic tactics to more integrative, long-term strategies.

Future implementations of Tipping Point could benefit from a more structured approach by defining explicit objectives at the outset (e.g., "fostering collaborative waste-management strategies" or "practicing adaptive planning under uncertainty") and systematically aligning each aim with relevant game elements. This strategy would allow for more targeted assessments of gameplay-driven learning gains while preserving the emergent, learner-centered qualities of the design. Adopting this

Table 1 A summary of specific game and facilitation elements that can support targeted learning outcomes.

Game element	Learning outcome and related competency *(references)*	Example indicators/observables	Rationale
Random resource draws	Adaptive planning and risk management *(strategic & anticipatory competency:* Wiek et al. 2016; Rieckmann 2018*)*	Players adjust their building or waste-removal strategies based on unpredictable tokens. Uncertainty is discussed during debriefings.	Blind resource draws simulate unpredictable constraints, forcing rapid strategy adjustments and risk assessment without relying solely on short-term tactics.
Limited island board	Awareness of resource limits and long-term planning *(consequence analysis* Wiek et al. 2016*;* Rieckmann 2018*)*	Participants discuss the diminishing space and plan actions to preserve available land.	The finite board visually represents limited resources, prompting players to consider long-term impacts of their expansion decisions.
Forced action every turn	Trade-off analysis and forward-thinking decision-making *(strategic decision-making & critical evaluation competency:* Wiek et al. 2016*;* Brundiers et al. 2021*)*	Players debate immediate gains versus preserving resources for later rounds. Group negotiations highlight opportunity cost considerations.	Mandating an action each turn forces continuous engagement, encouraging evaluation of immediate rewards against future benefits.
Increasing waste	Collective responsibility and shared stewardship *(collaborative and integrated problem-solving competency:* Wiek et al. 2016*;* Rieckmann 2018*)*	Teams encourage waste removal or opt for strategic constructions. Debrief discussions focus on the collective impact of waste buildup.	As waste accumulates, individual actions affect the whole board, underlining the need for cooperative management of shared resources.
House placement & renovation	Economic trade-off analysis and strategic planning *(integrated problem-solving & critical evaluation competency:* Wiek et al. 2011a, 2016*;* Brundiers et al. 2021*)*	Teams modify their building strategies in response to resource shortages. Discussions balance immediate point gains against long-term impacts.	Construction and renovation decisions illustrate the interplay between economic incentives and resource conservation, demonstrating broader impacts of local decisions.
Possibility of resource sharing	Emergent collaboration and negotiation *(Interpersonal and Collaborative Competency:* Rieckmann 2018; Brundiers et al. 2021*)*	Spontaneous proposals for sharing resources occur. Observations reveal token exchanges and shifts in group norms.	The organic emergence of resource sharing—without explicit instruction—highlights the development of cooperative problem-solving and peer negotiation skills.
Repeated cycles of play	Iterative learning and reflective adaptation *(Learning-to-Learn and Self-Awareness Competency:* Wiek et al. 2016; Rieckmann 2018*)*	Teams incorporate lessons from previous rounds into new strategies. Participants articulate how personal growth influences their evolving strategies over successive cycles.	Multiple rounds provide a safe environment for experimentation, allowing players to reflect on and adapt their strategies over time.
Immediate debriefing sessions	Critical reflection and evaluation *(critical reflection competency:* Rieckmann 2018; *Rounder sense of purpose – criticality)*	Participants draw explicit connections between game events and broader challenges. Facilitators observe increasingly detailed discussions.	Structured debriefings encourage players to critically assess their decisions and evaluate their performance, reinforcing a deeper understanding of sustainability challenges.

For each element, it lists the intended competencies, examples of observable behaviors during play or debriefing, and a brief explanation of how the game mechanic links to the learning process.

multidimensional framework may also advance the development of sustainability competencies (Wiek and Redman 2022) beyond what single-round or discussion-based formats typically offer. Subsequent research might refine these insights by contrasting Tipping Point with other sustainability-focused interventions, evaluating whether its integrated social–ecological–economic approach yields distinct shifts in participants' decision-making. However, brief gameplay and debriefing sessions could limit long-term skill retention, indicating a need for ongoing practice to reinforce real-world applications. Embedding games like Tipping Point into broader curricula—for instance, through project-based or problem-based learning—may help sustain and deepen these competencies (Brundiers and Wiek 2013; Corvers et al. 2016).

This study's design and methodology also impose several limitations tied to its framing, context, and analytical approach. First, the phenomenological and inductive method excels at revealing participants' lived experiences but depends on subjective reflections, which can be influenced by social desirability and limit generalization beyond this setting. Second, although 70 participants yielded rich qualitative data, this sample size may not capture the full diversity of potential responses. Third, embedding the game within health and systems-thinking courses shaped participants' engagement as both a learning exercise and a research activity; ethical constraints made control or comparative groups unfeasible, but this integration helps identify key variables and indicators for future comparative or longitudinal studies. Fourth, the researcher's dual role as facilitator and analyst, despite efforts to minimize intervention, may have subtly influenced participant behavior and interpretation. Finally, as an exploratory, single-case study of the Tipping Point game, the findings are context-specific, highlighting the need for further research using diverse educational settings and methodological designs to validate and broaden these insights.

Conclusion

The Tipping Point game proves to be a practical tool for cultivating systems thinking and sustainable decision-making. Participants shifted from focusing on immediate gains to embracing collective, long-term strategies through iterative gameplay and reflective debriefings. While the game simplifies many real-world challenges, it successfully exposes learners to the critical trade-offs and dynamic feedback loops inherent in sustainability issues. This experience underscores the value of experiential learning in engaging with complex system dynamics and suggests that further practice, as well as integration into broader educational programs, could enhance lasting behavioral change. Ultimately, the research invites educators and policymakers to consider game-based approaches as a promising means to inspire and prepare individuals to tackle real-world sustainability challenges.

Data availability

The data that support the findings of this study are not publicly available due to the nature of the consent provided by participants, which did not include permission for open data sharing. The data include sensitive qualitative material (e.g., voice recordings and written responses) that could risk participant identification, even if anonymized. For these reasons, the data cannot be shared openly. Requests for limited access to anonymized excerpts may be considered on a case-by-case basis, subject to ethical approval and institutional review.

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Author contributions
ITJ participated in the collaborative development of the serious game, contributed to study conceptualization, conducted data collection, and drafted the initial manuscript. YPSA undertook responsibilities related to data curation and analysis. PL contributed to the creation of illustrations for manuscript figures. PB and FD provided joint supervision of the project, ensuring textual coherence, and edited the manuscript. RRS contributed to the co-creation of the serious game and study conceptualization. NAM contributed to the co-creation of the serious game, project supervision, coherence review of the text, and manuscript editing. All authors reviewed and approved the final version of the manuscript prior to submission.

Competing interests
The authors declare no competing interests.

Ethical approval
The waiver of ethical approval (reference 2023/77) was issued on 21 March 2023 by the Comité d'Éthique Hospitalo-Facultaire Universitaire de Liège (707), University of Liège. The study was submitted for review in advance. As it did not fall within the scope of the Belgian law of 7 May 2004 on experiments involving human subjects—being non-interventional and educational in nature—a full ethical review was not legally required. Due to delays in receiving the formal response and the need to begin activities with participants at the start of the academic year, the study proceeded after submission but

before the waiver was received. It was conducted in accordance with institutional guidelines and the principles outlined in the Declaration of Helsinki.

Informed consent

Informed consent was obtained for the period from October 2022 to October 2023 through voluntary participation, confirmed by vocal consent and the submission of written materials. All participants were clearly informed of the study's objectives, procedures, and the possibility that focus group discussions would be recorded.

Additional information

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