Received: 9 February 2021 | Revised: 25 May 2021 | Accepted: 11 June 2021

DOI: 10.1002/sres.2805

RESEARCH PAPER

SYSTEMS and BEHAVIORAL RESEARCH SCIENCE

WILEY

System dynamics gamification: A proposal for shared principles

Giovanni Cunico[1,2] | Eirini Aivazidou[1,3] | Edoardo Mollona[1]

[1]Department of Computer Science and Engineering, Alma Mater Studiorum – University of Bologna, Bologna, Italy

[2]Business School, University of New South Wales (UNSW), Sydney, New South Wales, Australia

[3]School of Mechanical Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece

Correspondence
Giovanni Cunico, Department of Computer Science and Engineering, Alma Mater Studiorum – University of Bologna, Mura Anteo Zamboni 7, Bologna 40126, Italy.
Email: giovanni@cunico.org

Funding information
European Community's HORIZON 2020 Programme, Grant/Award Number: 693529

[Correction added on 17 May 2022, after first online publication: CRUI funding statement has been added.]

Abstract

As gamification has been gaining ground in research practice, system dynamics is no exemption. Despite the long tradition of system dynamics gamification, capitalizing on lessons learned from previous experiences is still challenging for practitioners. Specifically, the extant literature introduces a repertoire of system dynamics-based simulators and games under quite divergent perspectives and nomenclatures, while a comprehensive set of practical 'how-to-gamify' guidelines and a resource repository are lacking. Thus, this research aims to propose a set of shared principles by (i) providing an embryonic definition of system dynamics gamification and (ii) framing the most relevant challenges and drivers, to fill in the literature gaps and allow for effective knowledge accumulation. Overall, this work anticipates rendering gamification as a recognized branch of the systems dynamics domain by establishing a common language and recommending directions to improve practice and research efforts.

KEYWORDS

gamification, interactive simulators, serious gaming, system dynamics, virtual learning tools

1 | INTRODUCTION

Gamification is becoming popular within the research and business communities (Bohyun, 2015; Larson, 2020; Wünderlich et al., 2020), fostered by accelerating technological advancements. Particularly, the diffusion of information technology rendered gamification as an established technique within the human–computer interaction field (Rapp et al., 2019). Notably, the global gamification market value equalled USD 10 million in 2020 and forecasted to reach USD 38 million by 2026 with an annual growth rate of 25% over 2021–2026 (Mordor Intelligence, 2020). The gamification outputs that have a broader scope beyond sole entertainment are usually called *'serious games'* (Abt, 1970; Hendrix et al., 2016; Liu & Santhanam, 2017). These games can translate systems science and simulation modelling into learning experiences to capture human behaviour through interaction and feedback (Hämäläinen et al., 2020) and increase engagement and learning (Looyestyn et al., 2017; Robson et al., 2016). In fact, not only does the deployment of game-based learning tools provide a deeper systemic understanding, but it also offers additional benefits to the users, such as behavioural changes, knowledge retention, actions' stimulation and soft skills' development (Connolly et al., 2012; Rooney-Varga et al., 2020; Wouters et al., 2013). Notably, serious games based on simulation models have been broadly used in environmental management (Aubert et al., 2019; Flood et al., 2018) and social learning and engagement (den Haan et al., 2020).

The system dynamics (SD) field has also been involved in obtaining and delivering systemic insights through innovative learning tools. Beyond the above-mentioned positive aspects of serious gaming, SD gamification efforts have been focusing on improving researchers' and players' comprehension of non-linear complex systems evolving over time, aligning with the core purpose of the SD methodology (Forrester, 1961). Several practitioners have gamified their SD models across a wide range of research areas, such as operations strategy and management (Adamides, 2018; Lainema & Hilmola, 2005), business growth (Bianchi & Bivona, 2000), agricultural operations (Gómez Prada et al., 2020; Saysel, 2017), sustainability and climate change (Nordby et al., 2016; Rooney-Varga et al., 2020; Sterman et al., 2015), urban mobility (Papathanasiou et al., 2019), cybersecurity (Jalali et al., 2019; Zeijlemaker et al., 2019) and education and teaching (Sweeney & Meadows, 2010; Thomas & Milligan, 2004).

Given the important role of simulation gaming in policymaking and decision-making (Flood et al., 2018; Ryan, 2000), the use of SD gamification has been steadily increasing over time; however, this growth rate could be considered as lower compared with other domains (van Daalen et al., 2014). In fact, despite the variety of SD-gamified tools in the literature, authors use different nomenclature to describe their models, limiting researchers' ability to gain insights from existing efforts (Maier & Größler, 2000). Hence, the absence of a consistent standardized terminology is a critical challenge for the discipline's implementation and dissemination (Rabin & Brownson, 2012). To the best of our knowledge, a lack of a comprehensive overview of guidelines, technical options and successful past experiences is evident. In this context, the scope of this paper is to revive the debate about the state of the art in SD gamification and highlight the need for structured research to support practitioners in transforming their models into effective learning tools. Thus, this research poses the following research questions (RQs):

- *RQ#1: Which are the literature gaps in SD gamification that may hinder knowledge accumulation and challenge practitioners in their attempt to create effective SD-based learning tools?*
- *RQ#2: How can these gaps be addressed by offering a concrete definition of SD gamification and identifying the major challenges and drivers during the related process?*

Overall, this effort contributes towards supporting SD researchers and practitioners, as well as proposing a set of shared principles to start from. First, a literature overview is performed as scientific background to establish context and identify existing gaps. Then, we aim to advance SD gamification through (i) proposing an original broad definition to facilitate the adoption of a common language and (ii) developing a conceptual framework of challenges and drivers for supporting practitioners' efforts. Finally, recommendations for future research are provided for improving SD games in terms of utility and effectiveness.

2 | GAMIFICATION AND SD: LITERATURE OVERVIEW

2.1 | Gamification domain

The development of mediated or media-based settings for learning as result of gamification activities has a long tradition (Djaouti et al., 2011b). In general, the nomenclature *'serious game'* is used as an overarching category for referring to concepts (Bente & Breuer, 2010), such as edutainment, entertainment education, (digital) game-based learning or e-learning; although these terms are not synonymous (Michael & Chen, 2006), they are often used interchangeably (Ratan & Ritterfeld, 2009). Despite the rather chaotic nomenclature about gamified learning tools, the gamification motives and benefits are quite evident. In particular, games can be used as effective tools for intervention (Mayer et al., 2016) with diverse purposes: education, (e.g., teaching and training), experimentation (e.g., hypotheses validation and exploration and behavioural analysis), operations management (e.g., brainstorming, exploration and planning), policy development (e.g., public policy) and therapy (e.g., group or individual therapy) (Garris et al., 2002; Michael & Chen, 2006; van Daalen et al., 2014). In fact, the gamification strength lies in exploiting *'the motivational "power" of game design'* (Rapp et al., 2019, p. 1), and thus, 'fun' can be the mean through which learning is conveyed. Hence, players' entertainment is pivotal in any successful gamification process. Regarding the most important benefits of gamified efforts compared with traditional learning tools, the improvement of users' engagement (e.g., decrease of boredom in students) (Akkerman et al., 2009; Gee, 2003) and the learning experience facilitation (Gee, 2005) constitute indicative examples.

The spectrum of game participants can be quite broad (e.g., students, researchers and policymakers). At the same time, all educational attempts can range from board and card games to immersive virtual environments and role play games (Djaouti et al., 2011a; Ratan & Ritterfeld, 2009), while they can be designed for individual or group learning experiences. In this respect, Lou et al. (2001) indicate that group learning could have an added value on learning compared with an individual setting. In this perspective, the environment (e.g., social context and dynamics), in which the gamified tool is set, is of crucial importance for designers to facilitate usage and not to face resistance (Frank, 2007). Nevertheless, participants are not necessarily the only ones who are expected to learn from game implementation; a game can be also used to investigate specific variables and/or relations among them, explore human behaviour and inquire systemic behavioural patterns. In these cases, the players constitute the subjects of the experiment (Shubik, 1972), whereas the game developers are the learners.

2.2 | SD context and attributes

During the last decades, the attention of the SD community towards gamification has been high. Depending on the goals and contexts, SD games can be used by researchers to test and support a policy (van Daalen et al., 2014), as well as to learn about the decision-making process and the system in general (Moxnes, 1998). Indicatively, within the behavioural SD field (Lane, 2017), Barnabè and Davidsen (2019) developed a role-playing game to collect data on players' behaviour and then built a model replicating players' actions to analyse their decision-making heuristics. Notably, SD games are predominantly used as educational tools (Mayer et al., 2016) for conveying dynamic insights to participants who are asked to intervene into a system and control the impact of their decisions (van Daalen et al., 2014). In these cases, it is possible either to maintain the structure of the system fixed and let the user act only on the values of inputs and stocks or to let the player affect the decision rules of the game by modifying the system structure. In any case, the decisions can be taken once or several times at each game session. These systems can be a literal representation of reality or a metaphorical simplification (Meadows, 2001). Metaphorical games are abstract games suitable for presenting key concepts of a system with rather minimal detail (Morecroft, 2012; Sweeney & Meadows, 2010), whereas literal games are usually combined with real-world case studies (van Daalen et al., 2014). The repetition of the decision-making process is expected to create a learning experience by investigating the consequences of the decisions (Lane, 1995).

As gaining systemic insights tend to be challenging in the real world (Lane, 1995; Sterman, 2006), the prospect of sharing knowledge also to non-SD experts is fundamental. SD-gamified learning tools allow players to get involved, experience the systemic effect of specific actions and inform their decisions (Saysel, 2017). In addition to the usual co-benefits delivered by gamification per se, the ones related to these tools, such as improved players' decision-making skills, have been identified and discussed in the literature (Lane, 1995; Meadows, 2007; Qudrat-Ullah, 2010). Indicatively, seminar-based games allow participants to test, communicate and share ideas, rendering policymaking processes more interactive and innovative (Ya, 2010). *'Stratagem2'* (Sterman & Meadows, 1985), *'Beer Game'* (Sterman, 1992), *'Fish banks'* (Meadows et al., 1993) and *'Climate Action Simulation'* (Rooney-Varga et al., 2020) are indicative successful and famous efforts. Interestingly, the open-ended city-building video game *'SimCity'* is another example of SD gamification, yet for pure entertainment purposes (Langley & Larsen, 1994; Starr, 1994). Gamified learning tools can be physical (e.g., boards and cards), virtual (e.g., computer simulation) or a combination of both (van Daalen et al., 2014). Simulation may or may not be involved. When SD-gamified tools are embedded into a virtual context, they act as enablers of human–computer interactions (Rapp et al., 2019). Games are either single- or multi-player (Maier & Größler, 2000), and multi-player games can be with or without social interactions (van Daalen et al., 2014). Finally, SD learning tools do not stand alone, but they are usually anticipated, accompanied and followed by briefing, facilitation and debriefing (Andersen et al., 1990; Lane, 1995; Qudrat-Ullah, 2010).

2.3 | Obstacles and gaps in SD gamification

The different nomenclature utilized by researchers to describe their work is a key challenge in SD gamification (Maier & Größler, 2000). In fact, the outputs of SD model gamification have been named in several different ways, including serious games (Zeijlemaker et al., 2019) or operational gaming (Meadows, 2007). Additional confusion arises when referring to simulators, namely, the user-friendly interfaces, which allow non-expert users to interact easily with models. SD simulators have been called, among others: management simulation (Lane, 1995), interactive learning environments (Alessi, 2000; Davidsen, 2000), dynamic simulation games (Barlas & Diker, 2000), management flight simulators (Bianchi & Bivona, 2000), dashboard flight simulators (Porter, 2018), SD-based interactive games (Andersen et al., 1990), simulation interfaces (Davies, 2002), SD model-based learning (Groesser, 2012), participatory simulation

(Groesser, 2012), interactive simulation (van Daalen et al., 2014), microworlds (Lane, 1995) and simulation-based learning environments (Stave et al., 2015). Although minor differences exist (e.g., interactive learning environments are generally more transparent than flight simulators), all these terms refer to similar SD gamification outputs. This variability hinders researchers and practitioners from exploring prior knowledge.

Moreover, there is an absence of an overview of the technical options available, as well as of the respective advantages and disadvantages. Over the years, several SD-gamified tools have been built, and many of them have been made available either for free or for sale. In addition, several environments and software development companies, creating and supporting SD-gamified tools, have emerged in the market. However, the developed tools are scattered over different platforms, websites and organizations (public or private), including GitHub, Isee® Exchange, SD society, MIT Sloan LearningEdge management flight simulators (Sterman, 2014), BTN® company repository, Forio® repository and Climate Interactive (Sterman et al., 2015). This situation can become problematic for practitioners; as an overview of all related efforts in the literature is lacking, the possibility of replicating, re-gamifying and building upon existing models decreases considerably.

Similarly, a structured set of detailed principles and guidelines, describing how SD models could be transformed into gamified tools, is not available; for example, if a researcher intends to convert their SD model into a physical (e.g., board) game to provide players with dynamic insights on a system, there is no specified procedure to follow. It is only possible to attempt to mimic accessible material and case studies, although the process of building these games is usually not reported. Scattered descriptions of challenges, pitfalls and warnings (Alessi, 2000; Andersen et al., 1990; Davidsen, 2000; Lane, 1995), which SD game designers should consider while gamifying their work, constitute the most pertinent evidence. However, the provided practical advices are rather outdated compared with software development and bypassed by the advancements in platforms during the last years. Only recently, van Daalen et al. (2014) provided an updated aggregate list of gamification choices that an SD practitioner should focus on while gamifying their work.

This dearth of inputs on how to gamify an SD model is of major importance because it may create confusion in newcomers or non-experts in SD gamification, rendering the development of SD learning tools challenging; although it might even be relatively easy to build an SD game, it is often difficult to create an effective and successful one (van Daalen et al., 2014). Moreover, the lack of guidance usually entails high costs in terms of time and quality. In addition, SD gamification is coming into the foreground as technological and knowledge improvements have put gamification within the reach of a broad range of people. Indicatively, modelling software has rendered simulators even more accessible (van Daalen et al., 2014); for instance, the development of user-friendly interfaces is becoming a common exercise in SD modelling classes.

3 | TOWARDS A SET OF SHARED PRINCIPLES

3.1 | A proposed definition for SD gamification

To the best of our knowledge based on the extant literature, an absence of a comprehensive and accepted definition of SD gamification is evident; thus, we propose the following embryonic one: *'SD gamification is the process of developing and designing media-based or mediated learning settings to be used as learning tools based on SD knowledge and formal models'*. This definition stems from the existing gamification theory (Bente & Breuer, 2010), while it is quite broad and flexible enough to embrace most of the gamification efforts undertaken by SD practitioners under this unique definition-umbrella.

With respect to the SD gamification process output, the learning tools deriving from gamification processes are usually generically named as *'simulation games'* (van Daalen et al., 2014). However, *'simulation'* and *'games'* are considered as two distinct concepts (Lane, 1995). Although these terms are frequently mentioned interchangeably or in combination with each other, their use is rather inconsistent (Lane, 1995) and contributes to increasing confusion about SD taxonomy (Maier & Größler, 2000). Lane (1995) distinguishes simulations and games based on the level of (i) the user's intervention on the item (*'A game is deemed to be a collection of information and relationships in rules, algebra and logic made visible to an observer, and presenting data to and requiring information from an observer/participant. A simulation, on the other hand, is simply a collection of information and relationships in rules, algebra and logic made visible to an observer'*, p. 605); or (ii) the verisimilitude with the real world (*'A "simulation" is a specified sequence of verisimilitudinous activities designed to convey lessons to the participants on the properties of a real-world situation. A "game" is then defined as a specified sequence of activities designed to convey benefits to the players'*,

p. 606). On the other hand, Maier and Größler (2000, p. 145), in their classification of learning-oriented computer simulations, distinguish simulators and games based on the number of users (i.e., single-user applications are defined as '*simulators*', whereas multi-user applications are labelled as '*planning games*'). In general, Lane's (1995) conceptualization seems to be preferred as it is in line with the broader concept of the gamification community (Elgood, 1988) and it has been already used in SD practice (Meadows, 2001).

Therefore, in terms of the user's intervention, a game requires an increased interaction by the player compared with a simulation that offers users a limited possibility to interact and renders a model mainly accessible to the observer (Elgood, 1988). Regarding the verisimilitude with the real world, a simulation aims to provide an as realistic as possible representation of the system under study compared with a game that primarily tries to convey policy benefits to the players (Elgood, 1988). These two aspects constitute key dimensions to elicit the difference between the concepts of simulation and game. As Lane (1995) and van Daalen et al. (2014) suggest, a metaphor of a continuum with two extremes is probably the most convenient and effective way to frame the SD gamification output. Accordingly, we suggest that the SD gamification output may be regarded as an overarching category lying in the spectrum between these two extremes with their own characteristics (Figure 1). The usual SD model can be considered as a simulation in which the user can only 'play' with few buttons (e.g., start and stop). In contrast, games are much more interactive user experiences based on SD knowledge and models (e.g., Beer Game). In between, it is possible to place simulators: SD models with user-friendly interfaces within which players can manipulate a considerable number of parameters' values and control the impact of their actions on the system.

3.2 | A framework to rationalize SD gamification challenges and drivers

The existing literature highlights several issues that practitioners might need to deal with when transforming their SD models into games. Unfortunately, as highlighted, these lessons are scattered (Andersen et al., 1990; Lane, 1995; van Daalen et al., 2014) and not necessarily categorized. To this end, we propose an updated rationalization of the major challenges and drivers, along with their mutual interrelations, during an SD gamification effort (Figure 2). The proposed framework is expected to support practitioners in embarking an SD gamification project by capturing and analysing the key aspects to be considered.

The challenges' rationalization aims, firstly, to identify the SD gamification's meta-areas of action and, secondly, to provide an indication of critical points before deploying a gamification effort. Overall, SD practitioners are expected to face a triple helix of interrelated challenges, namely, theoretical, operational and managerial ones (Figure 2, internal circle), when they attempt to gamify their work. In detail, we suggest that theoretical challenges involve the decisions about the cognitive theories to follow, the underlying SD model content and the analysis of the target audience and their expectations. Specifically, a crucial theoretical challenge includes the definition of the inference mechanisms that the game triggers to produce learning. Typically, in gamification, deductive and abductive inferences are considered as intertwined. Abduction is an inference that goes from the observation of a behaviour to the hypothesis of a principle that explains the observed fact (Burks, 1946; Fann, 1970). When building a game, it is important to specify how users, by looking at the model behaviour, enact an abductive reasoning that produces hypotheses about the structure of the underlying causal mechanism generating the observed behaviour. In contrast,

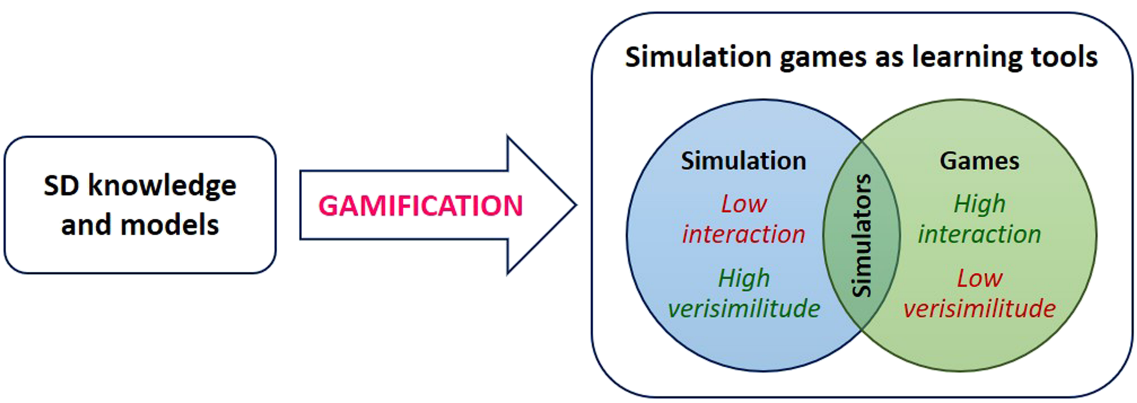

FIGURE 1 System dynamics (SD) gamification concept [Colour figure can be viewed at wileyonlinelibrary.com]

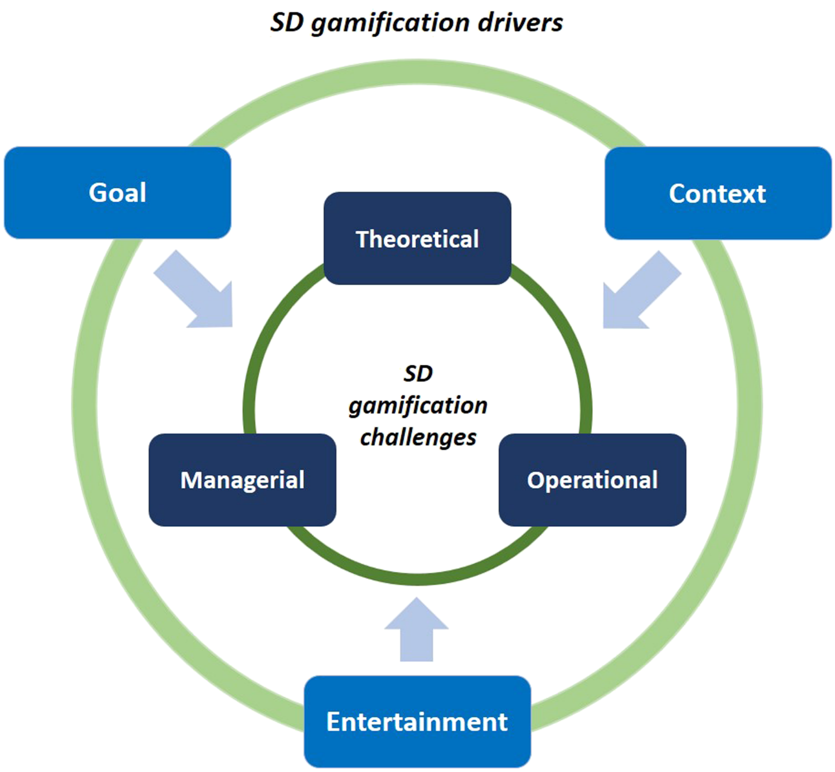

FIGURE 2 Framework of interconnected challenges and drivers in system dynamics (SD) gamification [Colour figure can be viewed at wileyonlinelibrary.com]

deduction shifts from the specification of a set of mechanisms or processes and explores the unfolding consequences of such specifications. In this respect, users need to employ deductive reasoning to verify the consequences of their theorizing; if their theory about the underpinning mechanism is true, by setting specific calibrations of parameters and simulating the gamified model, users should obtain the expected results. However, if simulations do not produce the expected behaviour, the deductive inference falsifies the accepted theory and triggers a new round of abductive reasoning. The structure of this interplay between abduction and deduction, which forces users to explain any *'surprise behavior'* (Mass & Sterman, 1991, p. 68) and rationalize cognitive dissonance, is the key generating mechanism of game-based learning.

In addition, operational challenges refer to the selection of the technical process of SD game development and the anticipated output; the decisions regarding the SD game's type (e.g., board game, role-play game and simulator) and format (e.g., virtual or physical, group or individual) are examples of operational challenges. Managerial challenges are associated with issues related to the management of complex SD gamification processes. In practice, the related decisions refer to the proper evaluation and administration of the available resources (e.g., financial, staff, knowledge and time constraints). In this respect, gamification might be a costly and time-consuming procedure, which requires a wider range of resources compared with the development of the respective SD simulation model only. Beyond the conceptualizations, we argue that all three challenges are interconnected. The game type that a practitioner desires to obtain (operational challenge) should be selected and assessed based on the theoretical objectives and managerial considerations. In addition, the available resources (managerial challenge) define the range of feasible theoretical goals and operational options. Finally, theoretical objectives without operational and managerial support are considered as impracticable.

However, the challenges, rather than being mechanistically defined, are shaped and steered by the SD gamification drivers: goal, context and entertainment (Figure 2, external circle). These drivers capitalize on the lesson gained within the broader gamification theory (Frank, 2007). Goal refers to the ultimate scope of the gamification project. Context indicates the social group, by which the tool is expected to be used, that determines the standards of the SD gamification efforts (e.g., language to be used). Entertainment highlights that any gamification process is indivisible from the 'fun' experience delivered to the players in addition to the underlying goal. Grounding on the study of Winnicott (1971, p. 1), simulation games are comparable to *'transitional objects'* (e.g., toys) through which users (e.g., children) learn to interpret the discrepancy between their own symbolic representations and the real world. In a similar way to the challenges, the drivers seem to influence each other, forming a triple helix. More specifically, the goal should take into consideration the sort of users/players of the SD game, further creating an entertaining experience. The type and level of entertainment, in turn, must be calibrated based on the audience (context) and the underlying goal of the gamification project. Finally, the context's suitability must be assessed based on the desired goal and of the related entertainment experience.

4 | DISCUSSION AND FUTURE RESEARCH

Besides developing an adequate and accepted nomenclature, the necessity of further studies and practical guidelines in the SD gamification field has been already raised by previous researchers. Andersen et al. (1990) recognize the difficulty in finding general guidelines on how to build interfaces out of SD models. Similarly, van Daalen et al. (2014), beyond the theoretical research on the effectiveness of the process, call for more studies in the field. Not only does Lane (1995) highlight the lack of practical indications, but he also goes further in defining two possible scenarios for the SD gamification discipline, one in which research issues exist (leading to a decline in the use of SD gamified tools) and another in which they have been avoided (paving the way for thriving SD gamified tools). In this context, this research constitutes a first effort towards identifying the aforementioned gaps, further proposing a research agenda for incorporating gamification into the SD field.

In this direction, we further suggest that upcoming research should be part of a structured effort by the SD community to render gamification as an organic and coherent branch of the SD field. Thus, we propose that future efforts should be driven towards three main directions:

1. ***Establishing gamification as an SD branch***. The SD approach should be integrated with the broad gamification theory (Crookall, 2010) that is currently available (e.g., gamification ethics, games' design principles, human–computer interactions and games' facilitation), as occurred for group dynamics and facilitation theories within group model building (GMB) (Vennix, 1996). For example, human–computer interaction lessons (Rapp et al., 2019) could provide support to the construction of SD-gamified virtual environments without depending exclusively on the modelers' personal preferences (Deterding, 2019). In addition, attention should be paid to the aspects of serious games' facilitation, which appears to be a crucial factor for meaningful insights during a gamified session (Bakhanova et al., 2020; Rooney-Varga et al., 2020). Overall, technological conquests, such as the reduced size of computers, along with their increased power and usability, contributed to the GMB popularity. This context made computer-based meetings (i.e., computer-assisted *'Group Decision Support Systems'*, Eden, 1992, p. 199), and then GMB sessions, easier and feasible. Similarly, technology has also rendered gamification more accessible and understandable, allowing system dynamicists to develop different types of gamified learning tools based on their SD models. In general, we envision the evolution and maturation of SD gamification similarly to what happened for GMB, which evolved from an unstructured discipline to a recognized SD domain (Gerrits & Vaandrager, 2018; Vennix, 1996) with its own shared set of 'pillars' (i.e., established definition, methods, guidelines and repository of scripts to be used). In this vein, SD practitioners could also obtain fruitful lesson from gamification progresses occurring in other operational research disciplines, such as discrete-event simulation (Padilla et al., 2016) and agent-based modelling (Mac Namee, 2009).
2. ***Developing an SD gamification guidelines' platform***. GMB ended up to define small group-generated *'scripts'* (Andersen & Richardson, 1997, p. 107), a list of best practices to be used in the GMB workshops collected and shared with the public through the *'Scriptapedia'* platform (Hovmand et al., 2011) and a set of roles and skills ideally needed to carry a GMB intervention (Richardson & Andersen, 1995). SD gamification could also benefit from a similar platform including a collection of best practices and/or strategies and a set of skills needed before deploying a gamification process. Specifically, all potential types of SD-based learning tools should be systematically categorized. The strengths and weaknesses of each type, along with a list of successful case studies, should be reported. In this respect, practical guidelines and principles should be elaborated for supporting SD gamification processes. In more detail, a body of technical solutions on how to code SD models into specific platforms and devices' languages could increase quality standards and speed up the development process, preventing practitioners from 're-creating' approaches and techniques that have already been developed, tested and validated. Lessons on how to translate a particular SD structure in a piece of a board game or how to code SD equations or delta times in specific languages (e.g., Java and PHP) are indicative examples.

3. ***Creating an updated SD games' repository***. A comprehensive and reliable repository of the generated SD-based learning tools (both physical and virtual, either for free or for sale) should be developed to be available in public. This repository is expected to facilitate practitioners' effort, enhance the usability of developed SD-based learning tools, support companies that gamify SD models and fill in the gap between offer and demand. Thus, future practitioners could receive inspiration, directly use or purchase them. Therefore, the repository should be updated over time to allow the accumulation of knowledge and avoid outdatedness, which could hinder its usefulness. The benefits of improved recognition and reputation could act as incentives for companies and individuals to share their work in the repository. Indicatively, we envision a repository similar to the *'CoMSES'* open platform (CoMSES, 2021); for more than a decade, it successfully collects and updates resources on agent-based modelling, including gamification attempts (Janssen et al., 2008). Notably, as the SD Society has already available online repositories of modelling efforts (SD Society, 2021a) and utilities (SD Society, 2021b), expanding their scope to gamified tools could be essential.

5 | CONCLUSIONS

The aim of this paper is to highlight the blind spots in SD gamification literature and to raise awareness among the SD researchers and practitioners of recurring pitfalls that occur during the SD gamification procedure. As outlined, the lack of theoretical and practical indications on how to perform SD gamification efforts and the massive variability in the taxonomy used in previous research efforts could impede the accumulation of knowledge and render the gamification process time-consuming and costly. In response to these issues, we (i) proposed a broad embryonic definition of SD gamification that could serve as an umbrella to contain and a label to describe future gamification efforts effectively and (ii) developed a framework rationalizing the nexus of challenges (theoretical, operational and managerial) and drivers (goal, entertainment and context) that could guide practitioners in their SD gamification processes. These principles are expected to act as a shared starting point and stimulus for gamification researchers, contributing to the body of knowledge on what SD gamification is and how to gamify an SD model.

Generally, the SD community should work towards *'adding more science to the craft'* as it occurred for GMB over the years (similarly to what Andersen et al., 1997, p. 187, claimed for GMB). Thus, we further discussed a list of directions that SD practitioners should focus on (e.g., integration with the broader gamification domain, list of best practices on 'how to…' perform SD gamification operations and repository with all successful cases and tools). As other simulation modelling methods and participatory techniques are at a mature stage in establishing gamification as a recognized domain (Bakhanova et al., 2020; den Haan et al., 2020), transdisciplinary future research could explore shared lessons and possibilities for integrating SD and gamification to trigger new synergies. In conclusion, this work builds upon scattered literature explanatory efforts (Alessi, 2000; Andersen et al., 1990; Lane, 1995; van Daalen et al., 2014) to urge SD researchers to take actions that could render SD gamification as a well-structured and recognized branch of the SD domain. Given the rapid technological advancements that increase the number of possible gamification options and raise the interest in games (e.g., virtual or physical, for learning or research purposes), establishing the SD gamification discipline emerges as a critical methodological challenge. Indicatively, a robust SD gamification domain could inform better the development of behavioural SD within which researchers broadly use gamified tools (e.g., Barnabè & Davidsen, 2019), creating fruitful interactions between different SD streams of research. To be best prepared, it is imperative to structure all past experiences in a new organic way. When focusing on SD gamification, today more than ever, it appears as crucial that the SD community should work to prevent practitioners from 'reinventing the wheel' through providing them with the appropriate conditions to learn in a systematic way.

ACKNOWLEDGEMENT

This research has been conducted in the context of the project *'Perception and Evaluation of Regional and Cohesion Policies by Europeans and Identification with the Values of Europe'* (project's acronym: PERCEIVE) that received funding from the European Community's HORIZON 2020 Programme (H2020-REFLECTIVE-2014-2015) under the Grant Agreement No. 693529. Open Access Funding provided by Universita degli Studi di Bologna within the CRUI-CARE Agreement.

ORCID

Giovanni Cunico https://orcid.org/0000-0003-0450-7725
Eirini Aivazidou https://orcid.org/0000-0002-4208-2361
Edoardo Mollona https://orcid.org/0000-0001-9496-8618

REFERENCES

Abt, C. C. (1970). *Serious Games*. New York City, NY, United States: Viking Press.

Adamides, E. D. (2018). Using a computer-based learning environment to enhance experiential learning of operations strategy. *International Journal of Information and Operations Management Education*, *2*(1), 40–57.

Akkerman, S., Admiraal, W., & Huizenga, J. (2009). Storification in history education: a mobile game in and about medieval Amsterdam. *Computers and Education*, *52*(2), 449–459. https://doi.org/10.1016/j.compedu.2008.09.014

Alessi, S. (2000). Designing educational support in system-dynamics-based interactive learning environments. *Simulation and Gaming*, *31*(2), 178–196. https://doi.org/10.1177/104687810003100205

Andersen, D. F., Chung, I. J., Richardson, G. P., & Stewart, T. R. (1990). *Issues in designing interactive games based on system dynamics models*. In Proceedings of the 1990 International System Dynamics Conference. Chestnut Hill, MA, United States: System Dynamics Society.

Andersen, D. F., & Richardson, G. P. (1997). Scripts for group model building. *System Dynamics Review*, *13*(2), 107–129. https://doi.org/10.1002/(SICI)1099-1727(199722)13:2%3C107::AID-SDR120%3E3.0.CO;2-7

Andersen, D. F., Richardson, G. P., & Vennix, J. A. M. (1997). Group model building: adding more science to the craft. *System Dynamics Review*, *13*(2), 187–201. https://doi.org/10.1002/(SICI)1099-1727(199722)13:2%3C187::AID-SDR124%3E3.0.CO;2-O

Aubert, A. H., Medema, W., & Wals, A. E. J. (2019). Towards a framework for designing and assessing game-based approaches for sustainable water governance. *Water*, *11*(4), 869. https://doi.org/10.3390/w11040869

Bakhanova, E., Garcia, J. A., Raffe, W. F., & Voinov, A. (2020). Targeting social learning and engagement: what serious games and gamification can offer to participatory modeling. *Environmental Modelling and Software*, *134*, 104846. https://doi.org/10.1016/j.envsoft.2020.104846

Barlas, Y., & Diker, V. G. (2000). A dynamic simulation game (UNIGAME) for strategic university management. *Simulation and Gaming*, *31*(3), 331–358. https://doi.org/10.1177/104687810003100302

Barnabè, F., & Davidsen, P. I. (2019). Exploring the potentials of behavioral system dynamics: insights from the field. *Journal of Modelling in Management*, *15*(1), 339–364. https://doi.org/10.1108/JM2-03-2019-0081

Bente, G., & Breuer, J. (2010). Why so serious? On the relation of serious games and learning. *Eludamos - Journal for Computer Game Culture*, *4*(1), 7–24.

Bianchi, C., & Bivona, E. (2000). Commercial and financial policies in family firms: the small business growth management flight simulator. *Simulation and Gaming*, *31*(2), 197–229. https://doi.org/10.1177/104687810003100206

Bohyun, K. (2015). The popularity of gamification in the mobile and social era. *Library Technology Reports*, *51*(2), 5–9.

Burks, A. W. (1946). Peirce's theory of abduction. *Philosophy of Science*, *13*, 301–306.

CoMSES. (2021). A growing collection of resources for computational model-based science. Retrieved April 17, 2021, from: https://www.comses.net/

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers and Education*, *59*(2), 661–686. https://doi.org/10.1016/j.compedu.2012.03.004

Crookall, D. (2010). Serious games, debriefing, and simulation/gaming as a discipline. *Simulation and Gaming*, *41*(6), 898–920. https://doi.org/10.1177/1046878110390784

Davidsen, P. I. (2000). Issues in the design and use of system-dynamics-based interactive learning environments. *Simulation and Gaming*, *31*(2), 170–177. https://doi.org/10.1177/104687810003100204

Davies, C. H. J. (2002). Student engagement with simulations: a case study. *Computers and Education*, *39*(3), 271–282. https://doi.org/10.1016/S0360-1315(02)00046-5

den Haan, R. J., van der Voort, M. C., Baart, F., et al. (2020). The virtual river game: gaming using models to collaboratively explore river management complexity. *Environmental Modelling and Software*, *134*, 104855. https://doi.org/10.1016/j.envsoft.2020.104855

Deterding, S. (2019). Gamification in management: between choice architecture and humanistic design. *Journal of Management Inquiry*, *28*(2), 131–136. https://doi.org/10.1177/1056492618790912

Djaouti, D., Alvarez, J., & Jessel, J.-P. (2011a). Classifying serious games: the G/P/S model. In P. Felicia (Ed.), *Handbook of Research on Improving Learning and Motivation Through Educational Games: Multidisciplinary Approaches* (pp. 118–136). Hersey, PA, United States: IGI Global. https://doi.org/10.4018/978-1-60960-495-0.ch006

Djaouti, D., Alvarez, J., Jessel, J.-P., & Rampnoux, O. (2011b). Origins of serious games BT. In M. Ma, A. Oikonomou, & L. C. Jain (Eds.), *Serious Games and Edutainment Applications* (pp. 25–43). London: Springer. https://doi.org/10.1007/978-1-4471-2161-9_3

Eden, C. (1992). A framework for thinking about Group Decision Support Systems (GDSS). *Group Decision and Negotiation*, *1*(3), 199–218. https://doi.org/10.1007/BF00126263

Elgood, C. (1988). *Handbook of Management Games*. Aldershot, United Kingdom: Gower Publishing.

Fann, K. T. (1970). *Peirce's Theory of Abduction*. Leiden, Belgium: Martinus Nijhoff. https://doi.org/10.1007/978-94-010-3163-9

Flood, S., Cradock-Henry, N. A., Blackett, P., & Edwards, P. (2018). Adaptive and interactive climate futures: Systematic review of 'serious games' for engagement and decision-making. *Environmental Research Letters*, *13*, 063005. https://doi.org/10.1088/1748-9326/aac1c6

Forrester, J. (1961). *Industrial Dynamics*. Cambridge, MA, United States: Massachusetts Institute of Technology Press.

Frank, A. (2007). Balancing three different foci in the design of serious games: engagement, training objective and context. In *Proceedings of the 2007 DiGRA International Conference: Situated Play*. Tokyo, Japan: University of Tokyo.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: a research and practice model. *Simulation and Gaming*, *33*(4), 441–467. https://doi.org/10.1177/1046878102238607

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment*, *1*(1), 1–4.

Gee, J. P. (2005). Learning by design: good video games as learning machines. *E-Learning and Digital Media*, *2*(1), 5–16. https://doi.org/10.2304/elea.2005.2.1.5

Gerrits, L., & Vaandrager, D. (2018). Group Model building in a pressure cooker: a field experiment with public policy. *Systems Research and Behavioral Science*, *35*, 139–151. https://doi.org/10.1002/sres.2446

Gómez Prada, U.-E., Hernández, M.-L.-O., & Salinas Ibañez, J.-M. (2020). Systems dynamics and serious video games in an appropriation strategy of a decision support system for small livestock farmers. *International Journal of Interactive Mobile Technologies*, *14*(15), 4–24. https://doi.org/10.3991/ijim.v14i15.14597

Groesser, S. N. (2012). Model-based learning with system dynamics. *Encyclopedia of the Sciences of Learning*, *1943*, 2303–2307.

Hämäläinen, R. P., Kumpulainen, K.-R., Harviainen, J. T., & Saarinen, E. (2020). Design gaming for learning systems intelligence in socio-emotional systems. *Systems Research and Behavioral Science* (In press). https://doi.org/10.1002/sres.2750

Hendrix, M., Al-Sherbaz, A., & Bloom, V. (2016). Game based cyber security training: are serious games suitable for cyber security training? *International Journal of Serious Games*, *3*(1), 53–61.

Hovmand, P., Rouwette, E., Andersen, D. F., et al. (2011). *Scriptapedia: A Handbook of Scripts for Developing Structured Group Model Building Sessions*. In Proceedings of the 2011 International System Dynamics Conference. Washington, DC, United States: System Dynamics Society.

Jalali, M. S., Siegel, M., & Madnick, S. (2019). Decision-making and biases in cybersecurity capability development: evidence from a simulation game experiment. *Journal of Strategic Information Systems*, *28*(1), 66–82. https://doi.org/10.1016/j.jsis.2018.09.003

Janssen, M. A., Alessa, L. N., Barton, M., Bergin, S., & Lee, A. (2008). Towards a community framework for agent-based modelling. *Journal of Artificial Societies and Social Simulation*, *11*(2), 6.

Lainema, T., & Hilmola, O.-P. (2005). Learn more, better and faster: computer-based simulation gaming of production and operations. *Internaqtional Journal of Business Performance Management*, *7*(1), 34–59. https://doi.org/10.1504/IJBPM.2005.006242

Lane, D. (1995). On a resurgence of management simulations and games. *The Journal of the Operational Research Society*, *46*(5), 604–625. https://doi.org/10.1057/jors.1995.86

Lane, D. C. (2017). 'Behavioural System Dynamics': a very tentative and slightly sceptical map of the territory. *Systems Research and Behavioral Science*, *34*(4), 414–423. https://doi.org/10.1002/sres.2465

Langley, P. A., & Larsen, E. R. (1994). *I Can't Believe It's a System Dyanmics Model!* In Proceedings of the 1994 International System Dynamics Conference. Stirling, Scotland: System Dynamics Society.

Larson, K. (2020). Serious games and gamification in the corporate training environment: a literature review. *TechTrends*, *64*(2), 319–328. https://doi.org/10.1007/s11528-019-00446-7

Liu, D., & Santhanam, R. (2017). Towards meaningful engagement: a framework for design and research of gamified information systems. *MIS Quarterly*, *41*(4), 1011–1034. https://doi.org/10.25300/MISQ/2017/41.4.01

Looyestyn, J., Kernot, J., Boshoff, K., Ryan, J., Edney, S., & Maher, C. (2017). Does gamification increase engagement with online programs? A systematic review. *PLoS ONE*, *12*(3), e0173403. https://doi.org/10.1371/journal.pone.0173403

Lou, Y., Abrami, P. C., & d'Apollonia, S. (2001). Small group and individual learning with technology: a meta-analysis. *Review of Educational Research*, *71*(3), 449–521. https://doi.org/10.3102/00346543071003449

Mac Namee, B. (2009). Agent based modeling in computer graphics and games. In R. A. Meyers (Ed.), *Encyclopedia of Complexity and Systems Science* (pp. 604–621). New York, NY, United States: Springer. https://doi.org/10.1007/978-0-387-30440-3_90

Maier, F. H., & Größler, A. (2000). What are we talking about? A taxonomy of computer simulations to support learning. *System Dynamics Review*, *16*(2), 135–148. https://doi.org/10.1002/1099-1727(200022)16:2%3C135::AID-SDR193%3E3.0.CO;2-P

Mass, N. J., & Sterman, J. D. (1991). Diagnosing surprise model behavior: a tool for evolving and policy insights (1981). *System Dynamics Review*, *7*(1), 68–86.

Mayer, I., Warmelink, H., & Zhou, Q. (2016). A frame-reflective discourse analysis of serious games. *British Journal of Educational Technology*, *47*(2), 342–357.

Meadows, D. (2007). A brief and incomplete history of operational gaming in system dynamics. *System Dynamics Review*, *23*(2/3), 199–203. https://doi.org/10.1002/sdr.372

Meadows, D., Iddman, T., & Shannon, D. (1993). *Fish Banks, LTD: Game Administrator's Manual*. Durham, NH, United States: University of New Hampshire.

Meadows, D. L. (2001). Tools for understanding the limits to growth: comparing a simulation and a game. *Simulation and Gaming*, *32*(4), 522–536. https://doi.org/10.1177/104687810103200408

Michael, D., & Chen, S. (2006). *Serious Games: Games That Educate, Train and Inform*. Boston, MA, United States: Thomson Course Technology.

Mordor Intelligence, 2020. Gamification market—growth, trends, COVID-19 impact, and forecasts (2021–2026). Retrieved January 22, 2021, from: https://www.mordorintelligence.com/industry-reports/gamification-market

Morecroft, J. D. W. (2012). Metaphorical models for limits to growth and industrialization. *Systems Research and Behavioral Science*, *29*, 645–666. https://doi.org/10.1002/sres.2143

Moxnes, E. (1998). Not only the tragedy of the commons: misperceptions of bioeconomics. *Management Science*, *44*(9), 1234–1248. https://doi.org/10.1287/mnsc.44.9.1234

Nordby, A., Øygardslia, K., Sverdrup, U., & Sverdrup, H. (2016). The art of gamification; teaching sustainability and system thinking by pervasive game development. *Electronic Journal of E-Learning*, *14*(3), 152–168.

Padilla, J. J., Lynch, C. J., Diallo, S. Y., et al. (2016). Using simulation games for teaching and learning discrete-event simulation. In *Proceedings of the 2016 Winter Simulation Conference (WSC)*. Washington, DC: IEEE.

Papathanasiou, J., Armenia, S., Barnabè, F., et al. (2019). *Game Based Learning on Urban Sustainability: The "SUSTAIN" Project*. In Proceedings of the 11th International Conference on Education and New Learning Technologies. Palma, Spain: International Academy of Technology, Education and Development (IATED).

Porter, N. W. (2018). The value of system dynamics modeling in policy analytics and planning. *Public Administration and Information Technology*, *25*, 123–150. https://doi.org/10.1007/978-3-319-61762-6_6

Qudrat-Ullah, H. (2010). Perceptions of the effectiveness of system dynamics-based interactive learning environments: an empirical study. *Computers and Education*, *55*(3), 1277–1286. https://doi.org/10.1016/j.compedu.2010.05.025

Rabin, B. A., & Brownson, R. C. (2012). Developing the terminology for dissemination and implementation research. In R. C. Brownson, G. A. Colditz, & E. K. Proctor (Eds.), *Dissemination and Implementation Research in HealthTranslating Science to Practice* (pp. 23–52). Oxford, United Kingdom: Oxford University Press.

Rapp, A., Hopfgartner, F., Hamaric, J., Linehan, C., & Cena, F. (2019). Strengthening gamification studies: current trends and future opportunities of gamification research. *International Journal of Human-Computer Studies*, *127*, 1–6. https://doi.org/10.1016/j.ijhcs.2018.11.007

Ratan, R. A., & Ritterfeld, U. (2009). Classifying serious games. In U. Ritterfeld, M. Cody, & P. Vordered (Eds.), *Serious Games* (pp. 32–46). Abingdon-on-Thames, United Kingdom: Routledge.

Richardson, G. P., & Andersen, D. F. (1995). Teamwork in group model building. *System Dynamics Review*, *11*(2), 113–137. https://doi.org/10.1002/sdr.4260110203

Robson, K., Plangger, K., Kietzmann, J. H., McCarthy, I., & Pitt, L. (2016). Game on: engaging customers and employees through gamification. *Business Horizons*, *59*(1), 29–36. https://doi.org/10.1016/j.bushor.2015.08.002

Rooney-Varga, J. N., Kapmeier, F., Sterman, J. D., Jones, A. P., Putko, M., & Rath, K. (2020). The climate action simulation. *Simulation and Gaming*, *51*(2), 114–140. https://doi.org/10.1177/1046878119890643

Ryan, T. (2000). The role of simulation gaming in policy-making. *Systems Research and Behavioral Science*, *17*, 359–364. https://doi.org/10.1002/1099-1743(200007/08)17:4%3C359::AID-SRES306%3E3.0.CO;2-S

Saysel, A.-K. (2017). Role of information feedback in soil nitrogen management: results from a dynamic simulation game. *Systems Research and Behavioral Science*, *34*, 424–439. https://doi.org/10.1002/sres.2466

SD Society. (2021a). List of all cases. Retrieved April 17, 2021, from: https://systemdynamics.org/list-of-all-cases/

SD Society. (2021b). Repository. Retrieved April 17, 2021, from: https://systemdynamics.org/repository/

Shubik, M. (1972). On gaming and game theory. *Management Science*, *18*(5), 37–53. https://doi.org/10.1287/mnsc.18.5.37

Starr, P. (1994). Seductions of Sim: policy as a simulation game. *American Prospect*, *17*, 19–29.

Stave, K. A., Beck, A., & Galvan, C. (2015). Improving learners' understanding of environmental accumulations through simulation. *Simulation and Gaming*, *46*(3–4), 270–292. https://doi.org/10.1177/1046878114531764

Sterman, J. (1992). Teaching takes off: flight simulators for management education—"The Beer Game". Retrieved July 27, 2020, from: http://jsterman.scripts.mit.edu/docs/Sterman-1992-TeachingTakesOff.pdf

Sterman, J. (2014). Interactive web-based simulations for strategy and sustainability: the MIT Sloan LearningEdge management flight simulators, part I. *System Dynamics Review*, *30*(1–2), 89–121. https://doi.org/10.1002/sdr.1513

Sterman, J., Franck, T., Fiddaman, T., et al. (2015). World climate: a role-play simulation of climate negotiations. *Simulation and Gaming*, *46*(3–4), 348–382. https://doi.org/10.1177/1046878113514935

Sterman, J. D. (2006). Learning from evidence in a complex world. *American Journal of Public Health*, *96*(3), 505–514. https://doi.org/10.2105/AJPH.2005.066043

Sterman, J. D., & Meadows, D. (1985). STRATAGEM-2: a microcomputer simulation game of the kondratiev cycle. *Simulations and Games*, *16*(2), 174–202. https://doi.org/10.1177/0037550085162006

Sweeney, L. B., & Meadows, D. (2010). *The Systems Thinking Playbook: Exercises to Stretch and Build Learning and Systems Thinking Capabilities*. White River Junction, VT, United States: Chelsea Green Publishing.

Thomas, R. C., & Milligan, C. D. (2004). Putting teachers in the loop: Tools for creating and customising simulations. *Journal of Interactive Media in Education*, *15*.

van Daalen, C. E., Schaffernicht, M., & Mayer, I. S. (2014). *System Dynamics and Serious Games*. In Proceedings of the 2014 International System Dynamics Conference. Delft, the Netherlands: System Dynamics Society.

Vennix, J. A. M. (1996). *Group model building: facilitating team learning using system dynamics*. Chichester, United Kingdom: Wiley.

Winnicott, D. W. (1971). *Playing and Reality*. London, United Kingdom: Tavistock Publications.

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249–265. https://doi.org/10.1037/a0031311

Wünderlich, N. V., Gustafsson, A., Hamari, J., Parvinen, P., & Haff, A. (2020). The great game of business: advancing knowledge on gamification in business contexts. *Journal of Business Research*, *106*, 273–276. https://doi.org/10.1016/j.jbusres.2019.10.062

Ya, L. (2010). Experimental policy research methodology: exploring China's policy issues adversarially in laboratory. *Systems Research and Behavioral Science*, *27*, 224–239. https://doi.org/10.1002/sres.1027

Zeijlemaker, S., Rouwette, E., & Cunico, G. (2019). *Results from the Cyber-Security Game: Decision Makers May Have Difficulties in Appreciating Dynamic Complex Systems*. In Proceedings of the 2019 International System Dynamics Conference. Albuquerque, NM, United States: System Dynamics Society.

How to cite this article: Cunico, G., Aivazidou, E., & Mollona, E. (2022). System dynamics gamification: A proposal for shared principles. *Systems Research and Behavioral Science*, *39*(4), 723–733. https://doi.org/10.1002/sres.2805