Gaming for Sustainability: An Overview

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Abstract: This study explored the potential of digital games as learning environments to develop mindsets capable of dealing with complexity in the domain of sustainability. Building sustainable futures requires the ability to deal with the complex dynamics that characterize the world in which we live. As central elements in this system, we must develop the ability of constantly assessing the environment that surrounds us, operating in it and adapting to it through a continuous and iterative individual and interpersonal process of revision of our frames of reference. We must focus on our world as a whole, considering both immediate problems and long-term consequences that decision making processes could generate. Educating for sustainability demands learning approaches and environments that require the development of systems thinking and problem-solving, rather than solely the acquisition of factual knowledge. Due to their characteristics, digital games present a high potential for "learning for complexity". Although they can be very different from one another, digital games can indeed be proper complex systems. In fact, many modern games are set in sophisticated cyberworlds, requiring players to engage in cognitively demanding tasks relying on problem-solving and decision-making skills, dealing with ill-structured problems, unpredictable circumstances, emerging system properties and behaviours, and non-linear development of events. Furthermore, these environments support remote interactions across large numbers of players, often requiring collective engagement in the pursuit of common goals. To understand how games are currently used for "learning for sustainability", we analysed twenty games. The games were selected based on their visibility on an online search engine. The analysis showed that there is an emphasis on using single-player games to educate children and to foster the acquisition of factual knowledge. Furthermore, our results show that sustainability games often do not leverage the usage of complex systems as gaming environments, hence not fully exploiting the potential of games as learning environments to develop "thinking for complexity".

Keywords/Key Phrases: sustainability, complex systems, game-based learning, digital games

1. Introduction

Over the last 40 years, there has been an increasing interest in supporting sustainable development to manage limited resources in a world facing growing population, industrialization and globalization. Although much work has been done, progress has been slow. Consequently, there is an urgent need to promote new ways of learning and thinking to help societies shift towards a more sustainable development (Tilbury and Wortman 2004).

This paper presents an exploratory study examining how games are used to educate for sustainability. It constitutes the preliminary phase of a research programme aimed at investigating how the science of complexity can guide game design to leverage the potential of game-based learning for the development of sustainable mindsets.

2. Conceptual framework

2.1 Defining sustainability

Sustainability is a constantly evolving concept (UNESCO 2005), involving multiple fields and perspectives, and related to very diverse phenomena. The UN World Commission on Environment and Development provided through the Brundtland Report the most widely used definition of sustainability, outlined as '(...) development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' (UNWCED, 1987). Sustainability is nowadays generally conceptualised in terms of the "Triple Bottom Line" (Elkington 1999), a concept involving three dimensions:

- 'Economic: An economically sustainable system must be able to produce goods and services on a continuing basis, to maintain manageable levels of government and external debt, and to avoid extreme sectorial imbalances which damage agricultural or industrial production.

- Environmental: An environmentally sustainable system must maintain a stable resource base, avoiding over-exploitation of renewable resource systems or environmental sink functions, and depleting non-renewable resources only to the extent that investment is made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classed as economic resources.
- Social: A socially sustainable system must achieve distributional equity, adequate provision of social services including health and education, political accountability and participation.' (Harris 2000, pp.5-6).

Although individual logics govern each of these dimensions, the three of them are tightly coupled, and their interplay originates global systemic effects that cannot be fully understood or predicted based on local events. This defines the complex nature of sustainability.

2.2 Educating for sustainability: how games can help

Dealing with the complexity of sustainability requires significant changes in government policies, social and cultural values, and public attitudes and behaviour. In order to foster these changes, in 2002 the UN proclaimed the Decade of Education for Sustainable Development, 2005-14, promoting the key role of education for enabling citizens to face the challenges of the present and future. A key postulate of this initiative is that a sustainable future is only possible if we understand the systemic interrelations among environment, economic growth and social development. Although domain-specific knowledge is relevant, it is equally important that we, as central actors, develop skills, attitudes and capacities necessary to engage in sustainability with "heads, hearts and hands" (Sipos, Battisti and Grimm 2008).

The literature on education for sustainability (Tilbury 2004; Tilbury & Wortman 2004; UNESCO 2005) has identified several characteristics of a sustainability mindset which enables individuals to engage in sustainable behaviours (Figure 1).

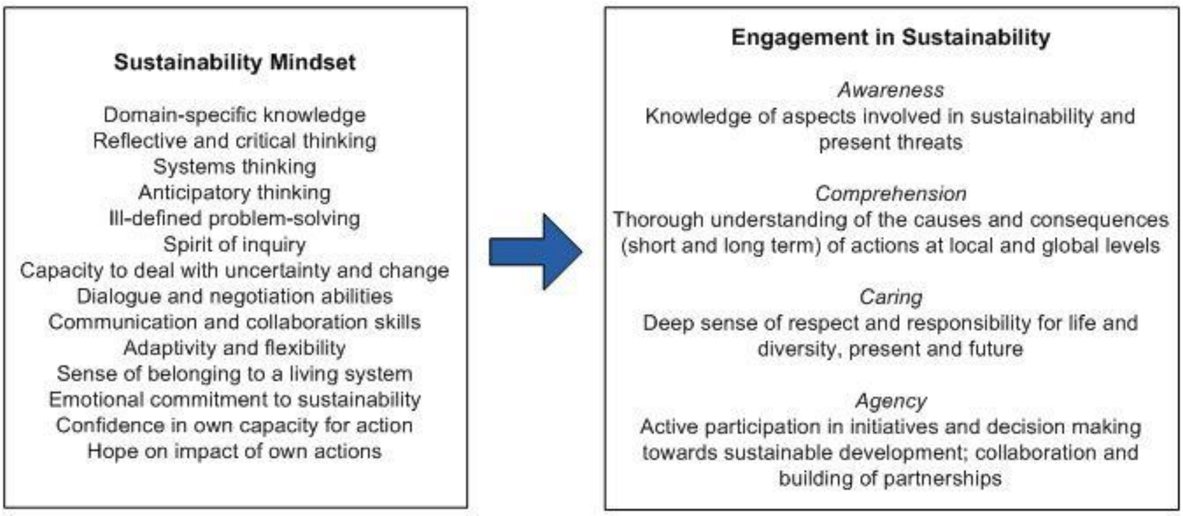

Figure 1: Mindset favourable to engage with sustainability at different levels

Educating for sustainability demands approaches and tools promoting systems thinking and learning to deal with traits of complexity, such as change, uncertainty, and emergence. Due to their characteristics, digital games can highly benefit learning for complexity. In fact, they can be regarded as excellent educational environments, supporting knowledge and skills learning through fun, in situated and meaningful contexts. Furthermore, digital games can address complexity, requiring players to deal with ill-structured problems, unpredictability, emerging systemic properties and behaviours, and non-linear development of events. Finally, gaming environments can support remote interactions across large numbers of players, requiring collective engagement in the pursuit of common goals.

2.2.1 Learning in games

Different authors identified numerous reasons why games can be considered educational tools, such as: the intrinsic motivation stimulated in games (Malone & Lepper 1987); the experiential learning occurring while playing (Dieleman and Huisingh 2006); the presence of pedagogic principles in game design (Becker 2007); and the access to shared social practices for the construction of knowledge (Gee 2007; Steinkhueler 2008). In our past research, we have outlined the characteristics shared by good games and good learning environments, and identified the intrinsic connection between fun and learning in games (Fabricatore 2000; Fabricatore and López, 2009; López 2010).

An analysis of the gaming experience reveals how digital games can be valuable tools for learning for sustainability. Most digital games require players to engage in activities organized as a sequence of steps involving different thinking processes, skills and knowledge (Figure 2). First, players identify or define a goal to accomplish in the game. Goals can be partially or completely undefined, thus challenging players to complete their definition through exploration, deduction and inference. Then, players plan how to achieve the set goal, relying on problem-solving, decision-making and creativity. When planning players define one or more suitable courses of action, understand purposes, forecast outcomes, and manage available resources optimising their use. Planning is followed by action, which requires putting into practice the knowledge and skills acquired in the previous stages. Through action players are challenged to develop different types of skills and knowledge depending on the type of game, (e.g. psycho-motor skills; communication and negotiation abilities; attention; memory; rhythm; and timing, among others). While acting, players assess intermediate outcomes and relevant changes in the game state, deciding whether to continue, modify, or abort the current plan. After action is taken, players assess the final outcome. Based on this assessment they set goals for future planning, starting again the cycle. During the game play a spirit of enquiry is needed to explore different scenarios, and reflection and adaptation are required to deal with uncertainty, accept failure and investigate alternate strategies.

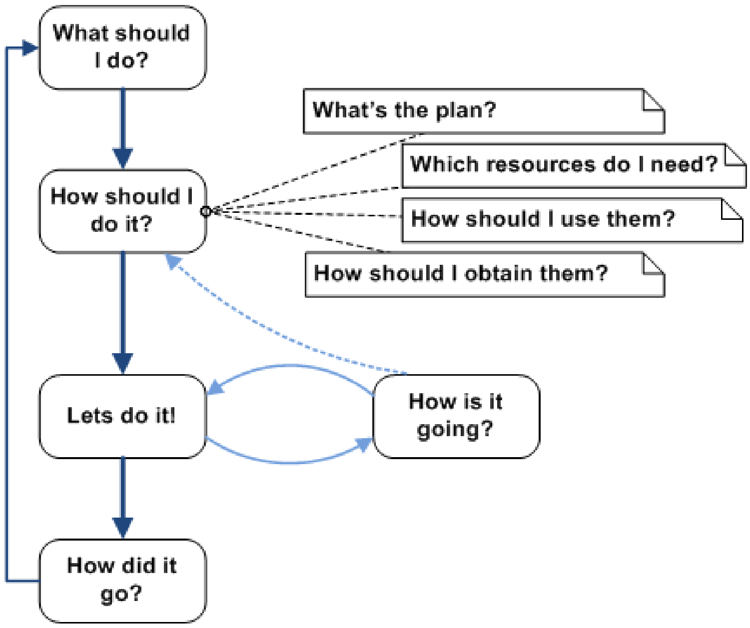

Figure 2: Steps of the game experience (Fabricatore and López 2009)

All these steps are carried out directly in the gaming environment that serves as a frame for meaning making (Gee 2007). Players receive just-in-time feedback, affording a situated and systemic understanding of the consequences of their actions. Furthermore, games foster the collective construction of knowledge, collaboration and sense of belonging by stimulating players to discover and discuss within the gaming community how to tackle game mechanisms, quests, rules and stories that define the game world (Steinkuehler 2008).

The contribution of digital games to education for sustainability also depends on their extraordinary potential to motivate players and emotionally engage them in the game dynamics. Emotional involvement and commitment is essential to engage in sustainability, the same way that motivation and fun are fundamental to engage players in the game. The key principle to motivate and engage players in learning processes is leveraging the intrinsic connection between fun and learning (López 2010). It is known that we learn more and better when we enjoy what we are doing, but the link between learning and fun in games is actually much deeper. In order to play a game, players must learn about elements of the game system such as goals, entities and rules, and develop individual and social skills required to succeed. Fabricatore (2000, 2007) emphasizes that meaningful learning is not only required in games but is actually a major determinant of motivation. If players do not have anything new to learn, discover, develop or improve they will not feel challenged. Consequently, their motivation will drop and they will stop playing the game. On the contrary, new challenges motivate players to continue playing and engage in further learning, exploring alternatives, increasing their knowledge, discovering mechanisms and improving their performance to progress and develop their mastery. Thus, learning can be considered an essential determinant of the game fun (Fabricatore 2007), engaging players at a cognitive, emotional and conative level. This is precisely what education for sustainability needs.

2.2.2 Games as complex systems

Any digital game can be considered a system, intended as a whole composed of parts which are interconnected and interact so that the system maintains its existence through the mutual interaction of its parts. At any given time the state of a game system is defined by the on-going dynamics and the current state of the system components (Meadows and Wright 2009).

Digital games can be merely complicated or properly complex systems. Complicated systems are composed of large numbers of elements and interrelations. These elements maintain a degree of independence from one another, can be fully understood in isolation, and interact based on predefined rules. Hence, complicated systems are knowable, and their behaviour can be predicted examining their parts and the laws that govern interactions among parts, although their study can be challenging (Miller and Page 2007; Patton 2010).

Complex systems too comprise large numbers of interacting and interconnected elements. What distinguishes them from complicated systems is, first and foremost, the phenomenon of emergence, whereby '(…) well-formulated aggregate behaviour arises from local behaviour.' (Miller and Page 2007, p.46). Hence, in complex systems interacting elements originate dynamics which cannot be predicted examining the behaviours of individual parts and the laws governing their interactions (Johnson 2001; McDaniel and Driebe 2005).

Elements interacting in a complex system may change their behaviours and properties, co-evolving in order to adapt to each other and to their environment. Consequently, new patterns of organization emerge spontaneously without the intervention of a centralized control, and the system as a whole displays properties of self-organization and adaptation (McDaniel and Driebe 2005; Miller and Page 2007; Patton, 2010).

Interactions among elements in a complex system are usually non-linear. Depending on the state of the system, a given interaction can: develop according to different patterns; generate different outcomes; and trigger reactions and changes that transcend the initial scope of the interaction (McDaniel and Driebe 2005; Miller and Page 2007; Patton 2010).

Emergence, adaptation and non-linearity make of unpredictability a further important characteristic of complex systems. Although unpredictability makes processes and related outcomes non-fully-controllable and knowable in advance, it is not synonym of chaos and randomness, since complex systems as wholes tend to change in order to self-organize and adapt (McDaniel and Driebe 2005; Patton 2010).

From a player-centric perspective digital game systems can display different degrees of complexity. The perceived complexity of a game depends mainly on: the player's cognitive capacity; mechanistic systemic complicacy; proper systemic complexity.

The cognitive capacity of the player is defined by subjective skills and objective limits on human capacity for gathering and processing information. Subjective skill limitations can prevent players from finding and gathering information actually available in the game (e.g. limited exploratory skills may lead to missing pieces of information in a virtual crime scene). However skilled they are, players are constrained by the objectively limited capacity of the human working memory (Miller, 1994) (e.g. a game of chess appears to be complex, unpredictable and non-fully-controllable mainly because players cannot remember all the possible sequences of chessboard configurations). Ignorance originates from these issues, leading players to wrongly perceive complexity where there is simple complicacy, or even simplicity (Miller and Page, 2007).

Perceived complexity can also result from mechanistic design decisions. Through mechanistic complicacy designers can plan and control game dynamics and progression, deliberately hiding information and gradually revealing or changing aspects of the game system. Mechanistic complicacy could lead players to believe that global phenomena spontaneously emerge from local interactions of entities through uncertain and non-linear dynamics, whereas everything actually unfolds based on predefined criteria.

Finally, games can be designed as proper complex systems when interactions among players and system entities can result in consequences of a higher order. These consequences: change the state and behaviour of the game; lead to new discernible and rational organizations of the game system as a whole; and are not planned or even predicted by the game designers (Sweetser 2007). In this case, 'A modest number of rules applied again and again to a limited collection of objects leads to variety, novelty, and surprise. One can describe all the rules, but not necessarily all the products of the rules (…) which may arise from evolution.' (Campbell 1983, p. 127).

Mechanistic design can originate what Sweeter (2007) calls first and second order emergence. Even if a game unfolds based on predefined causal mechanics and scripts, local interactions could have effects on both the game elements immediately involved and nearby elements in the game world (first order emergence). Furthermore, preconceived causal mechanics can allow players to use basic elements of the game system to create strategies and solve problems in alternative ways (second order emergence). Finally, mechanistic design decision allow for non-linear developments of game events. Hence, mechanistic design can generate dynamics requiring the player to face uncertainty, emergence and adapt to the unfolding of game events, almost as if the game were a proper complex system.

Systemic complexity is the only quality in a game that can require players to engage with third order emergence: changes on a global scale arising from dynamics happening at a local scale (Sweetser 2007). Third order emergence can change salient traits of the game system as a whole, requiring players and other entities to change and adapt through repeated processes of self-organization (e.g. in a gaming world populated by agents organized in social systems, a sudden flooding could change the value of resources and social relationships, triggering processes of adaptation at local and global scale and ultimately changing the winning strategies). In this case players have to deal with uncertainty, frequent change and ill-defined problems, and mastery and success are defined by the ability to adapt to change and facilitate the emergence of new favourable system organisations.

3. The Study

The purpose of this study was to explore to what extent broadly available sustainability games facilitate the development of sustainable mindsets. Our inquiry was driven by the following guiding questions:

- What types of games are being created?
- What sustainability-related topics are addressed?
- What is the target public?
- What is the nature of problem-solving activities embedded in games?
- To what extent are complex system dynamics leveraged by games?

3.1 Games selection

The study analysed twenty games, selected based on their visibility on Google search engine. Only games directly appearing or being mentioned by third parties in the first five pages of the search results were chosen. This procedure was carried out in February 2011, which is important to consider as visibility in search engines changes in time. The search strings used were "Games AND sustainability” and “Games AND sustainable development”. Consequently, the search only yielded games in English.

We frequently found labelled as “games” series of activities and game-like applications that cannot be considered as proper games (e.g. a website to calculate own carbon footprint). These were not included in the analysis.

3.2 Data collection and analysis

Selected games were analysed either by playing them directly or by examining detailed information found in online sources. Time spent analysing each game was varied, depending on their goals and dynamics. Not all the games were completed, since some were open-ended games with no final winning condition, and others repeated game dynamics across different levels.

Data was gathered using a structured template describing the analytical criteria and procedure. The analysis was based on game elements allowing identifying characteristics of systemic complexity in game dynamics. The template was structured in three parts:

1. General information, reporting the title, genre, creator and the general purpose of the game
2. Context analysis, identifying the setting, storyline and game objectives
3. Game play analysis, studying the main dynamics of the game focusing on:
    - How the entity personifying the player evolves throughout the game
    - The nature of problem-solving activities (i.e. quiz-like, well-defined or ill-defined problems)
    - Non-linearity of progression and procedures (i.e. to what extent players can define their path of progression and/or decide how to achieve game goals)
    - Emergence in the game system (i.e. to what extent local dynamics generate organised changes in the whole system)
    - Unpredictability (generated by situations which cannot be forecast and explained based on local information, thus requiring adaptation)
    - Multiple motivations (i.e. affordances to embrace alternate motivations mapping to different play approaches)
    - Social interaction (i.e. possibilities for in-game and out-of-game social dynamics)

Data was analysed calculating frequencies for individual game characteristic.

4. Results

Figure 3 shows the distribution of games by country and genre. Most games analysed were developed in the UK (6), Australia (5) and the USA (4). Eight (40%) games were supported by sustainability organisations (e.g. institutions promoting education for sustainability); seven (35%) by companies offering public services (e.g. energy and communication); and three (15%) were games originating from private or independent efforts (e.g. students, scientific associations).

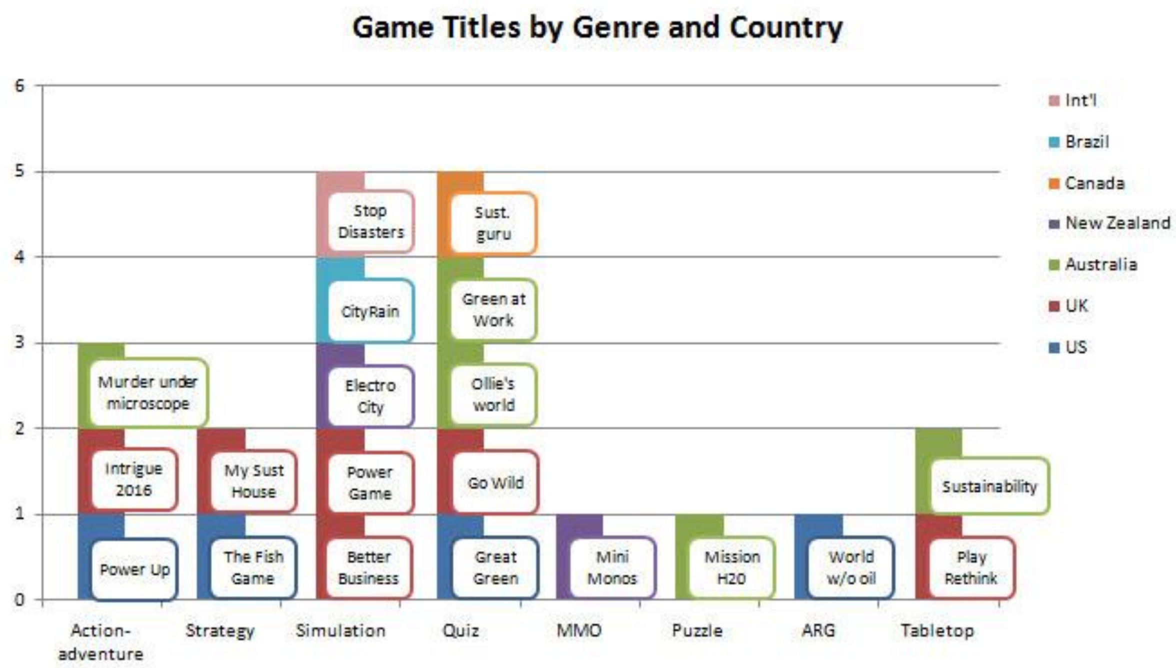

Figure 3: Games by country and genre

The vast majority of the games (75%) are single-player. The two most commonly found game genres are quiz-like and simulation games. In quiz-like games (25%) players rely on previously acquired knowledge to answer questions to advance and/or score more points. Feedback is usually given to promote understanding and memorisation of information. Simulation games (25%) simulate the dynamics of a system. We found that many games in this category demand players to create and administer a city or village, requiring sustainable economic, environmental and demographic management. Other games involve specific topics like water and energy management, and business decision making. Adventure games (15%) involve players in narratives, stimulating them to explore and analyse information to unfold a story (e.g. solve a mystery regarding who, when and how an environmentally-related crime was perpetrated). Strategy games (10%) require players to carefully strategise to win the game (e.g. plan how to make a living from fishing, maximising income while keeping an appropriate number of fish in a lake). We found one Massive Multiplayer Online game (MMO) in which players can freely explore and engage in different individual and collective activities (e.g. recycling). We also found one Alternate Reality Game (ARG) in which real and virtual spaces were combined to develop a fiction about an environmental crisis according to players' interventions.

Games have different target publics, although a significant proportion is oriented to children. 40% (8) are specifically created to be integrated in schools, usually complemented with supporting materials on how to use them in the classroom and/or combined with other educational activities. Two games (10%) are for pre-school and primary school-age children, requiring adult involvement or supervision. Two games were specifically oriented to adults (e.g. workplace-related games). 40% of the games have an unspecified target age.

The dimensions of sustainability are unevenly emphasised by games. The environmental dimension is present in all the games analysed. 35% of games include only topics regarding this dimension (e.g. energy efficiency, waste management, conservation of natural resources, gas emissions reduction). The same number of games deals with environmental and economic development (e.g. sustainable production and consumption). The remaining 30% of the games combine environmental, economic and social aspects (e.g. combining environmental and economic themes with demographics and development of human capacity and skills).

Game objectives are usually well-defined and are presented at the beginning of the game (55%). Few games (25%) have ill-defined goals, requiring the player to analyse and discover information during game play to better define the objectives. 20% of games present a combination of well and ill-defined goals, providing to players one or two explicit goals while requiring them to formulate new ones as they advance in the game.

The nature of problem-solving activities that players face during game play is variable. 35% of the problems have an exercise structure, requiring the application of previously acquired knowledge and skills (e.g. quiz and puzzle games). 40% are well-defined problems with a finite number of possible solutions, requiring investigation as the solution is not immediately visible to the player (e.g. a mystery game). 25% of the games analysed present ill-defined problems. They have an undefined number of possible solutions and thus no algorithm can be used to solve them. Solutions emerge throughout the resolution process, allowing the exploration of multiple strategies.

The possibilities to develop social skills and collectively engage players in the pursuit of common goals were explored by analysing the affordances for social interaction in in-game and out-of-game spaces. We observed that 50% of the games offer players out-of-game spaces to share game-related experiences and information (e.g. the presence of a game community; dedicated websites and blogs). Three games (15%) provide players with in-game communication tools (e.g. chat, posting). Among the multi-player games, three exploit competition dynamics, one combines competitive and collaborative dynamics and one is a collaborative-only game. One game strongly relies on collective efforts and multiple perspectives to manage a global crisis.

Overall, complex systems characteristics are found in less than half of the games analysed (Table 1). There is a tendency for complexity properties to appear in simulation, ARG and MMO games, although it is not possible to numerically verify this due to the insufficient number of games analysed belonging to each game genre.

Table 1: Complex systems characteristics in games

Complexity in games		
	Frequencies	Percentage
Non linearity	8	40%
Unpredictability	7	35%
Multiple motivations	9	45%
Systemic emergence (player triggered)	6	30%
Systemic emergence (game triggered)	4	20%

5. Discussion

Our results indicate that broadly available sustainability games are generally focused on environmental topics and/or targeted to children. Thus, the idea of "using games to educate children about the environment" seems to be the ultimate synthesis of the frequent associations between "games and children", "children and caring for environment" and "education and children". Focusing mainly on children and environmental contents may lead to underexploiting the potential of games. As to age, "learning for sustainability" is as important for children as it is for adults (UNESCO 2005), who currently constitute the majority of gamers (ESA 2010). Furthermore, games with an unspecified target age group usually rely on age-neutral dynamics and contents to attract a broad spectrum of players. We believe that it is important to create true multi-age games, integrating age-specific elements designed to appeal players of different ages, and fostering interaction and collaboration across different age groups. As to contents, most of the analysed games address the three main pillars of sustainability unevenly, particularly overlooking the social dimension (e.g. poverty reduction and social equity). The challenges of sustainability originate from the interplay between social, environmental and economic elements. Furthermore, this interplay is already key to massively successful leisure games appreciated by millions of users worldwide (e.g. FarmVille, CityVille and SimCity). Hence, designing games evenly integrating the three pillars of sustainability can enhance both game-based "learning for sustainability" and the entertainment value offered to players.

We found that many sustainability games rely on traditional educational approaches emphasising the dissemination of knowledge regarding environmental education (Tilbury, 2004). Furthermore, approximately one third of the games examined rely on Q&A dynamics, often fostering decontextualised knowledge acquisition and the development of basic cognitive skills. This indicates that significant efforts are made to embed traditional learning contents and activities in ludic contexts, frequently generating games overly education-centred and neglecting aspects key to make games fun and engaging. Sustainability games should be entertaining, so that players feel motivated to play them even outside formal educational settings. We believe that the potential of game-based learning would be fully exploited by designing intrinsically motivating games, engendering dynamics that naturally require situated and sustainability-relevant learning.

Our results suggest that games are not fully leveraged to develop mindsets and skills required to engage with sustainability. When designed as proper complex systems, games are most suitable to promote the development of complex systems thinking and facilitate a systemic understanding of the interrelations among environment, economic growth and social development. However, we found that games presenting characteristics of complexity (e.g. the ARG and MMO analysed in this study) are uncommon. Therefore, there is large space for improvements oriented at creating complex game systems incorporating emergence, uncertainty, ill-defined problems and requiring players to address issues from multiple perspectives, thus nurturing "sustainable mindsets".

Finally, we believe that efforts should be made to enhance the accessibility of sustainability games, addressing issues such as language, specific user needs (e.g. disabilities), geopolitical barriers and access to technology. This is essential to maximise the outreach of the benefits of gaming for sustainability.

6. References

Avedon, E. M. (1971) "The Structural Elements of Games", in Avedon, E. M. and Sutton Smith, B. (eds) *The Study of Games*, pp.419-426. New York: John Wiley and Sons, Inc.

Becker, K. (2007) "Pedagogy in commercial video games" in Gibson, D., Aldrich, C. & Prensky, M. (eds.) *Games and simulations in online learning: Research and development frameworks*, Hershey, PA: Information Science Publishing.

Campbell, J. (1983) *Grammatical Man: Information, Entropy, Language, and Life*, New York: Simon & Schuster.

Dickey, M. (2005) "Engaging by design: How engagement strategies in popular computer and video games can inform instructional design", *Educational Technology Research and Development*, vol. 53 no.2, pp.67-83.

Dieleman, H. and Huisingh, D. (2006) "Games by which to learn and teach about sustainable development: exploring the relevance of games and experiential learning for sustainability", *Journal of Cleaner Production,* vol.14, pp.837-847.

Elkington, J. (1999) *Cannibals with Forks: Triple Bottom Line of 21st Century Business*, London: Capstone.

ESA (2010) *2010 Essential Facts about the Computer and Video Game Industry*, [online], http://www.theesa.com/facts/pdfs/ESA_Essential_Facts_2010.PDF (accessed on 01/07/2011).

Fabricatore, C. (2000). "Learning and videogames: An unexploited synergy", Working paper for the *AECT conference*. California, [online], http://www.learndev.org/dl/FabricatoreAECT2000.PDF (accessed on 18/05/2011).

Fabricatore, C., Nussbaum, M. and Rosas, R. (2002) "Playability in Action Videogames: A Qualitative Design Model", *Human-Computer Interaction*, vol.17 no.4, pp.311-368.

Fabricatore, C. (2007) "Gameplay and game mechanics design: a key to quality in videogames", in *Proceedings of OECD-CERI Expert Meeting on Videogames and Education*, Santiago, Chile, [online], http://www.oecd.org/dataoecd/44/17/39414829.pdf (accessed on 18/05/2011).

Fabricatore, C. and López, X. (2009) “The impact of digital gaming on the development of the scientific mind”, seminar held at the *Third Advanced International Colloquium on Building the Scientific Mind*, Cairo, Egypt, 10-14 May.

Gee, J.P. (2007) *What video games have to teach us about learning and literacy* (2nd ed.), New York: Palgrave/Macmillan.

Harris, J. (2000) “Basic Principles of Sustainable Development”, Working Paper 00-04, Tufts University. [online], http://ase.tufts.edu/gdae/publications/working_papers/Sustainable%20Development.pdf (accessed on 18/05/2011).

Johnson, S. (2001) *Emergence*, London: Penguin Books.

López, X. (2010) “Videogiochiamo dunque impariamo? Un modello per l’analisi educativa dei videogiochi”, published PhD dissertation, Roma Tre University, Rome: Edizioni Nuova Cultura.

Malone, T. and Lepper, M. (1987) “Making Learning Fun: A Taxonomy of Intrinsic Motivations for Learning”, in Snow, R. & Farr, M. (eds.) *Aptitute, Learning and Instruction: III. Conative and affective process analyses*, Hilsdale, NJ: Erlbaum.

McDaniel, Jr., R. R. and Driebe, D. J. (2005) “Uncertainty and Surprise: and Introduction”, in McDaniel, Jr., R. R. and Driebe, D. J. (eds) *Uncertainty and Surprise in Complex Systems*, Heidelberg: Springer.

Meadows, D. H. and Wright, D. (2009) *Thinking in Systems: A Primer*. White River, VT: Earthscan Ltd.

Miller, G. A. (1994) “The magical number seven, plus or minus two: Some limits on our capacity for processing information”, *Psychological Review*, vol.10 no.12, pp.343-352.

Miller, J. H. and Page, S. E. (2007) *Complex Adaptive Systems. An Introduction to Computational Models of Social Life*. Princeton, NJ: Princeton University Press.

Patton, M. Q. (2010) *Developmental Evaluation: Applying Complexity Concepts to Enhance Innovation and Use*, New York: Guilford Press.

Salen, K. and Zimmerman, E. (2003) *Rules of Play: Game Design Fundamentals*, Cambridge, MA: MIT Press.

Sipos, Y., Battisti, B. and Grimm, K. (2008) “Achieving transformative sustainability learning: engaging head, hands and heart”, *International Journal of Sustainability in Higher Education*, vol.9 no.1, pp.68-86.

Steinkuehler, C. (2008) “Cognition and literacy in massively multiplayer online games”, in Coiro,J., Knobel,M., Lankshear,C. & Leu,D. (eds.), *Handbook of Research on New Literacies*, Mahwah, NJ: Erlbaum.

Sweetser, P. (2008) *Emergence in Games*, Boston, MA: Charles River Media.

Tilbury, D. (2004) “Rising to the Challenge: Education for Sustainability in Australia”, *Australian Journal of Environmental Education*, vol.20 no.2, pp.103-114.

Tilbury, D. and Wortman, D. (2004) *Engaging people in sustainability*, Cambridge, UK: IUCN.

UNESCO (2005) *The DESD at a glance,* [online], http://unesdoc.unesco.org/images/0014/001416/141629e.pdf (accessed on 01/05/2011).

UNWCED (1987) *Our Common Future* (The Brundtland Report). Oxford: Oxford University Press.