Journal of Computational Science 18 (2017) 32–45

Contents lists available at ScienceDirect

Journal of Computational Science

journal homepage: www.elsevier.com/locate/jocs

How people learn while playing serious games: A computational modelling approach

Wim Westera

Welten Institute, Research Centre for Learning, Teaching and Technology, Faculty of Psychology and Educational Sciences, Open University of the Netherlands, Valkenburgerweg 177, 6419 AT Heerlen, The Netherlands

ARTICLE INFO

Article history:
Received 14 June 2016
Received in revised form 18 November 2016
Accepted 5 December 2016
Available online 12 December 2016

Keywords:
Serious gaming
Learning
Simulation
Modelling
Flow theory
Methodology

ABSTRACT

This paper proposes a computational modelling approach for investigating the interplay of learning and playing in serious games. A formal model is introduced that allows for studying the details of playing a serious game under diverse conditions. The dynamics of player action and motivation is based on cognitive flow theory, which is expressed in quantitative terms for this purpose. Seven extensive simulation studies involving over 100,000 iterations have demonstrated the stability of the model and its potential as a research instrument for serious gaming. The model allows researchers to deeply investigate quantitative dependences between relevant game variables, gain deeper understanding of how people learn from games, and develop approaches to improving serious game design.

1. Introduction

1.1. The absorbing nature of serious games

Driven by the successes of the leisure game industry, games increasingly find their way into non-leisure contexts, serving serious purposes. These so-called “serious games” span a wide range of application areas, including training and learning, awareness raising and sensitisation, as well as marketing and the advancement of cultural engagement [1,2]. This paper focuses particularly on games for learning. A principal argument for using games in education and training is the engaging nature of gaming and the motivational power that games display: the ability of hooking and absorbing players in such a way that they can hardly stop playing [3–5]. This potential is ascribed to their dynamic, responsive and visualised nature, which goes along with novelty, variation and choice, effecting strong user involvement and providing penetrating learning experiences [4]. In addition, serious games allow for safe experimentation in realistic environments, stimulate problem ownership by role adoption, and allow for learning-by-doing approaches, which support the acquisition of tacit and contextualised knowledge [6].

1.2. The inherent complexity of games

Games are inherently complex constructs comprising knotty structures of highly interrelated components that may vary over time. Björk and Holopainen [7] qualify game design and development as a semi-formalised, fuzzy and incoherent domain, which eclectically combines various approaches that cannot be fully covered by prescriptive or even descriptive theories. For serious games, which pair game design with instructional design, the complexity may even be larger because of the multiplication of two ill-structured domains, requiring the cautious balancing of “playful” game mechanics and “serious” instructional principles [8,9]. To some extent games suffer from an impenetrable interior. Salen and Zimmerman [10] note that the link between the designed structural properties of a game and the effected user experience remains often unclear, because of the vast space of game states and the large number of trajectories a player could travel through the game’s state space. Consequently, different players may have different game experiences as they engage in different trajectories and game events and thereby experience different cumulative narratives: different runs of a game may be very different. It would not be sufficient to test a game for the “average pathway”, because no single player would ever traverse the “average pathway”. In serious games it may be hard to tell how individual decisions will impact on

E-mail address: wim.westera@ou.nl

http://dx.doi.org/10.1016/j.jocs.2016.12.002
1877-7503/

the game experience and how this affects the game's effectiveness for learning [11].

1.3. A computational modelling approach

This paper presents a computational model for simulating how people learn while playing serious games. Its main purpose is to allow and support researching what happens during playing a game under a variety of conditions. Such model should reflect the structural dynamics of the game and should help to enlighten its capacity as a learning aid. The research is decomposed into the following research questions:

- How to formulate an expressive computational model for the process of playing a serious game that avoids inherent complexity?
- To what extent is such computational model capable of producing stable results?
- To what extent does the model produces acceptable outcomes, which are consistent with empiricism on learning from games?

The paper is setup as follows. First the main methodological considerations for this study will be summarised. Second, the model's starting points and its grounding in theory will be made explicit. Third, the computational model will be defined and substantiated. Fourth, a variety of simulation experiments will be reported, which include over 100,000 simulation runs in total. The paper is concluded by discussing the results and their potential implications.

2. Methodological considerations

2.1. Methods fight

For many years the social sciences have shown a strife between methodological camps with on the one hand the empirical hypothesis testing framework, which tries to validate hypotheses by subjecting observed measures to statistical analysis, and on the other hand deductive modelling (e.g. game theoretical methods), which aims to specify benefits and costs schemes for explaining individuals' behaviours [12]. The empirical methods of experimentation have been persistently criticised for their unintelligent data crunching, limited explanatory power, their biased focus on positive effects and their arbitrary significance measures [13,14]. Game theorists in turn, who describe gaming in terms of strategic decision making by rational human players, have been blamed for their believe that formal theory doesn't require empirical referents [12]. Less well known as an additional research method in social sciences is computational systems modelling, which incorporates aspects of both empirical research and game-theoretical research approaches by capturing the individuals' behaviours in behavioural rules along with a set of contextual parameters and constraints, and produce a dynamic model that recreates observed phenomena [12]. Although computational system modelling has been criticised for allowing large parameter spaces, which easily lead to model overfitting, in the last decades computational methods have been successfully applied in diverse complex domains, ranging from atomic scale protein design and nuclear fusion to superconductivity and a billion-particles simulation of the Milky Way. Various authors advocate the widespread application of computational models for the integration of theoretical, technical and empirical research [15].

2.2. Serious gaming as an emerging field of research

In the domain of serious games the contributions from computer science have gained importance, particularly because of the impact of advanced digital game technologies [16]. Still, most research adheres to empirical research particularly grounded in the learning sciences. These aim to professionalise teaching on the basis of sound, empirically supported instructional methods rather than viewing teaching as an art, driven by intuition and feeling [17,18]. The link with gaming is readily in experiential learning, learning-by-doing, motivation theory, multimedia learning, social and collaborative learning, connectionism or networked learning. But those theories are largely qualitative and descriptive by nature and seem to lack the level of formalisation and precision required for making valid predictions. Because of this, research in the learning sciences as well as the instruments used have been persistently criticised [15,19–22]. Despite the valuable insights and confirmations that learning sciences research has produced over the last decades, it has not been capable of making predictions about instructional situations.

2.3. Strengthening multidisciplinary research

Given the multidisciplinary nature of the field of serious gaming, its research would require a close connection between its constituting domains such as learning sciences, game theory and computer sciences. However, the cross-fertilisation between these sub-domains has been weak, not just because of different cultures and paradigms in these disciplines, but also because of the disparate backgrounds and expertise that is required. Apparently this is the inevitable fate of any emerging multidisciplinary field. Current research on serious games is dominated by case studies, that is, the research focuses on case-by-case descriptions of a highly qualitative nature about particular games under study and its appreciations by users. Although an increasing body of evidence is becoming available that reveals the effectiveness of serious games for learning, various authors note that many studies fail to evaluate the educational effectiveness of serious games in a rigorous manner and they call for quantitative research and comprehensive frameworks for increased scientific robustness [23,24]. Still most studies focus on post-practice results and they neglect what actually happens during playing games. Given the inherent complexity of serious games, representing a game by a computational model would allow for testing and evaluating a wide variety of behaviours and thus would allow for a more representative view on game experiences. Once computational models have been generalised and verified for explaining behavioural phenomena, e.g. playing and learning in a serious game, the model could – in principle – be run and rerun to reveal behavioural diversity across different personal traits and external conditions.

3. Model starting points and ingredients

Before elaborating the serious gaming model, first the main issues and starting points will be reported.

3.1. Avoiding the combinatorial explosion of game states and player states

The deterministic idea that knowing all potential game states and all player states and their progression over time would eventually allow us to devise the player's optimal learning strategy, that is, the optimal trajectory through the game state space, is illusive. Game representation is likely to suffer from a combinatorial explosion of game states. Even a simple game such as tic-tac-toe (noughts and crosses) has a state space up to $3^9 = 19{,}683$ different states (neglecting any symmetries) allowing for $9! = 362{,}880$ different trajectories. Taking into account symmetries and including games that end within 9 moves only, the number of trajectories is still 26,830 [25], an inconceivable number way too high to even be depicted in a game tree.