Understanding Complex Adaptive Systems by Playing Games

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Abstract. While educators teach their students about decision making in complex environments, managers have to deal with the complexity of large projects on a daily basis. To make better decisions it is assumed, that the latter would benefit from better understanding of complex phenomena, as do students as the professionals of the future. The goal of this article is to evaluate the relevance of the use of simulation games for learning about the complexity of large-scale socio-technical projects. Relevant concepts from complex adaptive systems will be introduced or described. The conjecture is that complex adaptive systems can be simulated by games, in which players are able to experience the system workings, and retrieve more insight in their complex behaviour as a result. The multiplayer computer game SimPort-MV2 illustrates this by simulating the decision making process revolving around Maasvlakte 2 (MV2), an extension of the Port of Rotterdam into the North Sea. The game has been played by hundreds of students of higher education. Based on this study, we present preliminary indications of learning and conclusions on how simulation games can provide insights in a complex adaptive system and be used to educate both students and professionals.

Keywords: complex adaptive systems; simulation games; education; infrastructure; students.

1. Introduction

The multidisciplinary study of complex systems in first the physical and later the social sciences over the past decades has led to the articulation of new conceptual perspectives and methodologies that have been proven of value both to researchers in these fields as well as to professionals, policymakers, and citizens who must deal with social challenges and global problems (Jacobsen and Wilensky, 2006). The applicability of complex systems concepts such as self-organization, emergence and level hierarchies, and methodologies such as multi-agent modelling and simulation gaming, to a wide range of natural and social phenomena offers a rich palette for educators to reach students and help them learn important scientific knowledge and skills (Jacobsen, 2000). The complex systems' perspective has also informed corporate managers' thinking, about their organisations and about their relationships with employees and other companies and corporations, including concepts such as synergy and competitive advantage (Axelrod and Cohen, 1999). Apparently, a way to explain undesired or unexpected behaviour in a real world system, such as power black outs, economic market crises and social systems, is to consider the

system at hand as a complex adaptive system (CAS) (Kauffman, 1993; Gell-Mann, 1994; Holland, 1995). Usually, these systems are analysed in retrospect due to the inherent difficulties in monitoring and predicting their behaviour in advance. For understanding, specific concepts are needed to describe their specific characteristics. These concepts aid in both understanding CAS, as well as the design of tools that aim to disclose them. As the large and complex projects, that future managers and designers will encounter, can be considered CAS, understanding them is important for society.

How can educators transfer this understanding to students? A substantial body of literature is available on CAS, which provides explanations, examples, concepts and insights (Lansing, 2003). The body of knowledge from the physical sciences has been dispersed in other sciences, such as policy analysis and social science. In biology and mathematics education, CAS are being studied with the aim to improve citizens' understanding of the world as comprising interlocked complex systems, with regard to the decisions they make about their lives (English, 2007). Real world managers and designers of large and complex projects have to make decisions under uncertain current conditions that have consequences for the long term. The effects of decisions are for a large part uncertain and unknown and involve unexpected and undesired effects. Educators that intend to teach their students about decision making in a complex socio-technical environment may benefit from the concepts and tools managers, designers and academics utilize, to cope with and learn about complexity.

Literature can not provide a hand on experience of what it means to be an actor intervening in a CAS. How can this experience be realized? Purely technical simulations are generally aimed at predicting system behaviour. A serious caveat of many computer simulations is that the decisions of human beings are left outside their scope, while human decisions crucially affect the future behaviour of the system. Secondly, there is still a gap between (computer simulation) modellers and decision makers and as a consequence, models are hardly ever used (Lee, 1973; te Brömmelstroet, 2008). In an attempt to combine the technical system with the actor network, academics and professionals design and use simulation games to deal with human decisions in a learning context. Such games can provide free environments where human players can experience the consequences of their decisions and react to undesired and unexpected situations. Players of games become part of the system, which allows a highly interactive and informational relation with rules, other players, and the technical environment. After playing a simulation game, the participants are encouraged to step out of the game, in order to reflect and learn. In the debriefing they look back, share, explain their experiences, and connect their experiences to game results (scores, statistics, etc.) and real world systems. If properly facilitated, simulation games have a positive track record, and have been used in policy and decision making processes and military training for decades (Duke and Geurts, 2004).

The aims of this article are to evaluate 1) the relevance of the use of simulation games for learning about CAS, 2) whether learning conditions for the players of these games (mostly students) are met, and 3) whether there are indications of learning about the CAS. First, CAS concepts will be shortly introduced. Second, simulation games are identified themselves as CAS, which is proposed as a necessary condition for them to be able to

simulate real world CAS. The subsequent conjecture is, that simulation games can simulate a real complex adaptive system and provide conditions for the learning and understanding of their behaviour. If indeed so, simulation games can be considered a valuable method for learning and one of the few tools to accomplish this with regard to CAS. Last, in relation to the third aim, we illustrate the argument by describing results from the case SimPort-MV2, a multiplayer simulation game played by students, that combines the social actor network as well as a simulation of the spatial and economic aspects.

2. Complex Adaptive Systems

Unexpected phenomena in a physical real world system, such as earthquakes, avalanches and tornados are hard to explain with traditional methods of analysis. Methods from complexity theory and chaos theory, however, have made progress in providing partial or complete understanding of such systems (Lansing, 2003). Whereas physical systems can be expected to follow known rules such as the laws of physics, socio-technical systems show similar phenomena, without such rules readily available. Moreover, both the socio-political and the physical-technical aspects are intertwined and interact with each other (Herder and De Bruin, 2009).

Common to all studies of complexity are systems with multiple elements adapting and reacting to the patterns these elements create (Arthur, 1999). This gives rise to patterns of self-organization and emergence. Much can be explained using methods derived from the natural sciences, which have viewed infrastructures and urban systems as multi-particle systems, such as in traffic modelling and crowd simulation (Helbing, 2004). However, if the elements in the complex system are not only technical-physical elements but cognitive social actors who are capable of acting and reacting with strategies to the patterns they help create, this adds a layer of complexity not experienced in the natural sciences (Lansing, 2003).

Agent-based modelling (ABM) can capture some of the nonlinear effects of socio-technical systems that would otherwise be out of reach (Herder and de Bruin, 2009). In addition, ABM enables one to subject hypotheses for socio-technical phenomena to a rigorous test. However, purely computational models have a fundamental limitation because they lack the capacity of real stakeholders for 'double loop learning', i.e., for re-interpreting their environment, re-framing their problems, and developing novel strategies (Argyris and Schön, 1978). Recent advances in computation power, visualization and human computer interaction provide new possibilities to make real-life stakeholders an integral part of an advanced simulation-game model (Mayer 2009). Part of the complexity of the system can be modelled and simulated in the computer, while at the same time, significant dimensions of strategic actor behaviour and learning are being captured in the social-interactive gaming part.

When it comes to theoretic modelling of complex systems, these strengths are suddenly "weaknesses". Human beings are known for their resistance to adequate description and prediction, while they play a crucial role in the systems that future designers and managers of complex projects will encounter. Analysis of social systems is hampered because

monitoring or measuring key variables is hard or impossible. To support further analysis of these systems, one may consider viewing a system as a complex adaptive system (Kauffman 1993; Gell-Mann 1994; Holland 1995).

Complex adaptive systems (CAS) are studied on different levels by several disciplines using different terms and concepts. As is the case with educating all hard problems and complicated systems, confusion and ignorance of terms and concepts are to be prevented, for example by means of a unified framework (Wilensky and Resnick, 1999). Both students and managers need to recognize the language and concepts used to describe and communicate about CAS, for understanding the complicated phenomena that arise within CAS. When comparing experts in complex systems to novice undergraduate students, Jacobsen suggests "... that helping students understand and use complex systems knowledge will require attention to issues of conceptual change and to helping students construct a richer conceptual ecology which embraces both non-reductive and decentralized thinking, multiple causality, non-linearity, randomness, and so on." (Jacobsen, 2000). For the purpose of unambiguous communication about CAS, we will first elaborate on the occurring phenomena, before identifying their origins on the micro level.

3. Phenomena in CAS

CAS are known for among others their surprising behaviour. Their intrinsic structure on the micro level causes a number of phenomena on the macro level: tipping points, self organization, path dependency, and emergence. As these phenomena are ubiquitous in the everyday systems that surround us, they become relevant to education in management and intervention.

One of the goals of managers and policymakers is to guide systems to more desirable states, within financial, material and human constraints. At *tipping points* a sudden shift to a contrasting dynamical regime may occur. A tipping point represents a system state from which the system can access multiple paths, with minimal intervention costs. The avalanche, triggered by a critical snowflake, is a well known metaphor in complex systems, but the reverse probably occurs more often. Large interventions in a system damp or extinguish through nonlinear relations, resulting in hardly any observable effect on macroscopic behaviour.

Due to the time dependence of many CAS, the timing of interventions becomes a crucial factor in their success and survival. Both immediate and postponed interventions may result in an unpredictable reaction from the adaptive agents in the system itself. In the positive case, the agents *self organize* to solve an issue they are facing. In the negative case, the system descends into *chaos*. Attempts at the other extreme, intervention aiming at maximum control, may result in paralysis of the system.

Human agents have the ability to imagine possible futures and conduct strategies, through which they might prevent future scenarios, which were deemed probable from a simpler model. Prediction is again hampered by *path dependency*, which means that the precise historical path, taken by the system, is of crucial importance to its development in the near future. In short, agents will *adapt* to the *emerging* patterns they or the environment created, resulting in considerable difficulties for the intervener.

In the case that from this hidden information or from uncertainty in variables, the system displays behaviour that is not explainable by the observable variables, one may speak of *emergence*. A common example is the occurrence of hexagonal Bénard cells when heating a liquid (Koschmieder, 1993). The emerging convection direction and placing of the hexagons depends on the initial configuration of molecules and their temperature on a microscopic scale, both of which are unknown to the external observer.

4. Micro Level Origins of Phenomena and Concepts in CAS

On the road from the micro level description to the actual phenomena observed in CAS on the macro level, some concepts are introduced to support the connection between the levels (see Fig. 1). In general, systems are described with the following three components: system, subsystem, and relation. The relations can be internal, connecting subsystems, or external: between subsystems and the environment of the system. The subsystems on the lowest level are regarded as elements. The challenges for interveners, such as managers arise, if a system has the properties of complex systems:

- many elements and variables,
- nonlinear relations between these elements and variables,
- uncertainty about the state of elements, the values of variables, and the relations.

When a system fulfils the above three conditions and by human action or otherwise, *adapts* to its environment and itself, it may be called a complex adaptive system. The third property, 'uncertainty', covers a number of situations. When one has an error in one's measurements this is considered uncertainty, because one is uncertain (within the limits of the error) about the real value. When there are hidden variables one cannot measure or know, and when relations are unknown, this is also considered to be covered by uncertainty. If a system is not monitored, which is relevant to management, the uncertainties on the micro level grow through the nonlinear relations, until unexpected behaviour is observed on the macro level.

We have to keep in mind that educators want to make the complexity of a *real* system understandable for students, not of a severely simplified system. As a consequence of the specific phenomena and characteristics described earlier, specific concepts are necessary
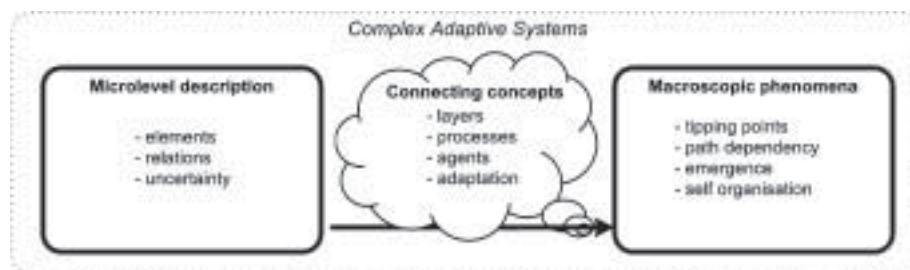

Fig. 1. The connecting concepts support the understanding of macroscopic CAS phenomena.

to describe CAS. The connecting concepts used to analyze CAS and SimPort-MV2 for this study may also be of use to educators and students. Concepts such as layers (levels), networks, processes, agents, adaptation and control (Fig. 1) aim to aid both understanding of CAS as well as the design of tools that aim to disclose them, such as simulation games. *Layers* and networks illustrate how elements and relations from the micro level form networks on a higher level. Failures in a lower layer typically influence the behaviour of the layers above. *Processes* are the changing relations and variables in time that occur in the layers and networks. The processes in CAS are likely to involve movement of people (traffic), goods (transport), and information (communication), between places and people. Humans and their occasional irrational behaviour are an intrinsic part of socio-technical systems. In simulation games they are being represented by real human *agents* or artificially intelligent agents. If socio-technical systems need to survive in a changing environment, they need to be resilient as well as *adapt* to this environment. Some adaptations, however, may not be desirable. In such cases a limited degree of control can be exerted through intervention by policy makers or system managers. These are therefore typical candidates for roles in a simulation game, with the aim to learn in a safe environment about the consequences of decisions in a complex environment.

5. Learning about Complex Adaptive Systems

Wilensky and Resnick (1999) have documented the considerable difficulties people have in making sense of emergent phenomena, i.e., global patterns that arise from distributed interactions and are central to the study of complex systems. They specifically mention difficulties with emergent 'levels', defined as levels that arise from interactions of objects at lower levels: "... we argue for an expanded role for this concept of 'levels' in the study of science. ... confusion of levels (and 'slippage' between levels) is the source of many deep misunderstandings about patterns and phenomena in the world. These misunderstandings are evidenced not only in students' difficulties in the formal study of science but also in their misconceptions about experiences in their everyday lives." (ibid.: 1). The notion of levels can be identified as the 'layers' concept introduced earlier. Misunderstanding may be caused by a lack of detailed knowledge about the workings of the system on the micro level, by a lack of experience or absent frames of reference. On the road to understanding and learning about CAS, misconceptions such as these, have to be addressed.

The importance of learning about complex systems is being emphasized in education on elementary (English, 2007), college (Jacobsen and Wilensky, 2006) and undergraduate levels (Jacobsen, 2000). Incentives are drawn from a broader belief, that an appreciation and understanding of the world as comprising interlocked complex systems is critical for all citizens in making effective decisions about their lives as both individuals and as community members. The educational aims that are met in these studies include displayed awareness of the comprehensive nature of the problem and the need to consider each of the different parts, their interactions and interdependence, and their functions in creating

the system itself (English, 2007). Across domains, complexity concepts have the potential to organize the otherwise bewildering number of properties of diverse phenomena in the physical and social sciences (Jacobsen and Wilensky, 2006). Of central importance to education and simulation gaming are the conditions under which learning may occur. It is suggested that students (and many adults) may have difficulty learning about complex systems if the focus is only on the conceptual level. At the same time, an enrichment of the students' conceptual toolkit is suggested to increase students' expertise (Jacobsen, 2000). Other reports indicate that students were best able to develop a deeper understanding of the observed phenomena when they made connections between the micro- and macro- levels of the phenomena, while most school curricula deal with macro and micro phenomena in separate classes (Wilensky and Resnick, 1999). The above observations represent necessary conditions that need to be satisfied for learning about CAS to emerge.

Despite the arguments in favour, complexity concepts are not being taught extensively on primary or secondary schools. It is suggested that current learning science theories are not sufficient to promote students' understanding of complex systems (Lesh, 2006). A good candidate to improve this may be serious gaming, in which learning by doing is central (Aldrich, 2005). Serious or simulation games adhere to the mentioned condition of not focussing only on the conceptual level, and e.g. stimulate interaction. In addition, they are able to integrate and simulate both the actor network and the technical systems the actors interact with (Herder and de Bruin, 2009). Before returning to learning aspects, a necessary step is to look under what conditions simulation games adequately represent the CAS they simulate? Common sense leads us to believe, that to adequately simulate a CAS, a simulation game must become one itself.

6. Games as Complex Adaptive Systems

To determine if a game can be considered a complex system, the categorization of Wolfram (1984) and Langton (1990) can be considered. This categorization uses both the number of elements and the number of relations, and subsequently systems are classified as fixed, periodic, complex or chaotic. For illustrative examples, see Lansing (2003: 188) and Conway's Game of Life (Gardner, 1970). Apart from the absence of the 'adaptive' part in these examples, the number of elements and relations are not so high as in real world systems and simulation games. This makes it almost impossible to characterize a real world system or a simulation game by assigning it to a single category. In addition, the categorization is only applicable to relatively simple elements, such as cellular automata's grid cells. Most real systems consist of a heterogeneous set of subsystems, further troubling analysis. The classification represents a macroscopic description of a general system, whereas complex adaptive systems are best understood bottom up. Hence, the micro level description at least needs complementation by subsequent levels, similar to the modelling of immune systems, cities and ecosystems. In the following, arguments are presented for viewing games as complex adaptive systems. By taking one

particular view on games, where *players are subsystems*, we identify variables, relations, adaptive feedback loops and their uncertainties, and expose them as the root cause for the phenomena that are observed in games that can be considered CAS.

Just as in Wolfram (1984) and Langton's systems (1990), any system perspective should be preceded by the identification and definition of elements and relations. Taking on the role of an observer of the system, we look at a game as a system of interacting human players: the subsystems. Their relations consist of communication by spoken, written (typed) and body language. As observers of this system, we are handicapped by uncertainty on several levels. To start with a cliché, communication is prone to errors (Shannon, 1948) and misunderstanding, depending on the transmitter-receiver pair's communication skills.

As the human mind is still largely a black box, there is a deep uncertainty about hidden factors and relations we do not even know exist. Then there is a set of behaviours one can explain, but not predict. Although game rules are important for the balance and fairness of the game, players can be expected to show strategic behaviour, circumvent rules and cheat. Each player not only acts based on what he senses and perceives at the moment, or has experienced in the game session. He also acts, based on a unique history which is largely unknown to us, illustrating path dependency. To conclude this non exhaustive series of observer handicaps, no exact relations are known between players' unique histories and their current in-game decisions. Although an individual player may have access to his individual information and relations, he is still a handicapped observer of the rest of the group. For research purposes, surveys can be used to try and get the best of the explicit part of this knowledge, as do debriefings, but part of the knowledge remains implicit, and therefore uncertain to the external observer.

Also on the player group level, the unique history of the game session up to a point in time, influences the decisions for the remaining duration of the game. The results of one round positively and negatively feed back as input to the next round, indicating again path dependency, but now on the game process level. In groups one may also observe tipping points as for example group opinion sways and suddenly tips over to a favoured view, often advocated by an active, extravert or lead personality.

In the mean time, the human players of a simulation game, not only interact with each other, but also with a simulation model of reality, be it computerized or not. The simulation itself, i.e., its substantive part, may consist of many interacting subsystems among which nonlinear relations exist, such as is the case in many agent-based models (ABM). Uncertainties and randomized events may occur frequently and without warning. As defined earlier, a simulation model that shows uncertainty, many elements, and nonlinear relations, already constitutes a complex system in itself.

The simulation model is influenced and adapts to the players, while these players are influenced by, react and adapt to the model. Thus both players and simulation models are adaptive, and together form a CAS. In the above observations, the connecting concepts of CAS introduced earlier – hierarchy (layers), processes, the human agent and adaptation – are found useful. Using these concepts and phenomena for analyzing games, we observe that not all games can be considered as complex. A puzzle, for example, has only one

final state, which is independent of the path chosen. There is no complicated hierarchy of layers identifiable in the puzzle game system.

Entertainment games, like SimCity 4 (Maxis, 2003), Civilization IV (Firaxis, 2005), and World of Warcraft (Blizzard, 2004), possess all characteristics of complex adaptive systems. On the micro level, uncertainties are observed in randomized events, limited information about the underlying simulation model, and player behaviour. The in-game simulations have many elements connected by nonlinear relations. For example in SimCity, crime equals population density *squared* minus land value, minus police effect, according to creator Wright (2006), illustrating a nonlinear relation. Multiplayer versions of these entertainment games naturally include multiple human players that react and adapt to each other, multiplying uncertainty of the game's development in time. Towards the macro level, several layers can be identified and one observes many interacting processes. Players can employ their own strategies, but while playing have to learn and adapt to new situations. Based on these observations, we conclude that these entertainment games (including the players) can be regarded as CAS.

In contrast to entertainment games, typical questions posed in relation to simulation gaming are: How to deal with a changing global market? What are the consequences of introducing a new energy infrastructure? How to deal with different scenarios for the introduction of renewable energy sources? In simulation games, one often needs a helicopter view of the system at hand, whether it is made available to the player or not. For many applications, simulation games have to simulate part of a complex system, adapt to user input and include human decision making just as in entertainment games. Consequently, simulation games can also be considered complex adaptive systems. But even if simulation games *are* complex adaptive systems themselves, understanding still depends on the in-game support for learning. Is the game immersive? Is there an appropriate learning curve? Is there reflection? As noted previously, certain conditions are to be met for understanding, and ultimately learning to emerge.

7. Understanding Complex Adaptive Systems by Gaming

Hypothetically, the concepts of CAS could also be explained to students and managers of complex adaptive systems from literature. It is even possible to use concepts of CAS to explain the cause of failures in complex real world systems. However, this does not necessarily provide support for managers and students increasing their understanding about the simulation model and interventions in the system. The concepts on their own, do not give insights in the effects of restructuring a city or building a new port area. They also give little clues about how to manage these projects. If we want to educate future (system) managers via education or professional training, lectures about CAS are not sufficient.

The authors introduce simulation gaming as an educational and training tool for teaching about CAS. Simulation games are probably the only decision support method that can realistically incorporate human players and social interactions, physical and social rules,

mental and computer models, as well as individual and collective goals. Hence, games mimic real-world systems in a more controlled fashion and participants of a game become part of the complex system and can experience its dynamics and behaviour. Conditions are being provided in which it becomes possible for players to learn by doing (Aldrich, 2005).

The conjecture is that simulation games can support the understanding of complex adaptive systems. But the availability and development of simulation games is not standard or common yet. The lack of sufficient empirical data on the transfer problem, still impedes drawing strong conclusions about learning through gaming. On the other hand, simulation games can use learning principles stumbled on by entertainment games (Gee, 2003), such as tutorials and immersion.

If the objective of gaming is to understand and learn about an existing complex adaptive system, the game has to simulate at least some part of that system. An important disadvantage of entertainment games (e.g. SimCity, Civilization IV, and World of Warcraft) is that they usually do not simulate an existing real world system. They take place in a fantasy world or are based on a simplified real world system. To make simulation gaming useful for (future) managers of real world complex systems, the game ought to have such a degree of realism, that allows players to associate the game elements with the real world. Care has to be taken, as unintended inaccuracies in the game world are easily spotted by students and professionals, which might lead to rejection of the entire game, impeding educational aims.

To achieve understanding, managers and students must be tempted to look for interdependencies, pay attention to long-term effects, perceive complex cause-effect relations, and identify emergence in the system. Unlike reality, a simulation game can be specifically designed to stimulate their search. Even though it is not possible to model the whole world, managers and students must be supported to try and look at the simulation model (of reality) from a higher level and develop a complete – almost holistic – view. Therefore, the system needs to be modelled (mentally or otherwise) in a dynamic but complete way, focusing on feedbacks, non-linear development, and system behaviour on both the short and long term. Because complexity is not only caused by technical factors but also by socio-political actors, both factors and actors must be included in a simulation game.

Simulation games rarely work in isolation, and ought to be embedded in an educational setting. Sufficient time ought to be spent on the debriefing of the game. If they are open for it, players of simulation games step into a learning experience. Players are part of the simulated system, which is (in principle) a safer environment to explore different paths than reality. As stated before, with games it is possible to simulate the effects of policy decisions and train on the unknown, the unexpected and unlikely behaviour of a system. Games are useful for arriving at a complete view of a given issue (Duke and Geurts, 2004) and for integrating different perspectives and disciplines (Kriz, 2003). By switching roles, players can adapt and learn to understand different perspectives, experience the system from different angles, and learn from these differences (Duke and Geurts, 2004; Mayer, 2009). In short, it is found that a complete view, an understanding of different perspectives, an experience of the system from different angles, all support understanding and learning, are also conditions fulfilled by games. It is expected that when the

conditions are met, and the full richness of games is exploited, the understanding of a specific complex adaptive system can increase through gaming.

8. SimPort-MV2: A Simulation Game about Planning a Port Area

To answer the question if gaming indeed supports the understanding of a CAS in an educational setting, we present a case study of the multiplayer simulation game SimPort-MV2 (see Fig. 2). SimPort-MV2 is a game about the planning and design of the Maasvlakte 2 (MV2), a new port area built on reclaimed land extending into the North Sea, adjacent to the port of Rotterdam in the Netherlands. The simulation game was primarily intended for staff of the Port of Rotterdam (PoR). The PoR wanted to gain insight in the consequences of strategic decisions about construction, exploitation and division of clients at MV2. The game SimPort-MV2 was developed to gain insight in the consequences of different strategic choices in the long term and to improve communication and coordination between different departments of the PoR to synchronize the construction and negotiation process (Bekebrede and Mayer, 2006). But its emphasis on strategizing, project management, and teamwork make it appropriate for other audiences as well, such as graduate students and professionals as part of their education and training.

8.1. *Method*

SimPort-MV2 was developed in 2004/2006 by an interdisciplinary team of staff members of Delft University of Technology, Tygron Serious Gaming and in close cooperation with professionals working at the PoR. The first session of the game was played in 2005 by employees of the PoR Authority. Between August 2005 and July 2009, the game was played by 74 teams counting 415 participants.

In relation to the question if simulation gaming can be used for understanding CAS, data was collected of the dynamics in the game and the perceived learning of participants. By means of observations, questionnaires, and analyses of game log files and port maps,

Fig. 2. A team in a SimPort-MV2 session (left). Screenshot of the game SimPort-MV2 (right).

an integral image was reconstructed. At the end of each game session, extensive debriefings were held on what had occurred in the game and why. Players completed a survey after the game with closed and open questions about various aspects of the game (such as quality of the game, perceived learning effects, etc.). The closed questions were mainly statements in which the participants had to agree or disagree on a five point Likert scale, in which 1 means 'totally disagree' and 5 'totally agree'. The computer game stores all information and decisions by the players in log files for later reference. The game also provides feedback on the team's performance based on criteria such as revenues, costs, and client satisfaction. These are subsequently used to calculate the team's score for in-game comparisons. Furthermore, the data allows comparisons between different player groups, on the evolution of their port maps over 30 simulated years.

8.2. *The Game SimPort-MV2: Create Your Own Future*

The objective of the game SimPort-MV2 is to gain insight in the consequences of different strategic choices in the long term and to improve communication and coordination between different departments of the PoR, i.e., to synchronize the construction and negotiation process (For a more detailed description about the steps in the game visit www.simport.eu or Bekebrede and Mayer, 2006). Preceding the identification of subsystems and processes, the game will be described in some detail, in order to provide an appropriate background for the results.

The game can be played with 4 to 6 persons. The participants play the board of directors of the MV2 project. Within the board, the players are divided over three roles: general director, building director and commercial director. Together, they can take all decisions regarding the construction, negotiation and financing of MV2. The objective in the game is to build MV2, contract sufficient amounts of clients, while trying to make profit in 30 simulated years.

After a short introduction by the game leader, the players decide about their strategies, which consist of defining the flexibility of the construction of the MV2 area, the method of contacting and negotiating with potential customers, and the distribution of four different types of customers (container terminals, chemical industry, distribution centres and alternative type of clients) on the map. When these strategic decisions have been made the simulation time starts, allowing the players to start acting. The building director has to start constructing the MV2 area. Commercial directors ought to contact potential clients and negotiate contracts. General directors have to take into account the synchronization between the processes and financial balance.

While playing, the participants observe path-dependencies in the building of the area, dependencies between the building and exploitation processes and lack of communication between the separate departments. After each decade, time is paused for a 5-minute break in which the teams reflect on their activities in relation to their chosen strategy. Within this break, the players can redefine their strategy or restructure the organization within the team.

A game session takes about five hours and simulates 30 years of development and exploitation of the area. Generally, after 30 years the MV2 area is fully built and all

parcels are rented. The teams receive income from rent and transportation of goods. Subsequently, the debriefing starts, in which the players reflect on their final results. Questions for reflection include: What is the performance of MV2? Did you change or follow your initially chosen strategy, and why? Which dilemmas did you encounter? And what would this mean for the real MV2 project? Frequently, the game is played with several parallel teams, enabling direct comparisons of strategy, decisions and outcomes.

8.3. *Simulating a Complex Adaptive System in SimPort-MV2*

Before we can introduce the learning experience on complex systems, we have to establish whether SimPort-MV2 is a CAS, as argued earlier. To answer this question, the game is analyzed based on the connecting concepts of complex adaptive systems, introduced earlier and shown in Fig. 1. SimPort-MV2 is made up of different subsystems, like those concerning construction, negotiation, finance, scoring and the decision making teams (the players). Each subsystem can be further decomposed in lower level subsystems. Changes in the systems, for example in the construction of the area, affect other systems, such as the negotiation subsystem, indicating causal dependency.

In the game, several parallel processes are at work. Part of the team is building the port area, while other team members are negotiating with clients. For a successful result, these parallel processes have to be synchronized. Timing of actions (interventions) is essential, as it is only possible to contract clients when land is available for rent. This means construction has to be finished and the same area can not already be assigned to another client. The human agents are simulated by the players. As mentioned, a team consists of 4 to 6 persons and is responsible for all the decisions needed for developing the MV2 area. The complex and unpredictable behaviour of individuals and their reactions on the dynamics in the system are an integral part of the game. In the game, there is no centralized control and the players have to manage the port area by themselves. Players take decisions in continuous time. This means that while playing, the players also have to adapt in real-time. In particular their planning needs to be efficient but also flexible enough to accommodate delayed building activities and changing economic prognoses. The simulation game SimPort-MV2 shows elements, relations, uncertainty and the four connecting concepts of complex adaptive systems. In this sense the game is valid for the aim of understanding complex systems. In summary, when analyzing the simulation game SimPort-MV2, the phenomena of a CAS are observed (Bekebrede and Meijer, 2009). Earlier, conditions for learning through gaming were established. Based on the common sense assumption that a game has to simulate complex adaptive system behaviour to be used as an educational method for learning about CAS, we can conclude that the game SimPort-MV2 can be used for educational purposes.

8.4. *Learning Outcomes in SimPort-MV2*

Over the years, the game was played by 415 professionals and students. Except for the professionals of the Port of Rotterdam, the game was embedded in a course or seminar

about port design and planning or project management. At university the game was embedded in, or additional to: courses, lectures, exercises and excursions. Although there were slight differences in the aims for playing the game, generally 'increasing the understanding of a CAS' was the primary aim. A detailed and exhaustive discussion about the results of SimPort-MV2 and the explanation of this outcome is outside the scope of this paper. Therefore, we limit the results to the general conditions and learning results, based on the surveys.

Previously, SimPort-MV2 was established as a complex adaptive system. However, to become a valuable learning environment, the subject of the game has to be accurate and detailed, while the environment has to be motivating for learning. From the survey we conclude that the players agreed that the game was realistic and detailed enough for the purposes of the course or seminar (see statement 4 and 5 in Table 1). Secondly, from the enthusiasm of the players and the generally positive atmosphere during the sessions (see statements 1 to 3 in Table 1), the game SimPort-MV2 appears to be a successful learning intervention. Consequently, we argue that the game SimPort-MV2 does not only simulate a CAS, but is also a valid and motivating environment.

Finally, the question arises whether gaming has effects on the learning about CAS. Table 2 gives the results of the perceived learning of the participants. These results show that the game was successful in increasing the knowledge about the complex MV2 project. More specifically one sees an increase of insight on the real 2nd Maasvlakte, its commercial complexity and its strategic complexity (statement 2, 3 and 4). Secondly, the participants agree that the game provides a clear picture of the MV2 area (statement 5) and that the game showed why and how the different processes have to be integrated (statement 6). Finally, participants agree that the game can promote cooperation and communication between different departments and individuals (statement 7 and 8). The game SimPort-MV2 did not significantly increase the perceived theory-based knowledge about complex adaptive system or other theories explained in the courses (statement 1).

In short, the game is successful in getting more insights in complex systems, in this case, especially the complex system Maasvlakte 2 and its associated management process. A relation with theoretical notions is not directly found as a learning outcome. This could be explained, because in the game there is no direct link with the theory and surveys were filled out directly after the game. Whether the obtained understanding in games

Table 1

Results of the conditions of SimPort-MV2 for learning purposes (1= 'totally disagree' and 5 = 'totally agree')

		N	Mean	Std. dev.
1.	I found it educative to take part in SimPort-MV2 with others	400	4.0	.68
2.	I enjoyed taking part in SimPort-MV2 with others	402	4.3	.65
3.	I had fun working together with other students	220	4.2	.59
4.	Given the aims of the simulation game, the game was sufficiently realistic	397	3.6	.80
5.	Given the aims of the simulation game, the game was sufficiently detailed	400	3.8	.74

Table 2

Results of the perceived of learning about the complex system Maasvlakte 2 of the players (1= 'totally disagree' and 5 = 'totally agree')

		N	Mean	Std. dev.
1.	The theory from formal lectures and books became more understandable	211	2.5	.86
2.	Through my participation in SimPort-MV2, I've gained a number of new insights about the real 2nd Maasvlakte	401	3.7	.93
3.	SimPort-MV2 provided insight into the strategic complexity of the 2nd Maasvlakte	401	3.9	.76
4.	SimPort-MV2 provided insight into the commercial and economic complexity of the 2nd Maasvlakte	400	3.8	.76
5.	SimPort-MV2 provided a clear picture of how the 2nd Maasvlakte could turn out in the longer term	398	3.7	.80
6.	SimPort-MV2 has shown why and how infrastructure, management and commercial processes must be in sync	381	3.8	.75
7.	I think that SimPort-MV2 can promote cooperation between different departments and individuals	394	4.0	.70
8.	I think that SimPort-MV2 can promote better communication between different departments and individuals	392	4.0	.71

has an impact on the actual management of complex projects, remains a question to be answered in future research.

9. Conclusions

The aims of this article were to evaluate 1) the relevance of the use of simulation games for learning about CAS, 2) whether learning conditions for the players of these games: students and professionals are met, and 3) whether there are indications of learning about CAS. First, CAS concepts were introduced, which connect the micro level to the macroscopic phenomena. Secondly, we introduced simulation games as a learning intervention which could support the understanding of CAS. Several authors have reported that people have considerable difficulties in making sense of CAS phenomena. Specifically mentioned are: the confusion of levels, a poor conceptual toolkit, and the lack of connections made between the micro level and macro level. The positive counterparts of these, become the conditions for the emergence of learning about CAS.

An additional and necessary common sense condition for learning about CAS was introduced. In order to adequately simulate a CAS, a simulation game must *be* a CAS itself. It immediately followed that the game must consist of numerous different elements, with many relations and multiple possible outcomes. By taking players as interacting subsystems, simulation games were established to be CAS themselves. In this analysis, the four connecting concepts of complex adaptive systems were found useful to analyze games, and may serve educators and students in a similar way. The subsequent conjecture was that simulation games can simulate a complex adaptive system and stimulate learning and understanding of their behaviour. We view simulation gaming as practically the only

tool which is flexible enough to provide the conditions for students to experience and learn about a wide variety of CAS phenomena. In general it was found that a simulation game should provide a motivating learning environment and that the outcomes fed back by the game should be realistic.

The case of SimPort-MV2 is used to illustrate more specifically the argument by providing indications of perceived learning about the specific CAS it simulates. SimPort-MV2 is a multiplayer simulation game that combines the social actor network with a simulation of the spatial and economic aspects. First, SimPort-MV2 was shown to be a CAS itself, thus fulfilling the condition for being able to support understanding about CAS. Second, the results from surveys show that SimPort-MV2 fulfils also the conditions of realism and being a motivating learning environment. The learning outcomes generally support our argument. Although a relation with theoretical notions of CAS is not directly found as a learning outcome, the game was successful in increasing the knowledge about the complex Maasvlakte 2 project. Thus, the participants learned about the complex system at hand. Understandably, students and professionals alike had a hard time generalizing their knowledge of this one case, to general notions. We observe a difference in perceived learning between the specific complex system (MV2 project) and more general complex system concepts. This coincides with the findings of other authors' reports on the education of complex systems, mentioned earlier in this article.

Looking ahead, the empirical findings do not answer related questions, such as: in which way the acquired knowledge is used in other situations, and what the consequences are for the decision making process in the real Maasvlakte 2 project. These will have to be answered in future research. However, if the argument stands the test of time, while conclusive empirical data on 'transfer' is still lacking, simulation games can be considered a valuable method for learning and one of the few tools to accomplish this in complex adaptive systems. As a consequence, simulation gaming is expected to benefit education for both students and professionals.

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Kompleksinių adaptyviųjų sistemų įvaldymas naudojant žaidimus

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Mokiniai mokyklose mokomi, kaip priimti teisingus sprendimus sudėtingose aplinkose, vadovai nagrinėja didžiulių projektų sudėtingumą kasdienybėje. Norint priimti geresnius sprendimus, manoma, kad būtų naudinga nagrinėti sudėtingus reiškinius, kaip tai daro jaunimas – būsimieji specialistai. Šio straipsnio tikslas – įvertinti žaidimų panaudojimo tinkamumą didelio masto socialinių techninių projektų sudėtingumui pažinti. Pateikiamos ir apibrėžiamos sąvokos, susijusios su kompleksinėmis adaptyviosiomis sistemomis. Autoriai iškelia hipotezę: sudėtingos adaptyviosios sistemos gali būti pritaikomos imituojant žaidimus. Šiuose žaidimuose žaidėjai gali išbandyti sistemos veikimą ir tokiu būdu perprasti jos sudėtingumo lygį. Vienas iš tokių pavyzdžių yra kompiuterinis žaidimas SimPort-MV2, kuriuo imituojamas sprendimų priėmimo procesas: Roterdamo uosto plėtra į Šiaurės jūrą. Žaidimą išbandė šimtai aukštųjų mokyklų studentų. Remiantis šiuo tyrimu, buvo pateiktos preliminarios išvados apie mokymąsi, aprašyta, kaip imituojant žaidimus galima pažinti sudėtingas adaptyvias sistemas bei ugdyti ir mokinius, ir mokytojus.