International Conference of the System Dynamics Society, July 20-24, 2014

System Dynamics and Serious Games

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Abstract

This paper deals with the relationship between serious games and system dynamics. Games have been used in SD since the beginning. However, the field of serious gaming also has its own development. The purpose of this contribution is to provide a broad overview of the combination of serious gaming and SD and discuss the state of the art and promise. We first define serious game, simulation and case study and then point out how SD overlaps with them. Then we move on to define the basic components of a game and continue with an outline of important decisions and challenges of game design. After reviewing different possible purposes of SD-based simulation games, we discuss various approaches to game design with specific attention paid to learning effects. We also review the evolution of the interest for serious gaming in SD over the past 40 years. Our conclusion is that interest has oscillated between rising and declining, but that serious gaming is being recognized as an important component not only in educational settings, but also in policy design. We finish by offering important research questions for the future.

Keywords: simulation game, serious game, interactive simulation, management flight simulator

1. Introduction

1.1 Serious games

System dynamics based serious games have been around since the field of SD started. The purpose of this paper is to provide an overview of the combination of SD and serious games and to outline the current state of the art. SD-based simulation games are interactive simulations that have game-like characteristics, that are different from the real world situation represented in the simulation, such as fantasy or competition. Most SD-based games are decision making games. In an SD model, information feedback loops represent decisions which influence the state of the system, and the system state influences the decisions made. An SD model can be made interactive by cutting these loops and having one or more players make the decisions in the model.

Designing a meaningful simulation game, however, requires careful game design, departing from the objective of the game. Although games may be used for purposes such as experimentation or testing policies, the objective is often to convey specific dynamic insights to participants. This requires careful consideration of the type and sequence of activities conducted in a learning situation where the game is one component of a receptor-cognition-effector system. Research has been conducted on the learning effectiveness of games, but results have been mixed.

After the initial enthusiasm of simulation games in the 1960s, some studies showed disappointing results which led to less interest in games. In the 1990s there was a renewed interest in simulation games. In the SD community there seems to have been quite a steady interest in serious games since then, but the interest does not seem to have grown at the same rate as outside of the SD community.

1.2 Defining and relating relevant terms

1.2.1 Games

There is discussion in the literature about the definition of a *game*, and about whether a definition is even possible or desirable in order to communicate about games (Mayer *et al.*, 2014). In 1974, Duke reviewed a variety of then available serious games and stated that this "turned up the startling disclosure" (Duke, 1974 p. xvi) that there was no single property that they shared. We will therefore not attempt to define the general term. We will use the six dimensions that Garris *et al.* (2002) derived from the literature that characterise (instructional) games:

- Fantasy: imaginary or fantasy context, themes or characters,
- Rules/goals: clear rules, goals, and feedback on progress toward goals,
- Sensory stimuli: dramatic or novel visual and auditory stimuli,
- Challenge: optimal level of difficulty and uncertain goal attainment,
- Mystery: optimal level of informational complexity,
- Control: active (learner) control.

Many authors limit the term *serious games* to games in which the objective is for the participants to learn from the game, others use the term more broadly. In this paper we will consider other purposes as well and we will use the term serious for "games that do not have entertainment, enjoyment, or fun as their primary purpose" (Michael and Chen, 2005, p. 21) or "entertaining games with non-entertainment goals" (www.socialimpactgames.com). However, we are aware that, as

Ratan and Ritterfeld (2009, p. 11) indicate, this also raises issues related to who defines the goals (Mayer *et al.*, 2014).

1.2.2 Simulations and games

Simulations and games are often mentioned in combination with each other. The dictionary definition of a simulation is that it is “the imitative representation of the functioning of one system or process by means of the functioning of another” (Merriam-Webster.com, 2014). The underlying model for a simulation may, for example, be a system dynamics model, discrete event model, or Agent-Based Model. Crookall *et al.* (1987) emphasize that a simulation is a representation of some real-world system. This verisimilitude, or similarity with a referent system, is also discussed by Lane (1995). Lane (1995) and Crookall *et al.* (1987) state that, in contrast, games do not have this verisimilitude intention.

Simulations can have one or more of the game characteristics (Garris *et al*., 2002) mentioned above that are not present in the real-world system. According to Garris *et al.*, simulations with these characteristics are more game-like. We will use the term *simulation game*[i] for an interactive simulation that has game characteristics. Although the term *simulation game* implies a specific subset of simulations and games, it is more of a continuum and some interactive simulations are more game-like than others.

1.2.3 Simulations, games and case-studies

Ellington *et al.* (1982) compare games, simulations and case studies, and show how these three may relate. Ellington *et al.* suggest that the combinations of these may be seen as overlapping areas in a Venn diagram as shown in Figure 1. Note that, as mentioned above, this is a simplified representation as the boundaries aren’t this sharp.

“A case study is an intensive analysis of an individual unit (as a person or community) stressing developmental factors in relation to environment” (Merriam-Webster.com, 2014). Pure case studies include conventional non-interactive case studies used in the training of professionals.

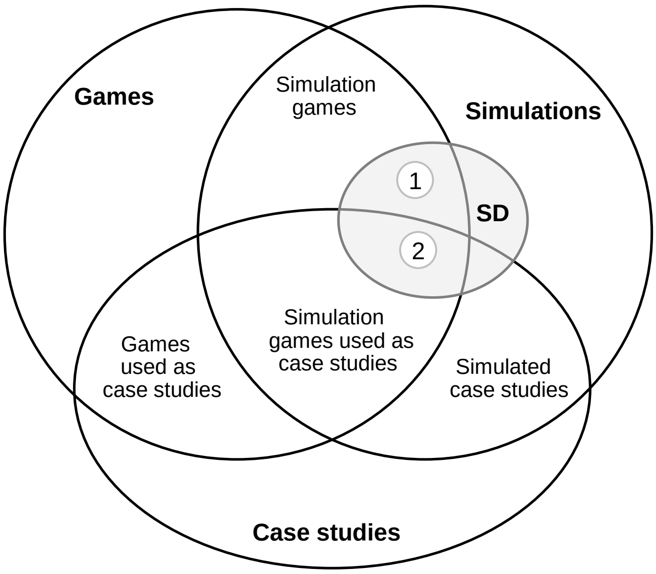

Figure 1: Games, (SD) simulations and case studies (Adapted from Ellington et al., 1982)

The topic of this paper is the relationship between system dynamics and serious games. We will therefore focus on SD-based simulation games, and SD-based simulation games used as case studies that are used for other purposes than pure entertainment. Whenever we use the term game below, it refers to a serious simulation game using SD. SD simulation games are usually not stand alone games, but embedded in some kind of exercise with facilitation, and briefing and debriefing.

The remainder of this paper is organised as follows. In section 2, we first explain the relationship between an SD model and a simulation game. Then, we look at the different components of a simulation game. Section 3 discusses the choices that have to be made when designing a game. In section 4, we briefly consider the different purposes a game may have. One of the main purposes is learning by the participants of a game, i.e. conveying dynamic insights. We consider the activities that are useful for making players reach the intended insights and the sequencing of those activities. An important issue that remains is the learning effectiveness of games. We touch on work in progress looking at changes in mental models before and after playing a game. Section 5 looks at the interest in SD and games over the years, and Section 6 concludes the paper.

2. System Dynamics and simulation games: a happy couple

2.1 Decision making games

Most of the SD-based games are decision making games in which players take on the role of a decision maker (we will discuss some exceptions at the end of this section). In his well-known book on serious games, Abt (1970) refers to this category of games when he states that "reduced to its formal essence, a game is an *activity* among two or more independent *decision-makers* seeking to achieve their *objectives* in some *limiting context*" (Abt, 1970; p.6). This seems to correspond with the notion of a game of strategy used in game theory. Ellington *et al.* (1982) resolve the possible weakness of the definition for situations where single players play against the "game system" by regarding the deviser of the game system as one of the decision makers.

If we look at the basic structure of an information feedback loop in SD, we can see the relationship with decision making. Decisions are made on the basis of information available to the decision maker about the system state. The decisions will influence the system state and information about the new system state will reach the decision maker and he/or she will make a new decision that will again influence the system state. In its simplest version this forms a feedback loop in which a decision has an impact that again influences a decision, and so on (see left hand side of Figure 2). We could quantify such a model and run the simulation automatically. In this case we would have to model the "rule" the decision maker uses. We could also model and quantify all parts except the human decision maker, and stop the automatic simulation at certain points and have a human enter the decisions, thus involving the player's own decision rules. An SD model that includes information feedback is easily made interactive by cutting the loop, and presenting the impact to the user who will then enter a decision of which the impact can be calculated (see right hand side of Figure 2).

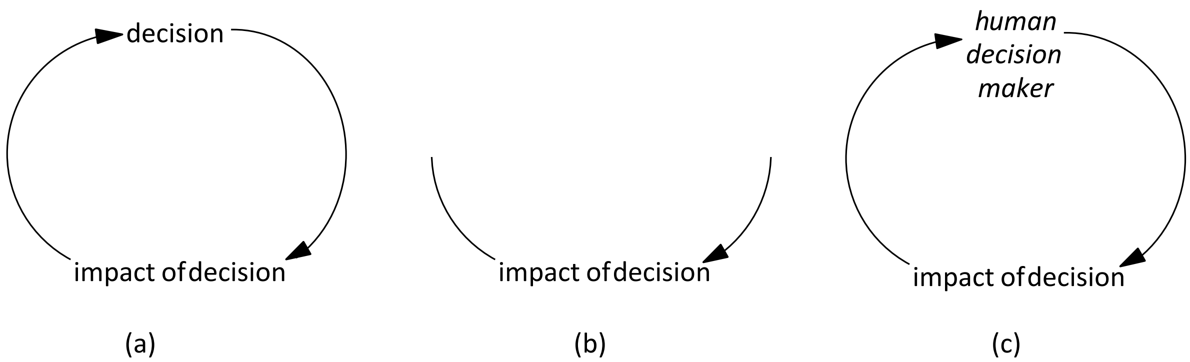

Figure 2: An information feedback loop (a) is cut (b) to make the simulation interactive (c).

We will call the latter an *interactive simulation*. The human player can, for example, test different decision rules/policies to see what the consequences of these decisions are. Rounds, as seen in a game, are thus very easily introduced when information feedback is present. In our view an interactive simulation is not the same as a *simulation game*, as game characteristics are not necessarily included in an interactive simulation. The distinction between these two is not always as black and white as it may seem. Some authors consider an interactive simulation to be a simulation game (e.g. Kopainsky and Sawicka, 2011; Maier and Größler, 2000). Klabbers (2003), for example, defines games as including actors, rules and resources, and simulations as only including rules and resources. In this definition, an interactive simulation is a game. Lane (1995) calls this the "intervention definition" distinguishing between simulation and game, and he prefers the "verisimilitude definition" mentioned in Section 1.2.2.

The description above is intended to show the relationship between information feedback in SD and decision making rounds in a game. However, it is not intended to mean that if you have an SD model with information feedback it can be turned into a meaningful interactive simulation or game by cutting the feedbacks. As will be discussed in more detail below, the intended objective of the game drives the design of the game. For an SD-based game the intended objective of a game will often be to convey *dynamic insights* which are based on feedback thinking (Andersen, 1990). If the modeller obtained these dynamic insights by building the model, it does not automatically mean that the same model is suitable for conveying this insight to others. A completely new or different model may be more relevant for achieving the objective of the game (Andersen, 1990).

2.2 General components of a decision making game

Figure 3 schematically shows a simulation game with a player and a representation of some kind of real world physical system as discussed above. This representation generates outcomes that are perceived by a player and used to make decisions and thereby to act on the physical system.

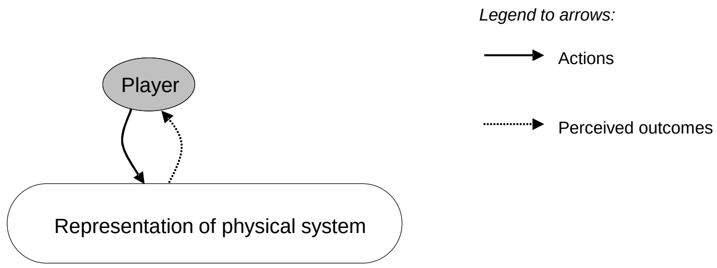

Figure 3: Schematic of a single player simulation game

The representation of the physical system can consist of a computer simulation, some kind of physical representation (e.g. a board), or a combination of both.

With or without a computer. The physical system is not necessarily represented using a computer. Determining the impact of a decision, i.e. the action of a player, may be done manually, by using a paper and pencil calculation, and/or by using some kind of physical representation of what happens when a decision is made, i.e. a physical representation of flows and stocks. The board game version of the Beer Game, for example, involves virtual crates of beer being moved around a game board.

Including some kind of graphical representation of the physical system can make it easier for the player to understand the system. This visual representation can be physical (such as on a board) or on the computer.

The actions of the players are represented accordingly. If a computer simulation is used, the actions will consist of entering decisions into the computer. If a computer simulation is not used, actions and outcomes may consist of physical representations of the action our outcome, for example using chips, notes, or game pieces.

With or without an SD simulation. Even if a computer is used during the game, the calculations underlying an SD-based simulation game do not necessarily have to be conducted by using an SD model. If there are no relevant dynamics within the time of one game (decision-feedback) round, no SD model is needed and hand calculations or a spreadsheet can suffice. This is the case for the Beer Game, for example. Another game for which this is the case is a game on innovations in health care (Daalen *et al.*, 2005). In this game, the players in different game roles use their resources to support different health care innovations. The basis of the game consists of three interacting information feedback loops, each with a participant in the loop. So, an SD-based game is not necessarily supported by an SD model. It would however be an SD model if the whole system, including decision makers, was simulated, but as a game, excluding decision makers from the simulation, it is not necessarily supported by an SD model.

Single or multi-player game. Figure 3 shows a single player game. In a single player game, there are either no other decision makers in the system, or other decision makers are represented as part of the physical system (e.g. by representing fixed decision rules for other decision makers). Figure 4 shows a diagram of a multi-player game in which the different players can all act on the physical system and perceive certain outcomes of the system. They don't all necessarily have the same types of actions or visible outcomes. The actions and outcomes have to be defined for each player.

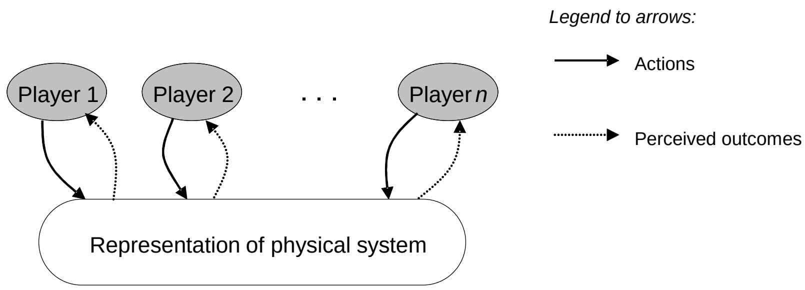

Figure 4: Schematic of game with more than one player interacting with the physical system

With or without direct interaction between players. In Figure 4, there is no direct interaction between the players. The players receive their information through the physical system. Depending on the purpose of the game and the characteristics of the system, direct interaction between the players may be relevant. If direct interaction is relevant, an inter-actor environment needs to be represented (Figure 5). This can consist of open discussion or negotiation between players, or there can be rules constraining the communication between players. For example, verbal communication may not be allowed, or negotiations are bound to certain rules. If there is social interaction among players during a game, group dynamics have to be taken into account.

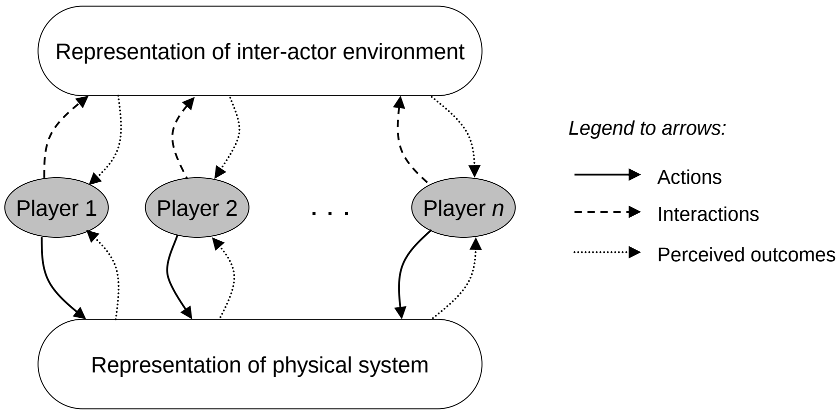

Figure 5: General components of a simulation game (Bots and Daalen, 2007)

In their proposed taxonomy of computer simulations, Maier and Größler (2000) distinguish between *simulators* and *planning games*. They make this distinction based upon whether it is a single-user or multiple-user application. They assume that in a multiple-user application group dynamics will take place. We make a further distinction between multi-player games with and without social interaction.

2.3 Literal and metaphorical games

Up to this point, we have (implicitly) considered decision making games in which players take on the role of human decision makers in a more or less realistic situation. Meadows (2001) found that with these *literal* kinds of games, such as STRATAGEM which had the essential features of WORLD3, most players still did not understand the deeper lessons. For this reason Meadows started developing *metaphorical* games (Meadows, 2001) which are abstract games that illustrate key insights of system behaviour. A number of these types of games have been described by Booth Sweeney and Meadows in the Systems Thinking Playbook (2010).

In addition to metaphorical games in which players play human decision makers, there are also metaphorical games in which players play other system elements. An example of such a game is the game of Living Loops (Booth Sweeney and Meadows, 2010) which is aimed at players experiencing the meaning of the polarity of a feedback loop. Participants stand in a circle holding hands, and all players play either a positive or a negative link. If they are a positive link they raise their hand if their neighbour raises their hand, and lower their hand if their neighbour lowers their hand. If they play a negative link, they lower their hand if their neighbour raises their hand and vice versa. One of the players then starts and the others react to the raising or lowering of the hand of their neighbour. This is a brief game that illustrates the polarity of a feedback loop. In the debrief this is then placed in context.

Another example is the game of Triangles (Booth Sweeney and Meadows, 2010). This is a game in which shows when policies have high or low influence. In our conceptualisation we can describe it like this. The players play the effect of an input; in the game they should always remain at a certain distance to certain people. So if these people move, they also have to move. There is also one person whose movements do not have any effect on other people. During the game, the players experience what high and low leverage means.

3. Game design

3.1 Choices in game design

Designing a game means making choices about objectives of and in the game and about the components shown in Figure 5. This includes the considerations shown in Table 1 below. The right-hand column of Table 1 is only an illustration of the possibilities related to these considerations.

Table 1: Choices in game design

Choice		**Comment**
1	Purpose	e.g. understanding, planning
2	Insights obtained	which, how and by whom (e.g. player, observer, researcher)
3	Plot	the context of the game situation
4	Players	students, knowledgeable people, stakeholders
5	Roles	self, other role, mixed
6	Objective in game/incentive	e.g. high score, cooperative behaviour, creativity
7	Rules	rules for action rules for interaction
8	Representation of physical system	realistic, fictitious (continuum) computer, physical, mixed
9	Representation of inter-actor environment	realistic, fictitious (continuum) open, limited (e.g. rules), not present

It is important not to confuse the objective of the game (purpose) and the objective in the game. The objective *of* the game may be to learn about the financial management of a company, whereas the objective *in* the game is to make the largest profit. Both need to be clearly defined when designing a serious game.

3.2 Challenges in game design

A serious game was defined as an "entertaining game with non-entertainment goals". For the game designer this means that (1) the intended goals need to be achieved and that (2) participants should enjoy playing the game.

Achieving goals of the game. In order for the goals to be achieved, they firstly need to be clear. Many SD games have the intention of the participants learning something (dynamic insights) about a system. There is probably no substitute for building the model oneself for learning about a system (Sterman, 1994). The use of a game lacks the iterative phases of problem definition, model conceptualisation and formulation (Größler *et al.*, 2000). However, building a model may not always be feasible or desirable. For a serious game it needs to be very clear what the learning goals are and how the players will achieve these by playing the game. Not learning from a game or from an interactive simulation is an important pitfall when using these approaches. Participants may just have an enjoyable experience or have tried out things without the appropriate reflection (Lane, 1995; Sterman, 1994; Andersen, 1990). For a serious game, it is usually very important pay attention to the brief and debrief of the game. This holds for the lessons that directly follow from the game as well as for the transfer or generalisation of the in-game virtual world experience to situations the learner is expected to experience in the real world. Meadows (2007) emphasizes the importance of debriefing and Crookall (2010, p. 907) even states that "debriefing is the processing of the game experience to turn it into learning". Computer-based games allow data to be collected during game play that can be used for feedback/debriefing during play and at the end of the game (Crookall, 2010).

Providing enjoyment. An important property of a game is that the players should enjoy playing it. In their investigation of computer game enjoyment (Wang *et al.*, 2009) they found that serious games need to meet certain thresholds in terms of technological capacity (problems: does not run smoothly, not easy to use), aesthetic presentation, and game design elements (problems: options for players are very limited, actions don't result in logical consequences). There were some specific factors they found to relate to a high level of enjoyment. These were narrative related elements, humour, and social interaction.

3.3 Model based game development and game based model development

3.3.1 Using modelling to develop a game

Our point of departure in describing the relationship between SD and games was that there is a (conceptual) system dynamics model and this is transferred into a game. Usually the development of the model and the game are not carried out in a group model building setting. It is, however, possible to do it in this way. Ruud and Bakken (2003) describe how they developed a game using group model building. They propose that this can be used as a way to speed up game development and improve the process of developing a game. One of the reasons for applying this approach is to increase the efficiency of knowledge elicitation from those who have the content knowledge for game. In this case, the game was a decision training game related to air defence and the client knew what to train and how. In addition to the activities that are part of a regular group model building session, the participants were asked about the variables which should be decision variables, and they could provide suggestions for the interface. The model was refined and a draft game interface was added by the modellers, and the game was tested by the participants.

3.3.2 Using gaming to develop a model

In contrast to using modelling to develop a game, a game can inform model development. There are various purposes for which a game can be used in model development, such as:

- using a game to improve the model underlying the game (to improve the game),
- using a game to be able to model decision making (to make a non-interactive simulation),
- using a game to elicit expert knowledge (to build a model).

These three purposes will be explained below.

In addition to presenting how a game was developed in a group model building session, as discussed above, Ruud and Bakken (2003) propose that game playing itself can be part of a group modelling process. They talk about "modelling games - with games". Playing a preliminary version of a game during a group model building session provides participants with the possibility for discussion and further development of the model underlying the game.

A game can be also used to provide information about decision making, which can then be used to build a non-interactive simulation (that includes decision making). We don't know of any examples of this in SD, but we take an example from Agent Based Modelling. For a case about irrigation water in Bhutan, Gurung *et al.* (2006) first developed a game which was played by actual stakeholders in Bhutan. Of course the starting point for this game also consisted of some kind of model, but this game is not the final stage. Based on the playing of this game, a model was developed which could then generate different scenarios. In the case, Gurung *et al.* apply the Companion Modelling approach (http://cormas.cirad.fr/ComMod/en/). This approach is much broader than the part that is mentioned here. It is aimed at facilitating dialogue, shared learning and collective decision making (Gurung *et al.*, 2006). We mention this part of the work here to illustrate that it is possible to make a game first and then use it to (further) develop a model.

Another possibility of using games in model development is described Bots and Daalen (2005). They used a brief (non-SD) role playing game as a way to generate relevant variables during a group model building process. In a project on innovations in health care, they were looking for possible consequences of innovations. In order to generate variables that were relevant, the participants received role descriptions and had to play specific proponents and opponents of fictitious health care innovations and try to convince each other. This way of working was used instead of regular discussion or brainstorming, because the identification activity had to be conducted at the beginning of the workshop, and most people did not know each other, which might inhibit the participants in putting forward their ideas. By assuming a role in the safe environment of a role playing game, they expected that participants would speak out more freely. In addition, it was expected that the game setting would enhance imagination and creativity. Finally, brainstorming does not automatically include argumentation of the factors and actually forbids criticism. Although this was not tested formally, the participants enjoyed this way of generating factors and it quickly led to a list of relevant variables.

4. SD-based games for learning

4.1 Purposes of SD-based games

Shubik (1975) gives an overview of many different purposes of serious gaming, including teaching (e.g. facts, theory, interpersonal relations), experimentation (e.g. validation of hypotheses, exploration of hypotheses), therapy and diagnosis (e.g. group or individual therapy), operations (e.g. planning, exploration, brainstorming) and training (e.g. skills, dress rehearsals). These can all be framed as games as interventions (Mayer *et al*., 2014). Mayer *et al.* (2014) distinguish four different frames, or ways of looking at games and gaming research, that are not mutually exclusive.

- Serious gaming as tool, therapy. This frame is the one most often used in SD-based games and is also the one most often used in the gaming literature, and relates to the purposes mentioned above, such as education, decision making, therapy. Research focuses on the question of whether the game is more effective as a tool than other possibilities, which is also what we will further discuss below.
- Serious gaming as creative innovation. In this frame, serious gaming is seen as a part of evolutionary change. In contrast to games in the first frame, which are directed at curing/repairing, games within this frame aim to build a new future. Research issues relate to understanding the principles of creativity and innovation in and around games (and the game industry) and finding ways to utilise them.
- Serious games as persuasion. In this frame games are seen as a powerful new means of communication (e.g. advergames, games to bring about change in social behaviour). Research can address how discourses in society respond to such games and ideas.
- Serious gaming as self-organisation. Games are seen as part of an evolution in society and cultures at large. Some research is related to explaining ludification of cultures. Others try to find and exploit game principles for self-organization, for example in the work place.

For each of the purposes related to serious gaming, someone learns from the game: the participants, researchers, or policy makers. Most of the literature about SD and games is about learning by the participants in a game. In this paper, it has been implicitly assumed that it is the player who learns from a game. This is not necessarily the case. Serious gaming can also be used to investigate system behaviour. In this case, the players are not involved because they need to experience the game, but because it is impossible or infeasible for a modeller to model the human decision maker. The players are experimental subjects (Shubik, 1972). An example of this is a study by Moxnes (1998) who performed an experiment in which participants were asked to manage a fish stock to investigate mismanagement of renewable resources. A game can also be used to test policies that are being considered. An (non-SD) example of this is described by Anderson (2004) who investigates different types of trading rules for a tradable trap certificate system for the Rhode Island inshore lobster fishery. See Daalen *et al.* (2004) and Bots and Daalen (2007) for different functions of games for policy analysis and natural resource management policy development. Although the examples are mostly non-SD, the functions of games are independent of the kind of game. Mayer and Veeneman (2002) present examples of simulation games that support the design and management of infrastructures. There are only few examples of SD-based games that are used in support of policy. However, given the nature of the issues addressed using SD modelling and the obvious coupling of SD and games there seems to be much more potential for SD-based games in this area.

Conveying insights to participants. Gaining dynamic insights from an interactive simulation or game can be relevant, because it is difficult to gain them from experience. When decisions are made in the real world it is often difficult to see or understand the effects of the decisions. In such a situation, there can be little learning by experience since there is no effective learning cycle (Lane, 1995; Sterman, 1994). SD models focus on systems with feedback and time delays. An SD-based simulation game allows compressing time and space (Bakken *et al.* 1992; Lane, 1995), which enables "experiencing" consequences of actions which would normally not be possible.

4.2 Games for conveying insights to participants: examples and terms

4.2.1 Well-known SD simulation games for learning

SD-based games for learning have been around for almost as long as the field itself. As mentioned above, most simulation games are developed to convey dynamic insights to participants. The first and most well-known game is the Beer Distribution Game (Martinez-Moyano *et al.* 2005; Sterman, 1989). Although computer based versions are available, it is a board game intended for players to experience a production-distribution system to see how structure influences behaviour. It dates back to 1958 when J.W. Forrester had committed to an MIT summer session for which they had to assemble material. It was then known as the refrigerator game, as the game represented a distribution system of household appliances. It was based on a paper and pencil simulation representing instability in manufacturing household appliances at General Electric (Forrester, 2013). This simulation was the beginning of industrial dynamics (Forrester, 2007). Another widely known SD-based game is FishBanks (Meadows *et al.*, 1993; Meadows, 2007). It is a game about sustainable management of renewable resources in which teams of players play fishing companies. The games will not be discussed here as they have been widely published about. Lane (1995) includes an appendix in which a number of games are summarized. One of the most well-known entertainment games, SimCity, was inspired by Urban Dynamics (Fullerton, 2008; Starr, 1994).

4.2.2 Management Flight Simulators and Interactive Learning Environments

Interactive computer simulations that are meant to provide (prospective) managers with dynamic insights are relatively popular in the SD community. These types of simulations are often called *management flight simulators* (MFS) or *microworlds*. They usually combine computer simulation models with conventional case studies (Graham *et al.*, 1992; Hsueh *et al.*, 2006) (see Figure 1). The People Express management flight simulator was the first of this type of simulators (Lane, 1995; Sterman, 1988). The People Express management flight simulator focuses on running an airline at a high level. Most management flight simulators are based on a specific industry. An example of a more generic simulator is the Industry Evolution Management Flight Simulator (Hsueh *et al.*, 2006; Lyneis *et al.*, 2007) for teaching strategic management in business schools. It can be adapted according to the characteristics of an industry to make versions which illustrate specific issues for a specific industry, which has been done for, for example, salt and solar power. Examples of management flight simulators may be found on www.strategydynamics.com and www.mitsloan.mit.edu/LearningEdge. Most management flight simulators have game like characteristics, such as fantasy (e.g. in the role descriptions) and a challenge involving competition (with the computer, or with other players or teams).

Currently many of the interactive SD web-based simulations use Forio Simulate (http://forio.com/products/simulate/). The Forio Simulate software allows building and sharing simulations and making them interactive using an interface design tool. SD models can be imported or made in Forio Simulate. The MIT Sloan management flight simulators, for example, use Forio.

In their paper on a taxonomy of computer simulations, Maier and Größler (2000) propose the term *business simulator* instead of management flight simulator or microworld. They see a number of disadvantages to the use of the term management flight simulator. A real flight simulator is aimed at being as realistic as possible, whereas a management flight simulator abstracts from details. In addition, the term suggests that behaviour is trained instead of providing insights into the relationship between structure and behaviour (Maier and Größler, 2000). They also criticize the use of the term microworld which is often used as a synonym for a management flight simulator in the SD community. In the original meaning of a microworld by Papert, it allows a learner to construct his own knowledge, which means that it is open-ended and usually does not involve explicit learning goals.

Davidsen (2000) and Spector (2000) use the term system-dynamics based *interactive learning evironments* (ILEs). Davidsen calls management flight simulators a first generation ILE, and discusses advanced ILEs that facilitate model transparency. This means that it should not only simulate system behaviour, but it should also clarify the underlying structure and promote understanding of the structure-behaviour relationship. Some work has been done on "transparent-box simulators" (Machuca, 2000) that, for example, show causal-loop diagrams (CLDs) with the variable's behaviour next to it. However, the question of how to design ILEs so that understanding of the structure-behaviour relationship is achieved is a challenge that largely remains (Davidsen, 2000; Kopainsky and Sawicka, 2011; Größler *et al.*, 2000).

4.3 Approaches to conveying insights/learning

An SD-based learning game will strive to make players come to specific insights. In order to reach this goal, the designers/developers have to make some decisions beyond those presented in Table 1 (p. 8). They must have

a) defined or articulated the target insights or learning effects (choice 2)
b) defined a conceptual frame (key variables) and reference behaviours (choice 8)
c) developed an SD model with the causal structure to drive these behaviours (choice 8)
d) a "theory" of the previous knowledge and capabilities of the players
e) a "theory" of which activities are useful for making players reach the intended insight

The game itself will have a surface or interface which contains certain parts of the conceptual framework, of the behaviours and of the causal structure, while hiding others. Referring to points b) and c), the following figure illustrates the game's components and how the player can relate to them.

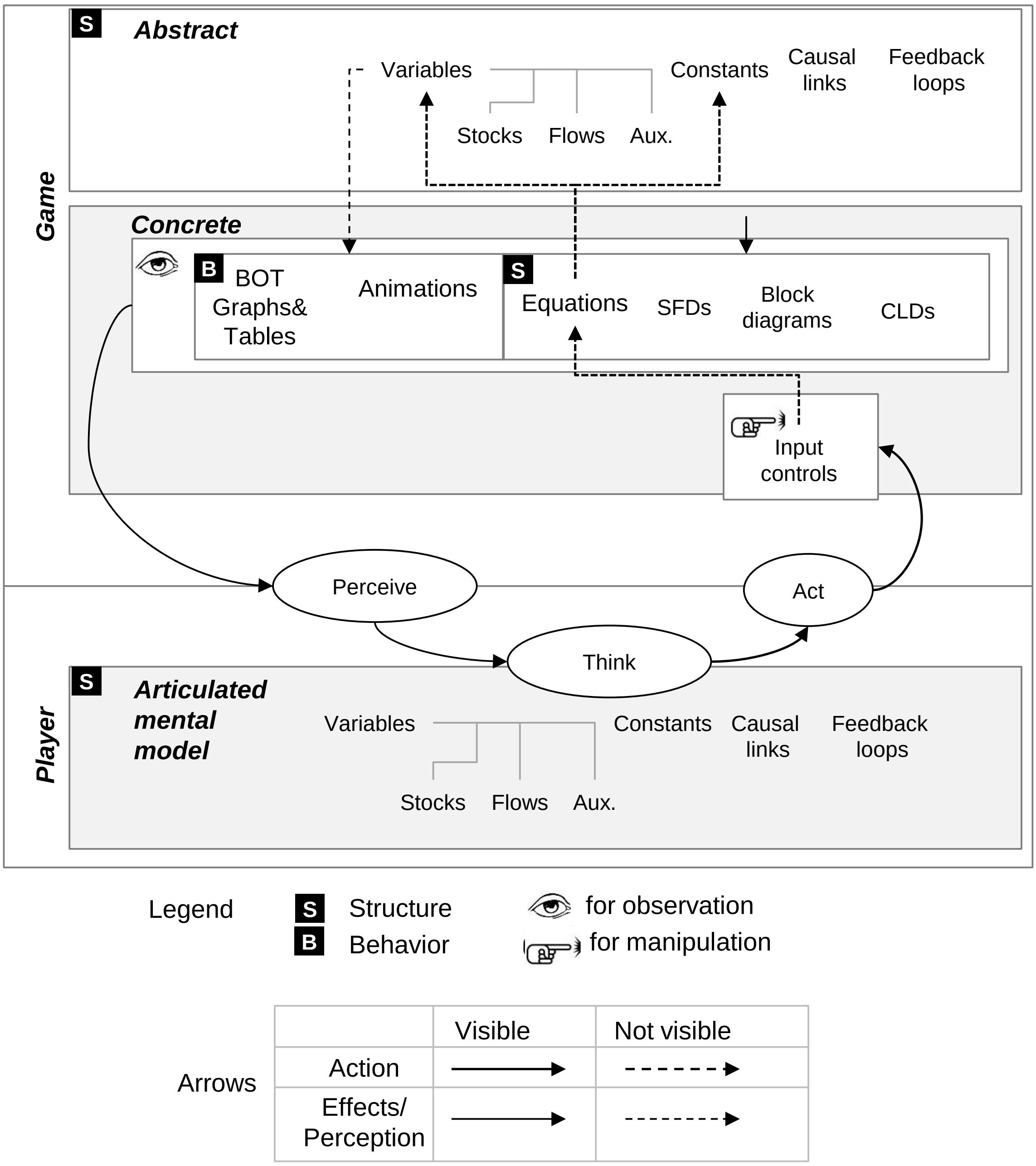

Figure 6: the relationships between the player and the game's components

In principle, an SD-based game consists of components for observation and others for manipulating a model, which at an abstract level is a causal structure captured by variables of several types, links and feedback loops. At the concrete level such a model is represented in one or several ways (equations, different forms of diagram), and devices that represent variables' behaviour (graphs, animations). Sometimes a descriptive text/video will be included. All these components are for the player/user to *observe*. There will also be controls which enable players/users to *act on* parts of the model, by setting parameter values, inputting variable values (or overriding those calculated by the model) and switching on and off specific links, loops or modules of the model. The behaviours can be made visible by graphs and animations. The causal structure to be assimilated and understood by players can be made visible as game boards (like in the Beer Game), CLDs (like in MacroLab, see Wheat, 2007) or stock-flow diagrams (SFDs) unfolded as "stories" (iThink, STELLA). Beyond this, user input controls can be provided for players to define parameter values, override variable values and switch on/off specific loops or parts of the simulation model.

We can therefore think of the game as one component of a receptor-cognition-effector system in which the game has replaced the usual “real” world (not to say that the game is not real). This leaves another important activity for the player: the cognition. In the figure, this is represented as the mental model, which is supposed to become more similar to the game’s underlying model over the time of the game. We do not claim or believe that in a player’s mind there is an SD model; however, the articulated mental models in the player’s awareness will contain the variables, many links and a varying number of feedback loops (Groesser and Schaffernicht, 2012).

The designers then must consider the players’ previous knowledge of SD and the game situation (point d) in the above list) to decide which parts shall be visible (perceptible), which parts the players can manipulate and how such manipulations can be realized. It cannot be stated that making the underlying model visible for players is always an advantage: being able to interpret an SFD requires a substantial amount of previous knowledge, and to unprepared players, such diagrams are too mysterious to be useful (using them would increase cognitive load instead of reducing it). There are cases where the SFD is simple and playing the game does not require analysing it – it just visually frames the game manoeuvers; the Beer Game takes this approach, and since it is a board game, players can directly manipulate the variables (without the detour of screen controls). In other cases, the game situation requires complex SD models to capture the “physics”; for instance, the MacroLab environment (Wheat, 2007) has around 400 variables and its users are economics students without previous SD training. Therefore MacroLab shows them selected CLDs, a control interface and behaviour-over-time graphs (BOTs) of selected variables. Nonetheless, the MacroLab can also be used as a “transparent-box” game when players are SD students.

Also, if the designers adhere to learning theories stating that own elaboration improves or is necessary for deep learning, then *observing* may be deemed insufficient and players will be given more input controls in order to *act on* the causal structure.

According to this view, “black-box” and “transparent-box” (or “white-box”) are only two extreme possibilities on an axis of varying visibility, and there appears to be a design indication: *do not make visible what players are not prepared to understand unless inquiring and studying it is one of the purposes of the game*.

This leads to point e): which type and sequence of activities will be useful for achieving the learning objectives? Inside the SD community, the question of developing models versus using models has been debated ever since user friendly modelling software made game development easy. Attempts to find ways that would allow sufficient cognitive effort to replicate the essential features of modelling can be traced back at least to the collection of contributions which added “Modeling for learning” to the SD bibliography (Morecroft and Sterman, 1994).

SD’s model-driven learning is very similar to a sequence of phases proposed in the discovery learning literature: learners have to be able to develop hypotheses, design experiments, observe the generated data and interpret it to corroborate their hypotheses (Joolingen, 1999). The SD-version of this cycle is shown in Figure 7.

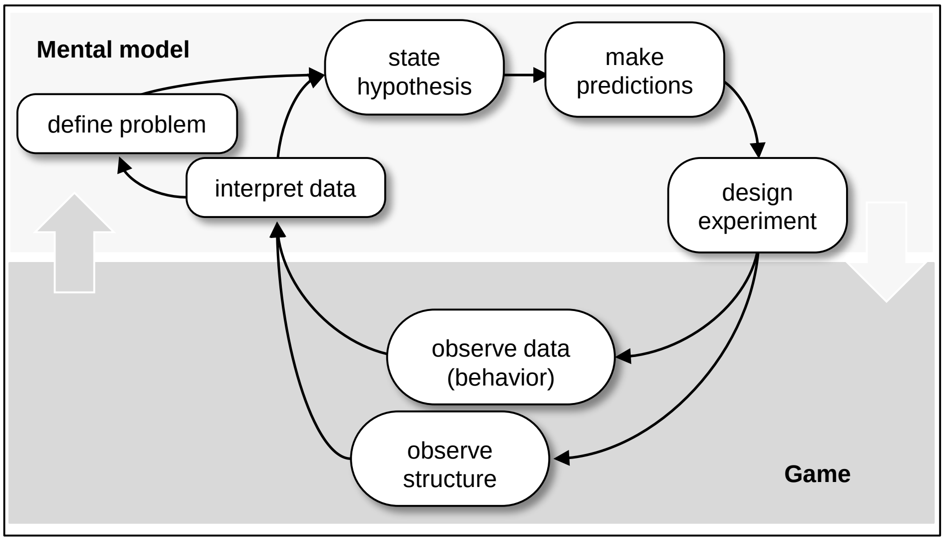

Figure 7: the process of discovering insights with a SD-based game

For sure, the players will make hypotheses and tentatively predict what should happen when they do this-or-that. They then will carry out actions and from our viewpoint these are experiments they have designed. The game's reaction and optionally the structure rendered visible will then be observed and interpreted, maybe to refine the understanding of the problem, and anyway to restate or modify the hypothetical understanding of the game's structure.

Players need to accede descriptive information and personal experience with the game in order to reflect upon what is going on and which is the big picture everything seems to fit in (the mental model). There are different activities and various ways in which they can be sequenced.

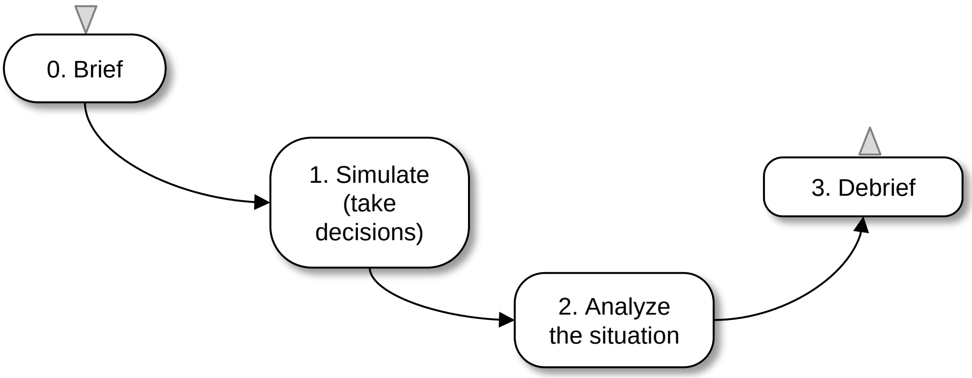

Figure 8: phases of the Beer Game

The Beer Game – beyond all other aspects discussed elsewhere – is a game with a linear sequence of phases: players are briefed, then go through the game, generating and recording behaviour. Then they elaborate BOT graphs and recount why they took which decisions and discover how this generated the "bullwhip" effect of amplifying oscillations. This game generates personal experience and is useful as source of analogies for courses introducing SD or logistics. However, the game itself does not allow to test the new insights, unless additional components are inserted between phases 2 and 3 (Schaffernicht, 2013 a).

Insights elaborated during the analysis of recorded behaviours have a hypothetical status unless they are tested. Therefore games can be designed such as to contain iterations between reflection and action. There are two ways to do so because one can start with reflection or with action. The following figure illustrates the first possibility:

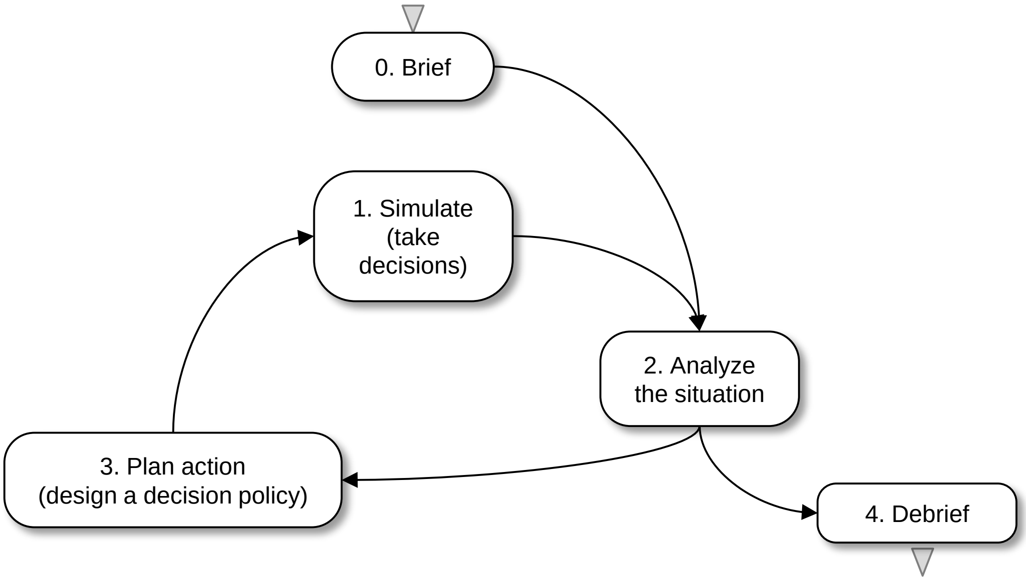

Figure 9: analysis-driven process for simulator-based games

One can brief the players and then make them analyse the situation. There are different possibilities like on-screen animations (Wheat, 2007) or text-based reflection and group discussion (Kopainsky and Pedercini, 2010). Recently, this approach has been use in laboratory experiments to design the work process of a control group (Kopainsky and Sawicka, 2011), reflecting the fact that it tends to be the usual approach in SD-based games currently.

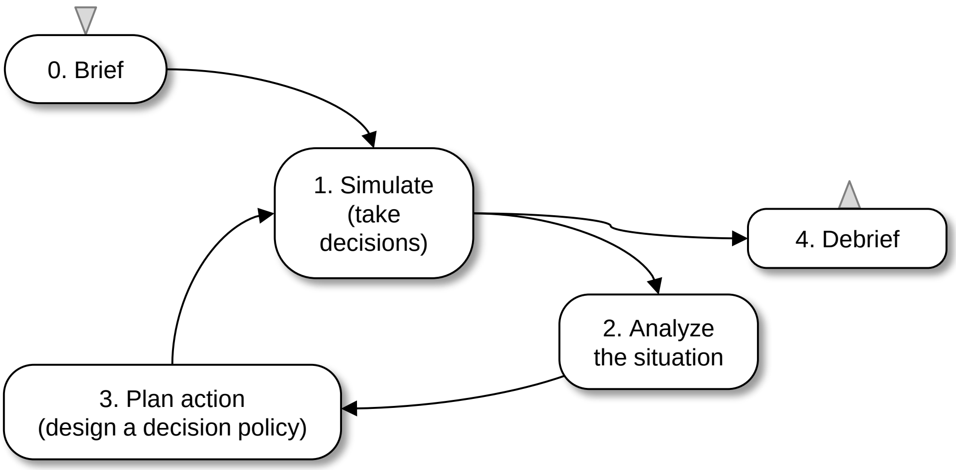

Figure 10: trial-driven process of

However, the other possibility has potential advantages. If the briefing is followed by an initial round of playing the game (note that this was also the case in the Beer Game), then players can start with an emotionally engaging activity and are not influenced by abstract ideas beyond their own mental contents. They will, of course, run into "surprises" (Mass, 1991), and the resulting cognitive dissonance helps to motivate the ensuing inquiry. Kopainsky and Sawicka (2011) suspect that the possibility to play the game as training rounds – starting with simplified conditions and gradually approaching the full complexity – may help to reduce the cognitive load (Sweller, 2005); therefore their treatment group followed a sequence similar to the one shown in Figure 10, passing through three training rounds. Their study suggests this to be the case.

This approach can be used to build a course around a game, starting with a black-box game, then introducing the pieces of causal structure (always using simulation to test proposed causal structure) and gradually elaborating the SD model underlying the game (Schaffernicht, 2013 b). By the time the debriefing is reached, the players have followed a metaphorical red thread through the labyrinth of cognitive ambiguity, and reproduced the relevant insights, being able to test each against the initial simulation game and therefore knowing how useful the discovered ideas are.

4.4 Measuring the effectiveness of simulation games for learning

There is controversy about the effectiveness of simulation games for learning. Before the 1980s, there had already been a rise and decline of the use of games in management education (Lane, 1995). The initial enthusiasm for business simulations/games in education in the 1960s was followed by doubts about their effectiveness (see Lane (1995) for an extensive discussion).

The next wave of interest in simulation games was due to the new technological possibilities of personal computers (Lane, 1995). However, with regard to effectiveness, the most important questions still had remained unanswered: “do simulation or game participants acquire knowledge and can it be transferred to a work situation?” (Lane, 1995). Currently, these questions still have not been answered. Garris *et al.* (2002, p. 444) also indicate that “although students generally seem to prefer games over other, more traditional, classroom training media, reviews have reported mixed results regarding the training effectiveness of games”.

In our opinion it is unlikely that effectiveness questions can be answered in general (Connolly *et al.*, 2012; Faria *et al.*, 2008; Girard *et al.*, 2013; Gosen and Washbush, 2004; Graafland *et al.*, 2012). We need to investigate what works in which situation and what does not work, and why this is the case. This requires careful pre- post- and in-game measurement and experiment design. Some work has been done on developing frameworks for investigating the instructional use of games in general (De Freitas and Oliver, 2006; Garris *et al.*, 2002; Kriz and Hense, 2006; Mayer *et al.*, 2013).

In the SD realm, a term which has been used for the understanding of systems has been “mental model” since the very beginning. A priori this is understandable for a discipline that gives much importance to simulation models, but also asserts that textual descriptions are one kind of informal model (Forrester, 1961). Over the years, the field has developed its own definition of “mental models of dynamic systems” or MMDS (Groesser and Schaffernicht, 2012) and a specific method for representing, analysing and comparing such mental models (Schaffernicht and Groesser, 2011). The complete presentation would be out of scope here, but the underlying argumentation goes as follows:

Dynamic (social) systems are complexes of feedback loops, which consist of stock and flow variables (Forrester, 1968). According to this statement, there are three different levels of description: the elements (variables and links), the individual loops and the whole model.

1) Any representation of a dynamic system can be re-represented as a model consisting of feedback loops and stock and flow variables composing them.

2) Then any mental representation of a dynamic system can be articulated as a complex of feedback loops consisting of (stock and flow) variables and links.

3) By consequence, one can elicit a person’s understanding of a dynamic system as an MMDS, according to the definition:

"A mental model of a dynamic system is a relatively enduring and accessible, but limited, internal conceptual representation of an external dynamic system (historical, existing, or projected). On a conceptual level, the internal representation contains reinforcing and balancing feedback loops emerging from stock, flow, and intermediary variables that causally interact in linear and non-linear, delayed ways which are sufficient to analogously represent the perceived structure of the external system." (Groesser and Schaffernicht, 2012, p. 61).

4) Learning occurs when the understanding of the person changes. Since an MMDS represents such understanding, comparison between the MMDS of a person before and after a SD-based game will reveal learning steps.

5) Differences between MMDS have to be indicated at each of the description levels. Therefore three "distance ratios" have been defined and operationalized (Schaffernicht and Groesser, 2011) as Element Distance Ratio (EDR), Loop Distance Ratios (LDRs) and Model Distance Ratio (MDR). The EDR represents the proportion of the actual differences amongst the variables and links of two MMDS and all the possible differences between them; a higher value means more distance, i.e. the compared MMDS are more different from one another. The LDR informs about how different two semantically equivalent feedback loops are in terms of their polarity, their delays and their elements. The MDS consists of the average of the LDRs of the model.

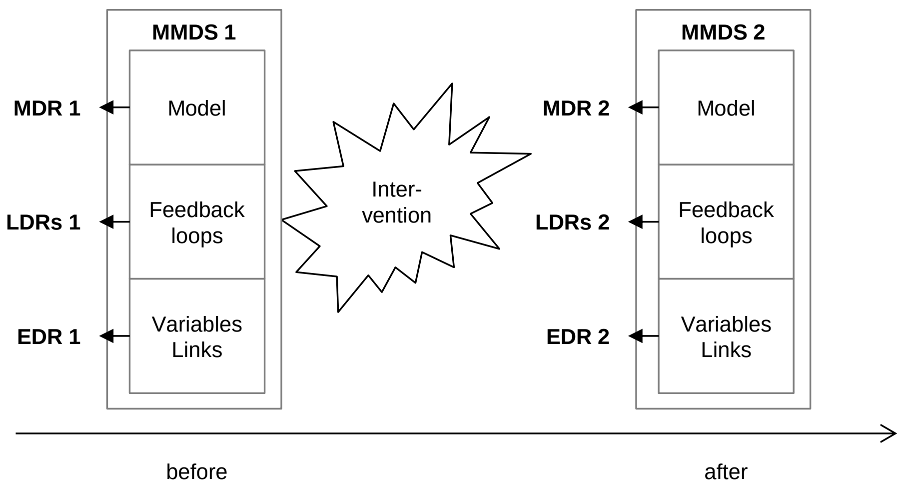

Figure 11: comparison of MMDS

This method is able to detect relevant changes in how a person understands a dynamic system. Initial applications have also shown that larger sets of MMDS can be compared and the ratios allow meaningful interpretations (Schaffernicht and Groesser, 2012). Comparison requires to define one MMDS as reference; this can be the initial MMDS if we want to make only individual comparisons. It can as well be one previously defined reference model, for instance the one underlying the simulation game; in such a case, we would calculate the distance ratios of MMDS 1 versus the reference model and MMDS 2 versus the reference models: if the distances have decreased, we can assert that the individuals have approached their mental models to the one underlying the game they played.

However, the work process is tedious; a specific software has been developed and the corresponding publication is presently under revision. The method will be further developed such as to allow to take into account the differences between the types of variables (stock, flow, intermediate) and the implicit presence of causal influences via a detour of longer paths (when the influence of a variable *a* reaches a variable *d* passing over variables *b* and *c* on the way).

There are several challenges to be addressed in the future. The biggest one has to do with how the understanding of a person is elicited and then re-presented as a MMDS. And, closely associated to this, how many tasks have to be carried out by the analysts themselves. In its current version, the MMDS method relies on human judgment interpreting the person's articulated statements and representing them as causal diagrams. This can introduce subjectivity and in certainly limits the number of individual MMDS that can be treated in one study.

Text analysis promises to automate these early stages of the work process and has been used by some researchers (Kopainsky *et al.*, 2012). However quick and reliable such computerized processing is, these algorithms work on the description level of the *elements* only; the resulting "blindness" for feedback loops is an important drawback. Therefore the questions of how to elicit statements of system understanding and how to transform them into the data structures processed by the "distance ratio" algorithms remains to be answered.

5. Interest in SD and serious games over the years

In order to obtain some indication of how the interest in system dynamics and games has developed over the years, the SD bibliography was searched to see how many publications on games have been published in each year[ii]. The search terms that were used were "gam", "interactive learning environment", flight simulator", and "microworld". A publication was included if the title, abstract, or the title of the journal included the term. Papers that clearly were not related to the types of games we are discussing (e.g. game theory) were discarded insofar as this could be judged from the information available in the bibliography. The frequencies related to the different search terms are shown in Figure 12 (publication lists are available from the author).

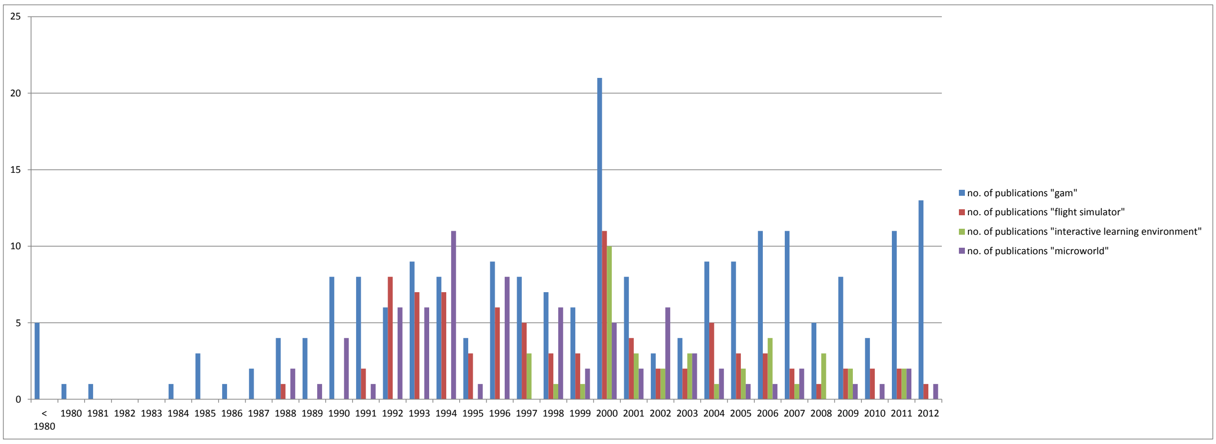

Figure 12: numbers of publications in the SD Bibliography found using different game related keywords

The first publication mentioned in the SD bibliography dates from 1963 is an MIT MSc thesis (A gaming approach to management education). In the year 2000, a special issue of the Journal Simulation & Gaming was published on Interactive Learning Environments, which partly explains the large number in the year 2000. In addition, learning and visualization with SD was one of the SD conference streams that year. The first SD publication using the term "flight simulator" was by Sterman (1988) and relates to the People Express flight simulator. The term was used most between 1992 and the early 2000s. When looking at the term "interactive learning environment" we can see apart from the year 2000, a few papers per year have been published on this topic since the first three SD conference papers in 1997. The first SD related publications on “microworlds” are by Morecroft (1988). At the SD conference in 1994 one of the themes was the use of games and microworlds. The term has become less used in recent years.

The total frequencies of game related publications were calculated by adding the numbers of publications in the different categories and removing any duplications (see Figure 13).

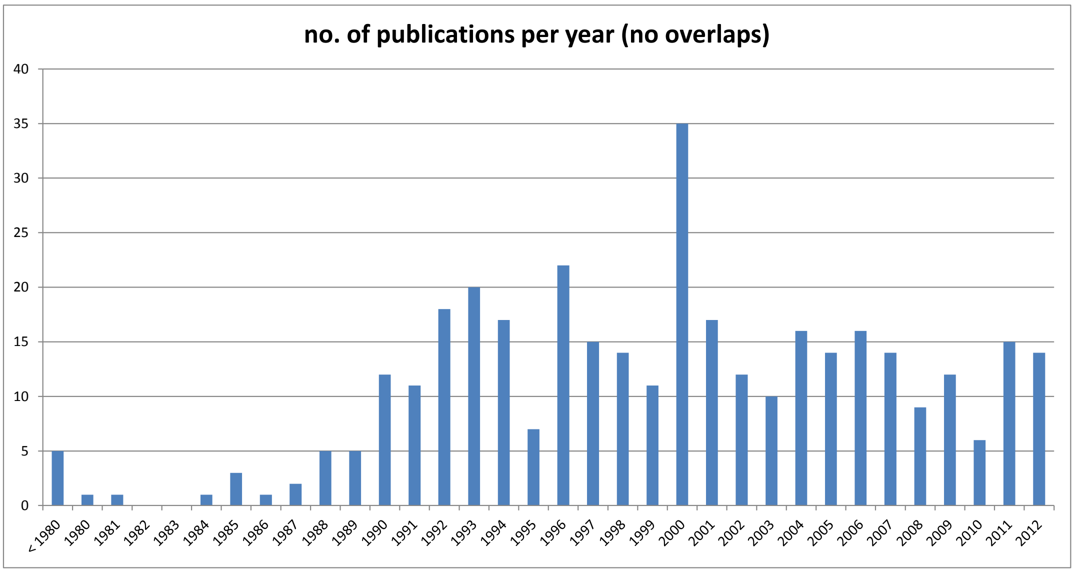

Figure 13: numbers of publications per year related to simulation games in the System Dynamics Bibliography

Figure 13 shows that with the exception of the year 2000, the yearly number of publications seems to have been relatively steady since the 1990s.

6. Conclusions

System dynamics and serious games are a logical combination. SD-based games have been developed and used since the start of the field. Most of the literature is about specific SD-based games. Some papers have been published on taxonomies or definitions, and there is some literature on game design and on evaluation. It is relatively easy to develop an SD-based game, but it is not easy to develop an effective SD game. There are few real success stories. More research is required on the topic of game effectiveness and how this relates to game design, in general and for SD-based games, i.e. games attempting to convey dynamic insights, in particular.

During the 1990s Lane (1995) saw a renewed interest in games, enabled by technological developments. Lane (1995) presents two scenarios for the use of simulations and games in management education. In the first scenario the research issues e.g. concerning the effectiveness of games have not been resolved and pitfalls are not avoided, which leads to a second decline. In the other scenario the pitfalls are avoided and research issues have been addressed and simulation games will thrive.

Neither of these two scenarios seem to have become reality. There is still interest in serious games in the SD community. Games are regularly used in (management) education, new games continue to be developed, and there has been some research into SD-based game evaluation and SD game design. However, considering the open questions and the interest in games outside the SD community, there seems to be a much larger potential for research into and applications of SD and games. This not only holds for educational games, but also for games in support of policy.

We conclude by proposing some research questions to the field:

1) How can we elicit mental models and (efficiently) evaluate changes in mental models?
2) How do the previous knowledge and capabilities of the players influence the choices of which parts of the underlying causal structure should be visible for players?
3) How do the previous knowledge and capabilities of the players influence the choices of which types of activities and which combinations yield good learning results?
4) How do the previous knowledge and capabilities of the players influence design choices, such as the advisable degree of realism/abstraction of a game, degree of computer use, or interaction with other players, given a specific objective of a game?
5) What are the differences in learning effectiveness and efficiency between SD-based games, interactive simulations, model building, and other teaching methods, for the same dynamic insights, and how can these differences be explained?
6) How can insights in the application domain (like management) be combined with learning about dynamic systems?

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[i] Simulation games are sometimes termed *operational games* (Meadows, 2001). However, there is no consensus on the use of this term. Duke (1974) mentions that the term operational-gaming (hyphenated sic.) was used in reference to the field of operations-research, before the general term gaming became used. Thomas and Deemer (1957) discuss the role of operational gaming in operations research, and describe operational gaming as "a way to formulate a game, solve a game, or to impart something of the solution of a game" (Thomas and Deemer, 1957, p.). The term game here is used as a competitive situation in the game theoretic sense. Alternatively, Shubik (1975) speaks of operational gaming when games are used for operational purposes, such as exploration, planning, or brainstorming.

[ii] The SD bibliography, rather than e.g. Web of Science, was searched to be able to say something about the interest in SD and games. The reason for this is that the terms “system dynamics” and “game” are used very differently in different fields. This means that in a general database it is difficult to be certain that the publications pertain to the intended topic.