A Taxonomy for Computer Simulations to Support Learning about Socio-Economic Systems

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What Are You Talking About? A Confusion in Naming

In literature as well as in discussions among scientists or practitioners one can find some confusion when computer-based simulation tools to support learning processes are under consideration. Besides the unsolved question of their efficacy, this confusion often is caused—or at least increased—by problems connected with terminology: many words are in use that symbolize the same object, or a single word is used for different objects. “Microworld”, “management flight simulator”, “business simulator”, “business game”, “management simulation”, “learning environment”, can sometimes be found to describe the same kind of simulation tool. But sometimes two instruments both called “management simulator” are quite different. Some authors distinguish between “business games” and “business simulators”, some do not.

For scientific research a clear, unambiguous terminology seems more than important: it is the basis of understanding other people’s work and gives the opportunity to criticize it. Furthermore, this will help analyzing the effects of different types of these simulation tools (see Kluwe 1993) and building a bridge between the many involved fields of science (e. g., management and decision science, psychology, instructional design, computer science).

The confusion is caused by various reasons: different academic backgrounds of the people involved, marketing aspects (some terms sell better than others), and a not reflected adoption of terms originally used with other intended meanings. In order to clarify these issues, in a first step this paper presents and criticizes commonly used terms for learning instruments. Then a list of possible characteristics is listed and applied to some well known tools. Finally, in order to establish our suggestions for a coherent terminology a proposal for naming conventions is shown.

A Critique and Explanation of Some Commonly Used Names

A reflected consideration of some already used terms for computer simulations to support learning can help to build a coherent naming scheme for these instruments. Often “management simulator” is used in the same way as “business simulator”. Sometimes this term is also in use for multi-person computer simulations (e. g., Milling 1995). However, its use is problematic because

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not management as a group of persons or as a function within a firm is simulated, but the company and market environment (the business). This allows to play the role of management. Or, in other words, players do (really) manage a (simulated) firm in a (simulated) business.

Quite often the term “management flight simulator” (MFS) is used (for single-user as well as for multi-user simulation games; see, for instance, Sterman 1992). This apparently fortunate analogy found wide spread use because not only under marketing aspects it seems quite promising: “like a pilot learns to fly, one can learn managing a company with the help of a MFS”. Nevertheless, when having a closer look this term shows two disadvantages: Firstly, at least for many persons whose mother language is not English, the American phrase of “flying a company” which stands for managing it is unknown. Due to that it could be misunderstood in a way that its use has something to do with flying (“the management learns to fly”). Secondly, business simulators do not aim to cover reality in an as congruent and comprehensive way as possible like real flight simulators do. While flight simulators try to be as realistic as possible (including almost every detail) business simulators try to abstract from details allowing to focus on important structures and behaviors. At its best, the term “management flight simulator” suggests that behavior is trained, but not that insights into the relation between structure and behavior are mediated.

“Microworld” goes back to Papert (1980). Again, the use of this term for computer simulations to support learning seems promising. However, Papert understands “microworlds” as learning tools which—following an “extreme” constructivistic approach—enable children to construct their knowledge themselves. What is more, such “microworlds” do not convey one or more learning goals: the user is free to define himself what he wants to learn. Considering this, the term “microworld” should rather be used for modeling-oriented software packages, which make it possible to construct models and which also contain some sort of formalism (programming language) to express thoughts about specific or general systems (see Laurillard 1993, p. 138, for differences between simulations and microworlds; p. 144, for differences between microworlds and modeling tools).

Also, simulation tools to support learning are mixed up with Decision Support Systems: the latter are built to increase performance in short term decision making. Usually, these instruments provide possibilities to test the outcome of decisions which have to be made (see Maier 1995, pp. 136–160 for a description of goals and characteristics of DSSs). They do not aim on long term changes in the users’ mental models; they are not constructed to support learning processes.

Frequently, the term “game” is used instead of or parallel to “simulator” or “simulation” (e. g. Jensen et al. 1997). This distinction mostly seems to be influenced by the scientific tradition of the author. Some authors therefore combine both terms to “simulation games” (e. g., Dörner 1992). We do not distinguish between “business game” and “business simulator” (in the same way, for instance, Keys and Wolfe 1996, or Klein and Fleck 1990; in contrast Lane 1995, who distinguishes between “simulation” and “game”).

The terms “learning laboratory” or “interactive learning environment” (ILE) usually contain more than a pure business simulator: one or more simulation models are embedded into a computer-based learning environment which could also include modeling tools (see Paich and Sterman 1993, for an appeal aiming in that direction). Such computer-based learning environments can also comprise background information, original source material, and working instructions integrated into one computer application (note the more general definition for “learning environment” as described below, p. 3). Through the use of the extended term “system dynamics based interactive learning environment” (SDBILE), however, it is clear that still a simulation model is a central part of such learning tools (with this meaning used, e. g., by Davidsen and Spector 1997). One can conclude that an interactive learning environment is a business simulator with additional components which are supposed to be necessary for its effectiveness.

Distinguishing Criteria of Computer Simulations

The manifold of different names and concepts led us to think about what the tools to which they are applied have in common and what makes them distinct. The starting point was our aim to investigate the “effectiveness of computer-based simulation tools to support learning”. Rather rapidly we realized that such a construct does not exist in a general way: “effectiveness” as well as “computer-based simulation tool” needs some further definition and explanation. This paper addresses the second issue. We found that a taxonomy could be helpful. A taxonomy is a division of objects into ordered groups or categories. The categorization indicates that there is a common criterion which “characterizes” the category and can be used to distinguish the objects in the particular category. However, the division of the objects (which is based on the observed characteristics of the objects under consideration) can never be made without bias: it depends on the reasons and the goals a taxonomy is constructed for.

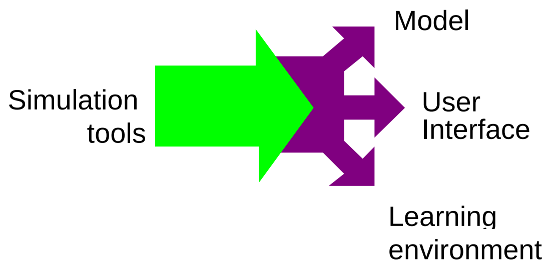

Figure 1: Three aspects of simulation tools

Figure 1 depicts our basic assumption that simulation tools are constituted by three aspects: underlying model, user interface, and (learning) environment, which contains, for instance, the situation the tool is used in, additional source material, etc. Note that in a broader definition of “learning environment” it comprises virtually everything connected with the learning process (see, e. g., Strittmatter and Maul 1997, p. 52). However, system dynamicists hold a strong belief that the model and its presentation are prominent factors when building simulation tools (for the relationship between model and user interface see Machuca 1991, and his later works). Following this idea, we consider it to be reasonable to separate these two factors from the rest of the learning environment.

Of course, computer-based simulation tools can be characterized by a lot of features. The following list is an attempt to systematize these features according to the three main aspects of simulation tools described above. In addition to these, a fourth aspect which regards the target group, goals and objectives of the tool is added for reasons of completeness and their potential impact for the research about the effectiveness of computer simulations as learning environments. Table 1 shows the four different categories.

1. Environment of application 1.1. Number of users 1.1.1. Single person 1.1.2. Multi person 1.2. Degree of integration 1.2.1. Stand-alone simulation 1.2.2. Integration in computer-based environment 1.3. Main area of application 1.3.1. Modeling-oriented 1.3.2. Gaming-oriented 1.4. Use of teachers/facilitators/coaches 1.4.1. Totally self-controlled learning 1.4.2. Support by teacher/facilitator/coach	**2. Design elements of user interface** 2.1. Chance of intervention while simulating 2.1.1. Discrete periods 2.1.2. Simulation in one run 2.2. Transparency of simulation model 2.2.1. Black-Box 2.2.2. Transparent-Box 2.3. Advancing of time in user interface 2.3.1. Self-Proceeding 2.3.2. User-driven 2.4. Characteristics of users' decisions 2.4.1. Policy-oriented 2.4.2. Decision-oriented
3. Model 3.1. Real-world domain 3.1.1. Business 3.1.2. Other 3.2. Structure 3.2.1. Feedback-oriented 3.2.2. Process-oriented (mostly without feedback) 3.3. Behavior 3.3.1. Deterministic 3.3.2. Stochastic 3.4. Generality of model in regard to domain 3.4.1. Special area of interest 3.4.2. Whole domain 3.5. Proceeding of time in simulation engine 3.5.1. Discrete 3.5.2. Continuous 3.6. Role of simulation model 3.6.1. Active generation of decisions 3.6.2. Clearing device for users' decisions 3.7. Influence of external data 3.7.1. With such influences 3.7.2. Without such influences 3.8. Domain of variables 3.8.1. Integers 3.8.2. Real numbers	**4. Target groups, goals, objectives** 4.1. Width of target group 4.1.1. Special target group (client specific) 4.1.2. Open target group 4.2. Goals regarding users 4.2.1. Judgement 4.2.1.1. Users are going to be tested 4.2.1.2. Users are not going to be tested 4.2.2. Change 4.2.2.1. In attitude towards specific issue 4.2.2.1.1. Users are going to be motivated 4.2.2.1.2. Motivation not intended 4.2.2.1.3. Learning about modeled system Domain specific knowledge 4.2.2.1.4. Domain independent knowledge 4.2.2.2. Mediation of knowledge about system's control 4.2.2.2.1. Imparting of procedural knowledge 4.2.2.2.2. No imparting of procedural knowledge

Table 1: Criteria for categorization of computer simulations

A strict distinction cannot always be made between listed pairs of characteristics. Furthermore, there are likely some characteristics missing. However, this list was made to show the literally thousands of possibilities how a computer simulation tool can be designed. Furthermore, all those characteristics possibly have an influence on the effectiveness of a simulation game and can therefore be varied in experiments.

But note that some combinations of characteristics do not make any sense, for instance, can modeling-oriented tools never be black-boxes. And, of course, can simulation tools with different characteristics in one or the other feature be summarized under one term. This is dependent on the goals which are aimed at with the taxonomy in question. Only these prerequisites allows to construct a taxonomy at all.

Proposal for a Taxonomy of Computer-based Simulation Tools to Support Learning

The criteria shown above can be applied to analyze the characteristics of existing computer-based simulation tools. However, the criteria also can be helpful to determine which of the characteristics a new simulation tool should have. Exemplary, for some popular computer-based simulation tools Table 2 visualizes the differences of the criteria which are considered in these applications. The categories and criteria correspond to those of Table 1. If a criterion is applied in the particular simulation tool, the according field in the table is marked red. In some cases both criteria of a category are applicable, for which then the field is marked gray. The visualization also is the starting point for the proposed naming convention of computer-based simulations to support learning processes in socio-economic systems as shown in the tree represented in Figure 2.

Considering the criterion “main area of application” at the root of this tree the first differentiation is made between modeling- and gaming-oriented instruments. Modeling-oriented tools then can be further distinguished through the criteria “structure” and “proceeding of time in the simulation engine” into feedback-oriented continuos simulation environments like Vensim, Powersim, Ithink or DYNAMO and process-oriented discrete simulation environments like Taylor or Simple++. The usefulness as well as the efficacy of modeling-oriented tools for learning, problem solving and insight is virtually undoubted within the System Dynamics community (see, for instance, Senge 1989). The aim of process-oriented discrete simulation environments is mainly to optimize process layouts and visualize the behavior of the system processes under consideration. Their main real world domain is business, especially, manufacturing and logistic processes.

The second branch of the tree shows the gaming-oriented simulation tools which are further distinguished by the criterion “number of users” into single-user and multi-user applications. Single-user applications are defined as “simulators”, whereas multi-user applications are designated as “planning games”. In a simulator usually a single person “plays” with and against the computer model, as opposed to the planning games where several groups of players compete against each other and the computer only has the role of calculation the resulting outcomes of each group’s decisions. The research about the effectiveness of computer-based simulation to support learning is mostly done in the area of simulators since it concentrates on the learning of individuals. Group dynamics which may have a strong influence on learning and decision making processes and therefore affect the effectiveness can not appear in single-user simulators.

Legend:
- ■ single criterion of category applies
- ▒ both criteria of category may apply
- n/a criterion is not applicable

	Model															
	Real world domain		Generality of model with respect to domain		Role of the simulation model		Influence of external data		Proceeding of time in simulation engine		Domain of variables		Behavior		Structure	
Examples	Business	Other	Special area of Interest	Whole domain	Active generation of decisions	Clearing device for the users' decision	With influence of external data	Without influence of external data	Discrete	Continuous	Integers	Real	Deterministic	Stochastic	Feedback-oriented	Process-oriented (mostly without feedback)
People Express MFS	■		▒	▒		■		■		■		■	■		■	
Copy Shop	■		■			■		■		■		■	■		■	
LEARN!	■		■		■	■		■		■		■	■		■	
Lobster	■		■			■		■		■		■	■		■	
Fish Banks		■	■			■		■		■		■	■		■	
Vensim	▒	▒		■	n/a	n/a	▒	▒		■		■	■		■	
Simple ++	■		■		n/a	n/a	▒	▒	■		▒	▒	▒	▒		■

	Design elements of user interface								Environment of application							
	Chance of intervention while simulating		Transparency of simulation model		Advancing of time in user interface		Characteristics of user's decisions		Number of usres		Degree of integration		Main area of application		Support of teachers/ facilitators/coaches	
Examples	Discrete periods	Simulation in one run	Black-box	Transparent-box	Self-driven	User-driven	Policy-oriented	Decision-oriented	Single person	Multiple person	Stand-alone simulation	Integration in computer-based environmet	Modeling-oriented	Gaming-oriented	Totally self-controlled learning	Support by teacher/facilitator/coach
People Express MFS	■		■			■		■	■		■			■	▒	▒
Copy Shop	■			■	▒	▒		■	■		■			■	▒	▒
LEARN!	■		■			■		■	■		■			■	▒	▒
Lobster	■		■			■		■		■	■			■		■
Fish Banks	■		■			■		■		■	■			■		■
Vensim		■		■	■		■		▒	▒	■		■		■	
Simple ++		■		■	■		■		▒	▒	■		■		■	

	Target groups, goals, objectiv								
	Width of target group		Goals regardin users						
			Judgement		Change				
					Change in attitude towards specific issue		Learning about modeled system		Mediation of knowledge
Examples	Special target group	Open target group	Users are going to be tested	Users are not going to be tested	Usres are going to be motivated	Motivation not intended	Domain specific knowledge	Domain independent knowledge	Imparting of procedural knowledge
People Express MFS	▒	▒	▒	▒	▒	▒		■	■
Copy Shop	▒	▒	▒	▒	▒	▒		■	■
LEARN!	▒	▒	▒	▒	▒	▒	■		■
Lobster	▒	▒	▒	▒	▒	▒	■		■
Fish Banks	▒	▒		■	▒	▒	▒	▒	■
Vensim		■		■		■	▒	▒	■
Simple ++		■		■		■	▒	▒	

Table 2: Exemplary application of the distinguishing criteria

In simulators as well as in the planning games the computer model often serves as a "clearing device" for the decisions the user has entered into the computer in each decision period. Though, several simulators demand one or more "computer-based players" which actively take part in the game having their own decision rules. This is the case, e.g, in the business simulator *LEARN!*, where one "real" player competes against three virtual players. Therefore, in this case for the category "role of the simulation model" both criteria are marked red. In contrast to this, in multi-user planning games the computer model just has the function of a clearing device for the inputs of the users. Note that in the case of the simulators *LEARN!* and the planning game Lobster the only difference is that the first is a single-user version with the decisions of the three competitors mapped through different policies within the computer model. The latter is a multi-user game where each of the four competitors are "real" groups which have to decide based on their mental models. The underlying computer model is apart from that identical.

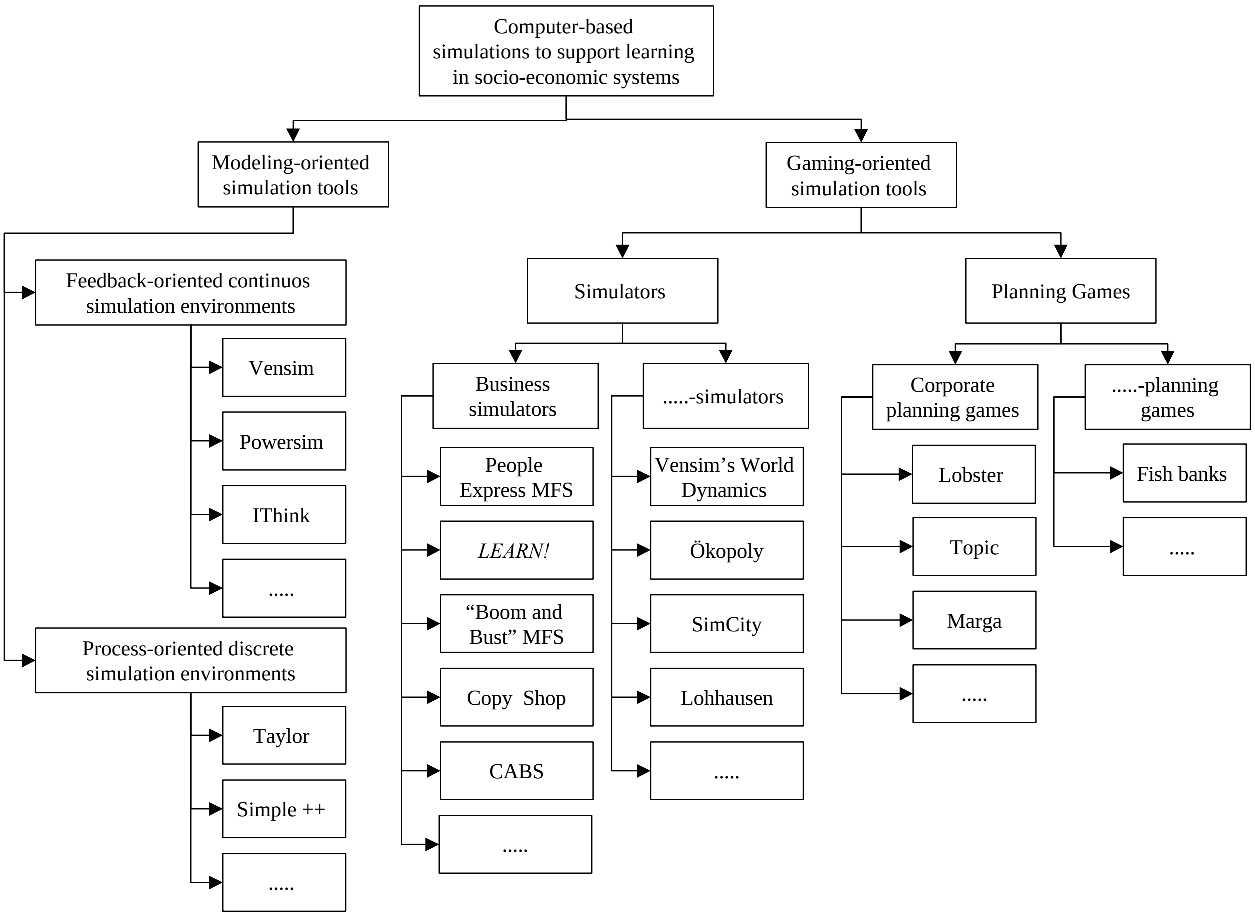

Figure 2: Taxonomy of computer simulations to support learning processes in socio-economic systems

Simulators and planning games can furthermore be distinguished by the real-world domain in which the simulation is situated. Here we differentiate between business applications and others, and consequently name the related tools as "business simulators" and "corporate planning games". Since there is a variety of different real-world domain and our focus lies in the business area, there is no further naming convention for the other simulators and planning games. The nodes contain our proposal for the terms to be used in future. In particular it is suggested to use the term “business simulator” instead of management simulator or management flight simulator, since neither management is simulated nor the aim of these simulators is to teach the management to fly.

Each of the leaves of the tree gives an example of an according simulation tool. Of course, this covers only the typical usage of these products: for example, there is always the chance that a group of people works with a business simulator like *LEARN!* or People Express. However, in this case the group can be seen as a single virtual user. Excellent examples for business simulators are the People Express and Boom and Bust Enterprises from Sloan School or *LEARN!* and Copy Shop developed at University of Mannheim in cooperation with Simcon GmbH. Examples for simulators from other real-world domains are the World-3 simulator included in the Vensim simulation environment, the famous computer game SimCity and Dörner’s Lohhausen simulator. As examples for corporate planning games serve Lobster, Topic, and Marga, a planning game from other domains is, for example, the Fish Bank Game.

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