Simulation and learning: the role of mental models

Franco Landriscina

E-Learning, Allianz, Trieste

f.landriscina@libero.it

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Abstract

A successful instructional use of simulations at school and in training courses requires a careful consideration of the cognitive mechanisms of learning. The most interesting educational simulations are not so much those which want to be a copy of reality, but those which favour in the student a process of internalization of the simulated model and a process of externalization and comparison of one's mental models. Model-based education represents a new and promising paradigm in the designing and the didactic use of simulations.

1 Simulations between hyperbole and reality

In recent years there has been a growing interest towards simulations and we often meet terms such as social simulations, serious games, game-based learning (Aldrich, 2003; Prensky, 2007). Simulations are generally presented as a revolutionary innovation destined to replace other educational techniques in comparison considered less interactive and involving. What is true in these statements? It is not the first time that a new technology is advertised as a revolution. When in the 1980s the first Cd-Roms appeared, opinion wanted that they would have caused the disappearance of printed books. During the 1990s many thought that hypertext would have changed even the way of writing and reading novels, replacing linear stories with ramified ones. Now there is web 2.0. In the field of e-learning, we must pay attention to the so-called "hype" (the abbreviation of hyperbole). Hype consists in the use of exaggerated statements which are not supported by solid scientific foundations to provoke an emotional impression for commercial purposes[1]. A well known graph prepared by Gartner Group, shows the typical life cycle of a technological innovation (Fig. 1).

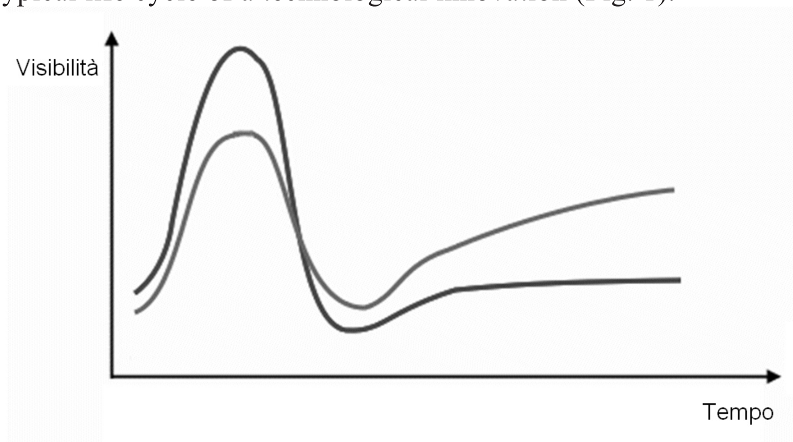

Fig. 1. Two examples of the life cycle of a technological innovation.

The early phase of rapid growth, caused by the initial expectations, is followed by a phase of disillusionment, when such expectations result excessive. Only with time the real possibilities of use start to emerge and we can then assist to a significant spreading of such technology or to the end of its development. Is the present enthusiasm for simulations just another hyperbole? From some points of view yes. To think that a didactic technology can generally be

[1] "Don't believe the hype", is the title of a song of the American rap group Public Enemy.

more valid than other ones without considering the context in which it is used is an example of how superficial this sector can be. Curiously, many of the declarations about simulations today remind us of those which where made some time earlier about hypertext: "Good bye to linear stories!", "Millions of possible alternatives!", "Everyone can chose his/her own ending!". Yet, in contrast with other cases of hyperbole, simulations have certain characteristi-cs which make us hope that once gone by the phase of easy enthusiasm, they will have a stable place among the didactic technologies. The first difference with other e-learning trends is that simulations have already been for years an important knowledge and work tool in the scientific field, where practically everything is simulated, from molecule structure to climate change. In addition, simulations were used with success for educational purposes even before the coming of computers. For example, in board games, in classroom role-play and in assessment centres. Finally, simulations have been successfully used in the field of military and industrial training. From the Instructional design point of view, we can identify a further reason of interest for simulations, that is the fact that the cognitive sciences show some important points of contact betwe-en simulation and the learning process. In fact, the human brain uses mental simulations to foresee and explain environmental events and this capability of simulation could be the base of the entire spectrum of cognitive capabilities: from perception to memory, from language to problem-solving. (Gallese, 2005; Barsalou, 2008).

2 Let's define simulation

The essential characteristic of a simulation is to reproduce a certain aspect of reality. It is not, however, a static reproduction, but an active, or rather, an "interactive" one. Parisi distinguishes an interactivity "between images" from an interactivity "with images" (Parisi, 1997). According to Parisi, the first type of interactivity is hyper-textual, in which we move from one image to another clicking on the links; the second type of interactivity is the one based on simu-lation, where behind the images there is a model of an object, of a person or of a situation. The images change according to the action performed by the user on the model of the system represented. Moving from these considerations, we can define simulation «an interactive representation of reality based on the construction of a model of a system of which we want to understand the wor-king» (Landriscina, 2009). It is also worthwhile to stress that simulations are different from games. Simulations use a model which resembles the working of a real system, while games are not tied to this restriction and they follow their own arbitrary rules[2]. There is also, however, an area where they overlap, that

[2] Other characteristics of games not necessarily present in simulations are competition, the assignment of roles and the presence

of the so-called “simulation games, like the famous SimCity, and this perhaps contributed to the confusion. For didactic reasons, it can be useful to classify simulations according to the model described below. This can be based on predefined steps or on mathematical models of various kinds[3].

3 The strengths of simulation

The creation or the simple use of a simulation for instructional purposes requires time and resources. It is therefore the case to ask what are the reasons which justify its use and when should we prefer simulations to other instructional technologies. If we consider action on a real system, simulations offer important practical advantages such as freedom from time and space, safety and cheapness. As a didactic method, simulations can be used to support the understanding of a theory, to show the interrelations between the parts of a system, to verify some hypotheses (what-if analysis) and to examine future situations (scenario analysis). The possibility to practice without being restricted by space or time allows you to try and try again, to make mistakes, to test alternative hypotheses and therefore also to reflect on the structure of the system and on one’s own decision processes. In suitable conditions, this can mean a strengthening of the cognitive processes of learning. There is the possibility to:

- integrate the information coming from different sources;
- connect new knowledge to what one already knows;
- recover analogies capable of favouring one’s understanding;
- produce explanations;
- coordinate representations and different perspectives;
- to create inferences;
- to abandon concepts which are no longer useful.

This can facilitate the construction of new mental schemes or the change and the replacement of the existent ones, therefore favouring learning. The value of simulations consists in their capability of creating a relationship of interpenetration and synergy between our mind and the computer[4]. Before studying in depth this aspect, we must however point out some possible weaknesses in the didactic use of simulations.

4 The myth of interactivity

A possible improper use of a simulation is to use it only because you consider it “more interactive” than other educational techniques, on the basis of

of scores.

3 For the differences between these types of models, see Landriscina, 2009.

4 Calvani (2007) talks about a “cognitive partnership”(p. 36).

the principle that the more a technology is interactive, the more it is easy to learn. Following this logic, some researchers have reached the conclusion that video-games are the most efficacious learning tool of our time (Prensky, 2007; Shaffer, 2008). It is a conclusion which would certainly be accepted by many students, but it does not correspond to reality. It is thanks to the theory of cognitive load that we recognize that interactivity can have neutral or even harmful effects on learning (Chanquoy *et al.,* 2007; Landriscina, 2007; Calvani, 2009). In the case of simulation, this can occur when there are too many possible choices, because of an interface made too heavy by unnecessary details or because the interactivity simply suffocates the students' capabilities of reflection. In contrast with the optimistic picture given by the "digital natives" trend, the cognitive sciences reveal that the full maturation of our cerebral functions takes place only during the late adolescence years and it continues even after we reach 20 (Sabbagh, 2006). Until this age, the cerebral regions involved in the decisional processes and in the control of behaviour pass through significant physical changes. The brain of a teenager behaves like that of an adult in tasks where the control of behaviour is exogenous (it depends on external stimulus), but less so in tasks which require an endogenous control of behaviour (voluntary and internally generated). To this regard, it is known that when facing a scientific simulation, students tend to change too many variables at the same time and they find it difficult to plan their decisions (De Jong, 2006; Van der Meij, 2007). In general, on the topic interactivity, it is necessary to be clear: when we talk about the active construction of knowledge, for what concerns learning, important are not the behavioural activities but the cognitive ones solicited by education. For example:

- the selection of relevant information;
- the mental organization of the information in coherent structures;
- the integration of new and previous knowledge;
- the change of mental models.

More than of a generic "learning by doing" we should talk about an "active elaboration", or better again about a "focused elaboration", that is explicitly connected to the main concepts and principles which favour the learning of a subject (Renkl & Atkinson, 2007).

5 The confusion between simulation and reality

The biggest mistake one can make in the instructional use of a simulation is to lose sight of the relationship between the model and reality. When put in front of a simulation, the student should be placed in the condition to understand that what he can see on the screen is a simplified representation of reality and that every model necessarily requires to consider some aspects of a real system and the exclusion of others. In the so-called "billiard ball" model of an ideal gas, the molecules are rigid balls banging against each other and the walls of the container in a perfectly elastic way, something that in a real gas is only approximately true. The understanding of the hypotheses at the bases of the experiment can be the first step to understand how one reaches the mathematical formulas which represent the "engine" of the simulation. To make sure that the student understands the hypotheses at the basis of the model used for the simulation is even more important when we pass from physical systems to the biological and social ones. The naïve concept that simulations "remake reality" can let both teachers and students become victims of what has been defined the "power of seduction" of simulation (Turkle, 1998). According to Turkle, simulations must not be accepted uncritically, but they must be a stimulus to develop new critical capabilities, which put the student in the condition to understand the hypotheses at the basis of the model and to discuss them. For example, a simulation game such as SimCity presents thousands of possible scenarios and situations, but it does not show the rules inserted in the game by those who created it. Facing the events which take place as a consequence of his/her choices, the player tends to attribute some of the rules automatically to the system, and these can coincide with those present in the programme or simply be the result of his/her own mental models. This way, the player can consider partial conclusions as indisputable truths.

"I ask Marcia, a student in her second year of Secondary school, some questions about SimCity; she, who thinks to be very good at the game, lists what in her opinion are "the ten most useful rules of the simulation". My attention was captured by the rule number six: «Tax rises always cause uprisings». It seems that Marcia does not possess a language to distinguish between this rule of the game and the rules in force in a "real" city. She has never programmed a computer. She has never designed a simulation. She does not possess a language to ask how you can rewrite the game so that you can obtain that a tax rise may determine an increase of productivity and an harmonic society. She certainly does not consider herself a person capable of changing the rules" (Turkle, 1998).

To be able to "read" a simulation is therefore a capability that we can compare with that of being able to critically analyse a text or a television programme. The image of simulations as a copy of reality characterizes also the frequent description of simulators as "virtual laboratories". It is true that some simulations make it possible to perform activities similar to those of a laboratory, but to insist too much on this analogy can be misleading[5]. In general the most

[5] There is also the risk of a further decrease of interest in the real activities of a laboratory and in nature observation, already

interesting simulations are not those which repeat the activities of a laboratory, but rather those which allow us to interact at a correct level of abstraction with a conceptual model and to do things which would be impossible in the real world. For example, an astronomical simulation of the seasons, in which the student can change the inclination of the earth's axis or the simulation of an electric circuit in which he/she can observe the movement of electric charges[6].

6 Learning by changing mental models

As happens in simulations, also the human mind is based on models and learning can be seen as a change of mental models (Chi and Ohlsson, 2005).

From this point of view we can say that:

- simulation is the most suitable instructional method when the learning objective requires a restructuring of the students' individual mental models;
- the crucial aspect of a simulation consists in the interaction between the individual mental models and the simulation one.

We have recently defined an "epistemic simulation cycle" the circular process of understanding of a system through the construction of a model and its manipulation (Fig. 2).

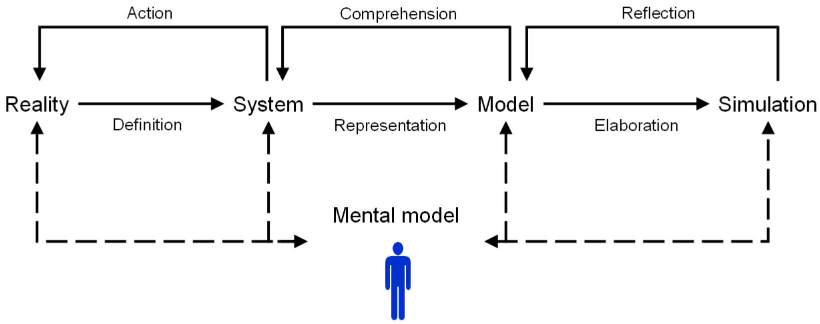

Fig. 2. Epistemic cycle of a simulation and a mental model.

To change the mental models of students is necessary when learning meets resistance which is revealed when pre-existent conceptions and models persist even after proof of the opposite has been presented (Vosniadou, 1999). This is the case:

so little present in our schools.

[6] Educational simulations of this type can be seen on the web site ExploreLearning (www. ExploreLearning.com).

- of the prejudice with which students start studying scientific concepts;
- of the mental models which refuse the change of strategies and attitudes of organizations.

Different educational techniques which follow a scheme of this kind have been proposed:

- to reveal the student's preconceptions;
- to discuss and evaluate the preconceptions;
- to create a conceptual conflict;
- to encourage and guide conceptual change.

The relationship between schemes, mental models and education has been recently examined in depth by the German psychologist Norman Seel (1991, 2003) who has formulated a learning and teaching theory based on models (Model-based learning and instruction). Model-based learning can be described as a progression of mental models, from an initial state, characterized by the student's preconceptions, to a desired final state, of causal explanation. Until a mental model does not represent for the student a sufficiently plausible explanation, he/she will not work to build a new one. It is therefore the instructor's task to organize a series of activities to arouse in the students the need to move from one mental model to another. Seel stresses the importance of the interrelations between mental models and external ones. The first are implicit and individual, the second are explicit and can be shared. The instructor's task is to bring the students to externalize and discuss their mental models and to internalize the external ones. To do this, he/she can use tools of cognitive mediation between the student and the simulation model. Examples of such tools are:

- verbal language, to provide explanations, compare ideas and take decisions;
- images and animations, to visually represent the change of the system over time;
- causal maps, to describe the cause-effect relations between the variables;
- graphs and diagrams, to study the behaviour of the variables as time goes by.

Clement (2007) distinguishes between "direction of the activities" and "creation of the ideas", indicating the first as a task of the instructors and the second as a task of the students. To favour reflection and the self-regulation of learning in learning environments based on simulation, we can use educational techniques such as:

- self-explanation: the student has to explain to him/herself out loud what he/she has understood;
- forecast: the student has to foresee what will happen in the next steps of the simulation;
- alternation of observation-practice activities carried out in pairs: the students have to work in pairs and in turn one of them performs the simulation while the other observes.

Conclusions

Simulation is the most suitable didactic method when the learning objective requires a restructuring of the students' individual mental models. The crucial aspect of a simulation is the interaction between the individual mental models and the model at the basis of the simulation itself. Learning can therefore be seen as a progression of mental models from an initial state to a desired final one. In learning environments based on simulation the students must however be given guidance and support because of the high cognitive load this didactic methodology usually implies.

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