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Simulation and learning: the role of mental models

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Synonyms

Organizational Learning Theory, Mental Models, Model-based Learning, Modelling and Simulation, Conceptual change, Perceptual simulations, Mental simulation, Thought experiments

Definition

The etymology of the word simulation (lat. "simulō", *imitate*) shows that it could also mean *to pretend* and therefore have a negative connotation. Simulation is often seen as a false representation of the real world. In many Sci-Fi films the protagonist finds him lost in a simulated world, created to hide the real world. This negative connotation can hark back to Plato's conception of the "μίμησις" (*mimesis*, Greek term for *simulation*) as the imperfect copy or fictitious replica of reality. On the contrary, according to Aristotle the *mimesis* is a means to know nature through representations which can be valid and acceptable. This shifting of the emphasis from imitation to representation corresponds to the shifting of the focus from the superficial aspects of a simulation, for example interactivity, to the underlying model, as happens currently in model-based instruction. In this wider concept of simulation, mental models assume a central role. In his dialogue "Politics" (Statesman), Plato describes the cognitive role of the models, or "paradeigmata" ("παραδεἰγματι"). In order to illustrate the nature of the statesman, one of the characters of the dialogue refers to the model of the weaver, where the technique of the politician is compared to that of the weaver who weaves fibers of different nature to create a single fabric. In general terms, Plato describes the usefulness of the model as a process of identification of similitudes and differences. Examining the similitudes and the conceptual differences between the model and the phenomenon being studied, the subject transforms his initial ideas, confused and approximate, into a more precise and rigorous comprehension. This is also what happens when a student compares his own mental model of a system with that of a simulation.

Theoretical Background

The role of mental models in simulation was first highlighted by organizational learning theorists. According to Senge (1990, p. 8), mental models are *"deeply ingrained assumptions, generalizations, or even pictures and images that influence how we understand the world and how we take action"*. Senge fostered the idea of computerized simulations, called *microworlds*, which could allow the managers of an organization to interpret their real

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roles and understand how these interact among themselves. The realization of microworlds of this type is one of the practical applications of "*system dynamics*", a computer-aided approach to policy analysis and design in organizations. *System dynamics* provides a series of methods for the elicitation, articulation and description of the tacit knowledge contained in the mental models of the experts and for the building of computer-based simulations on the basis of such models (Ford and Sterman1998). This corresponds to the shifting from the concept of model as representation of reality to a concept of the model as a cognitive artifact.

The relation between mental model and education has been examined in depth by Seel (2003) who has formulated a learning and teaching theory based on models (Model-Centered Learning and Instruction). Model-centered 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. One of the general functions assigned by Seel (1991) to mental models is mental simulation. In this interpretative framework, computer based simulation is seen as a teaching methodology, able to facilitate model-centered learning and is particularly effective when the learning objective requires a restructuring of the individual mental models of the students (seen here as cognitive structures in long-term memory). This is the case, for example, of the pre-conceptions with which the student starts learning scientific concepts, or the mental models which oppose the change of strategies and behaviors in the organizations.

Seel distinguishes between:

- *mental models*, the internal and subjective model of a system;
- *conceptual model*, which is objective and shared by a scientific community;
- *design and instructional model*, used for building the user interface and the learning tasks.

In order to be used as a simulation model, a conceptual model must be formalized in mathematical terms (such as rules and equations) which can be developed as computer programs. In a simulation-based learning environment, the student interacts with such a model only in a mediated way. Faced with a learning task, he must then build his own mental model of the phenomenon being studied and use it as a basis for prediction, inference and explanation. The field of Human-Computer Interaction (HCI) offers a series of design principles that can be applied to help the students build a correct mental model of the system. This requires a preliminary analysis to define the characteristics of the intended users and how they will be using the software. In the words of Senge (1991, p. 72): "*Simulations with thousands of variables and complex arrays of details can actually distract us from seeing patterns and major interrelationships*". In the case of "black-box simulation models" the student can explore the behavior of the system but the underlying conceptual model remains hidden and can only be inferred by what is happening on the screen. This could lead the students to believe their partial conclusions are undisputable assumptions. For example, a simulation game such as SimCity® presents thousands of possible scenarios and applications, but it doesn't show the rules put in the game by

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its creators. Facing the events which occur as the consequence of its own actions, the players tend to automatically attribute some rules to the system, which can coincide with those present in the program or be simply the result of their mental models. Instead, "glass-box models" simulations openly show the relationships between the variables and therefore the hypothesis at the basis of the model. This too might not be sufficient. It is tempting to identify the equations of a model with the model itself, but it has to be borne in mind that the same model can be implemented using different equations and models have different properties than equations. The system model can also be shown in a visual way. For example, in a simulation of an ideal gas, the underlying physical "billiard ball model", can be shown through the animation of molecules represented as rigid spheres, clashing with each other and with the walls of the container in a perfectly elastic way. For the purposes of the conceptual change, the construction of a simulation model is an activity potentially more effective than the simple exploration of the behavior of a pre-existing model, as the students (and the teacher) can represent, share and test their mental models.

In the building of a simulation to solve a problem the student must:

1. decide how to describe the system to be studied in terms of objects, relationships and quantities;
2. recognize which principles to apply to solve the problem;
3. infer qualitative rules between the values of the variables.

These activities are similar to those described by VanLehn (2009) in his study of the acquiring of conceptual expertise from modeling in elementary physics. The expertise in this domain is characterized by a qualitative understanding of real world situations. The capacity of solving conceptual problems arises from extensive practice of a certain kind and develops following a sequence from a *superficial* understanding, to a *semantic* understanding, and finally to a *qualitative* understanding. VanLehn (2009, p. 374) suggests that the students should not circumvent the model-construction and model-interpretation processes and focus on increasing their semantic understanding of the models.

In many cases, the restructuring of the mental models remains nevertheless an objective which is difficult to achieve, and therefore the extra-technological factors which characterize the context become decisive, among which are, for example, the attitudes and the expectations of the participants, the organizational and management models, the social relations and the relational systems underlying the use of technologies. Seel stresses the importance of the relationships between internal models and external models, where the former are implicit and individual, while the latter are explicit and can be shared. From this point of view, the task of the teacher is that of aiding the students to externalize and discuss their own mental models and internalize the external ones. In order to do this, he can use the tools of cognitive mediation between the student and the simulation model.

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Examples of such tools are:

- *verbal language*, to give explanations, compare ideas and make decisions;
- *images and animations*, to visually represent the change of a system over time;
- *causal maps*, to describe the cause-effect relationship among the variables;
- *graphs and diagrams*, to study the time-related behavior of the variables.

In order to favor reflection and self-regulation in the learning process educational techniques such as the following can be used:

- *self-explanation* (the student has to explain to him out loud what he has understood);
- *forecasting (*the student must foresee what will happen in the next step 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 one observes).

In order to evaluate the change in the mental models of the student within simulation-based learning environments many different approaches have been suggested, based on the think-aloud method, cognitive task analysis, concept maps, Bayesian networks or on the automated analysis of textual data (Shute et al. 2009).

Important Scientific Research and Open Questions

Some questions about the design and use of simulation-based learning environments are directly related to fundamental issues in the cognitive sciences. Significant cognitive science research supports the hypothesis that simulation is a fundamental form of computation in the human brain and this capability of simulation could be the basis of many capabilities: from perception to memory, from language to problem-solving (Barsalou 2008). Mental simulation is a type of reasoning based on the manipulation of a mental model "in the mind's eye". It can be part of everyday reasoning, such as when we have to decide how to move a sofa from one room to the next, or be used by scientists to carry out "thought experiments" (Trickett and Trafton 2007). According to Nersessian (1999), simulative modeling is a form of model-based reasoning that include mental models that are dynamical in nature, whereas analogical modeling and visual modeling may employ static representations. Mental simulations ostensibly imply the reactivation of patterns of neuronal activity in the perceptive and motor parts of the brain initially activated by the direct experience of the event and are therefore also called "perceptual simulations". The representations involved are in this case of a "modal" type, as they preserve the information relative to the modalities through which their external referents were experienced. For this reason, a promising research field is that of the role of perceptual factors in the use of simulations and on the relationship between imagistic simulations, as used by experts and scientists in their thought experiments and the type of visualizations used in simulation-based learning environments to represent the simulated processes (Clement 2009). Abstract concepts can be represented by spatial and kinesthetic structures, known in cognitive semantics as "image-schemas". For example, image-schemas of concepts such as "expansion" and "compression" can play a role in the construction of mental models of physical or biological phenomena supported by the simulation (Craig et al. 2002). Perceptual factors of this nature can be manipulated through stories, diagrams and animations, or utilizing new interfaces based on force-feedback devices and visuohaptic technologies.

Mental simulation is also one of the possible mechanisms at the base of the "Theory of Mind" (ToM), the ordinary ability people have to understand their own minds and those of others. Two contrasting arguments have been suggested to explain this ability. In the "Theory-Theory" perspective, the ToM is seen as a naive theory (*Folk psychology*) with posits, axioms and rules of inferences. The "Simulation Theory" (Gordon 2009), on the other hand posits that man uses his own mental resourses to simulate the psychological causes of others' behaviour by means of role–taking, that is by "putting oneself in the other's place". The term "simulation" in this case is used to denote automatic mirroring responses such as the subliminal mimicry of facial expressions and bodily movements ("low-level" simulation) or the use of one's own behavior control system as a manipulable model to predict and anticipate the behavior of others ("high-level" simulation), in analogy with scientific simulation.

However, mental simulation shows clear limits, the most important being that it relies on qualitative relations rather than on precise numerical representation. In simulative reasoning, the inferences derive from the use of the knowledge embedded in the constraints of a mental model to produce new states of the model. Where the situations are more distant from sensorial experience there are fewer guarantees that the simulation process will yield success. This is particularly evident in the case of non-linear and self-organizing systems, where also very simple equations or rules can determine complex and unforeseeable behaviours. For example, by observing the causal map of a system with feedback circuits it is not possible to infer the time-related behavior of the system. Only computer-based simulation manages to show these behaviours, sometimes counter-intuitive or unexpected also for those who built the model. The other limit of mental simulation is that it cannot be shared with others. The building of computer based simulation models can be useful in this case too, through the shifting from implicit metal models to explicit conceptual ones. Simulation models can thus extend our biological capacity to carry out mental simulations and simulative reasoning. Between student and simulation a form of "cognitive partnering" can then be set up, where the mental and the conceptual models modify each other in real time, a circular interaction thanks to which the computer can become a real "*tool for thinking*".

Cross-References

→ Mental Models
→ Model-based Learning
→ Model-based Learning with System Dynamics
→ Modelling and Simulation

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→ Models and Modelling in Science Learning
→ Simulation Based Learning

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