

# SIMULATION-BASED LEARNING

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## Synonyms

Similarity learning, Learning with games, Visual perception learning, Spatial learning, Simulation and learning

## Definition

The term *Simulation-Based Learning* refers to the use of simulation(s) for learning purpose. Definitions for the two parts of this term, i.e ‘learning’ and ‘simulation’, are provided in the following paragraphs.

*Learning* is a complex topic as illustrated by the variety of entries in the current encyclopedia. A broad definition is adopted in the current entry with learning defined as the process of acquiring or enhancing knowledge and skills, whether they are cognitive, physical, social, etc.

*Simulations* have been used in many if not all scientific disciplines, which has led to a variety of definitions sometimes reflecting influences and considerations of a specific discipline. For instance, some researchers suggest that simulations are necessarily related to computers. However simulations have emerged ways before the eve of Computers’ Age; to some extent, the old Chinese game of GO can be seen as a war simulation. Other researchers such as Aldrich (2009) conceive that simulations’ primary goal is oriented towards a learning purpose. Even though the current entry aims at discussing simulations for learning purposes, it will be later shown that simulations whose goal is not primary educational can also provide indirect support to learning, as illustrative elements for instance. Indeed, it would not be adequate to refer to a definition that would not consider the learning potential of simulations that aim at establishing theoretical proofs, or at representing natural phenomena to cite but a few.

Hartmann (1996)’s definition of simulation is an interesting step towards a generic definition of this concept. He states that “*a simulation imitates one process by another process*”. A key aspect of this definition lies in the temporal nature of simulations since processes that he refers to are perceived as elements that evolve over time.

Yet some controversies remain on the very idea of considering all simulations as genuinely dynamic. Hughes (1999, see also Grüne-Yanoff and Weirich, 2010) insists that simulations sometimes mainly focus on the imitation of the structural aspects of a model rather than on its dynamic characteristics, thus making such simulations relatively static elements.

Another noticeable feature for stressing the genuine nature of the simulation concept emerges from the previous point: a simulation is a manifestation of ‘*a model*’, the latter referring to a set of intertwined elements (such as rules, properties, or lower-order models for instances) providing a description of a target. Grüne-Yanoff and Weirich (2010) however state that there is not always a clear-cut distinction between a model and its associated simulation.

Accordingly, in this entry, ‘*simulating*’ is defined as the action of imitating a model’s dynamics and/or structure with its resulting element i.e. ‘*a simulation*’ possibly including static and/or dynamic features.

Several kinds of simulations exist and can contribute to learning activities at different levels, in a direct manner (as the primary educational element) or in an indirect one (as an illustration or as a positive side-feature of the learning objective). It is also worth noticing that game-based learning is frequently linked with simulations: *business games* are a very popular way to teach various aspects of economy, business and management for instance. However it is important to note that there exist games that are not based on simulations and simulations that are not games.

## Theoretical Background

Simulation-based learning can occur in two ways: (a) through observation, the simulation thus being an illustration of the content to be learned or understood, or (b) through experiential learning induced by direct interactions with the simulation. Specific characteristics of a given simulation can make the former, the latter or both learning approaches possible.

Furthermore simulations have been applied in various context that shape their inner properties and objectives. For instances, simulations have been used:

- in human and social sciences to understand civilizations and represent their past, present, and future evolutions, or to study social phenomena,
- in natural sciences to illustrate behaviours of complex systems such as societies of insects or swarms of birds, or to study the impact of a specific phenomenon on an ecosystem,
- in cognitive sciences to analyze intertwined mental processes at stake within the mind of individual human beings,
- in medicine to represent virtual patients that would express symptoms of a specific illness,
- in chemistry and pharmacology to analyze pros and cons of interactions between molecules,
- in physics to test theories and apparatus addressing atomic to cosmological issues,
- in engineering to test structures and mechanics, and ensure their efficiency and safety,
- in business, management, economy or finance to deal with processes occurring at the micro or macro level through actors of economical systems,
- in videogames as virtual worlds where a game occurs that could possibly be populated by simulated inhabitants.

Several features have been discussed in the literature to classify simulations, and influence simulation-based learning opportunities.

**Realization.** A same model (i.e. a set of rules and constraints) can lead to differently realized simulations. Three main realization classes can be distinguished: (a) simulations involving humans, (b) mechanical simulations, and (c) computer simulations.

- a) The business simulation game is a well-known example of simulation involving humans. It is a learning practice where (teams of) students act as if they were in charge of a real business. They may have to deal with stocks, to negotiate with suppliers in order to get the best deals to purchase goods, to compete with other teams of students that run companies with similar objectives, and so on. Similarly, virtual patient simulations have been used in medical education for years. Medical students confronted to trained actors playing the role of a patient with a specific disease, can learn the proper way to detect and cure the targeted disease. One of the learning interests of human-based simulations lies in the genuine adaptive skills of trained human beings who are able to develop coherent and realistic decision making in unplanned situations.
- b) Mechanical simulations refer to the use of artificial apparatus to reproduce natural (waves for instance) or artificial (machines for instance) phenomena or systems. Some mechanical simulations such

as professional flight simulators can simulate physical sensations that students could experience during the real activity. Among other things, mechanical simulations have been extensively used as reproductions of complex, costly, and dangerous systems such as spacecrafts, or airplanes, thus providing situated, secured, and safe learning environments for people who will have to manoeuvre them.

- c) Computers are frequently used to process and display models related to various aspects of life, with equation-based and agent-based simulations being the two main branches of computer simulations. As pointed out by Neumann (2010), in equation-based simulations, a centralized approach is adopted that implies to have a clear a priori theory about the phenomenon to be simulated so that all its characteristics are transcribed into a system of equations. In agent-based simulations, effects, knowledge, and decision making abilities are described and distributed among several entities known as agents. Hence characteristics of the global phenomenon are not known a priori but will emerge from interactions between the different entities. Several computer simulations also have both equation-based and agent-based characteristics. Computer simulations nowadays benefit of the steady computing power progression, which allows an always greater amount of information to be considered at the same time and lead to simulated result closer to reality.

Each kind of realization has specific interests for learning purpose, such as the ability to adapt to unpredicted situations, to reproduce physical experiences, or to deal with models that require lots of information. More and more, hybrid solutions are developed to combine various positive properties. For instance, professional flight simulators use computers to display cockpit views and to transcribe pilot actions into commands to a “six degrees of freedom” motion platform that reproduce physical changes (cockpit inclinations). A human simulator officer is also frequently in charge of the simulation and can trigger events such as material failures that could strengthen the learning experience.

**Fidelity.** Simulations can be characterized on a continuum going from low to high fidelity. Fidelity refers to the extent to which the model correctly represents the element it is supposed to illustrate. From a learning point of view, high and low fidelity simulations each have pros and cons.

High fidelity simulations more coherently represent the content to be learned, which results in a limited deformation between this content and the simulated counterpart that the learner is dealing with. Still, high fidelity simulations not always provide the best pedagogical opportunities since many potentially non-relevant details may have been modelled, that may distract learners from learning objectives or just reveal too complex for their current understanding abilities.

Hence, a lower fidelity simulation that would focus only on pedagogically relevant aspects of the domain to be learned is sometimes more adequate, especially for beginners that have to deal with lots of novel information. However lower fidelity is not necessary due only to an incomplete model, and fantasy elements may have been added (Hollan et al, 1987). While they might raise the fun level of a simulation serious game, and improve the users’ motivation, fantasy elements can also corrupt the learning message and confuse learners who could more hardly distinguish true learning information from fantasized one.

**Interactivity.** Interactivity refers to the possibility for users not only to be passive observers of the simulation, but also to act on it and to influence its evolution. Simulations can be interactive in different ways. The user could for instance have the possibility to modify simulation parameters, and learning would result from observations of changes induced by these modifications. Another possibility is to have the user directly involved in the simulation, as an inner actor that could even have its representation, frequently referred to as ‘avatar’. Hence the user would directly interact with characteristics of the simulated phenomenon, and could then extrapolate some experiential learning.

Constraints sometimes reduce interactivity. For instance, navigating from one location to another in a virtual world is sometimes restricted to a limited set of paths. But in other virtual worlds, freedom of move is total.

Such world simulations are sometimes labelled as 'open world'. Depending on the case, constraints can be perceived as guidance or as restrictions.

Interactivity can be beneficial to simulation-based learning because it is an efficient way of promoting motivation for an activity. As such, it can influence learners' perseverance in the activity and their willingness to re-use the simulation-based learning system in the future. Simulations can also propose interactive ways to answer to learners' needs of guidance and explanations. However interactive techniques can also distract learners from their objectives when they are not used with caution.

**Immersiveness.** Virtual environments sometimes provide rendering fidelity and accuracy in simulated behaviours, particularly if they are delivered with features that trigger immersive feelings. This frequently results in a better perception and more adequate reactions. In addition, pedagogical capabilities can be incorporated into autonomous agents (Johnson et al, 1998). CAVE(Cave Automatic Virtual Environment) are specific immersive virtual reality environments where several projectors are oriented to a curved screen (concave wall) or to a cube (three to six walls). In such a setting the user is thus located in the centre of a fully immersive environment with high-resolution projectors displaying images on each screen. Sometimes images are projected onto mirrors to reflect the images onto the projection screens, reducing the space required for the CAVE. Using stereoscopic glasses, images are separated for each user's eye that can see 3D stereoscopic objects floating in the air. Users can evolve around these objects with a dynamic tracking of their positions which increases the interaction and simulation between user and environment. They learn rapidly how to set up, improve, and test the environment..

The major advantage is that various prototypes (car, plane, building) or interfaces can be developed and tested, without spending any money on industrial development of the complete environment. Reactions of both the environment and the user into the environment can be tested in advance.

**Intelligence.** Simulation-based learning can also be enhanced by intelligent components such as intelligent agents (Lester et al, 1999) that are able to react to user's interaction and to propose various constructive alternatives such as counter-examples, corrections to the manipulation, or guidance towards correct gestures and actions. In addition, the system can react intelligently to user's interactions in order to progressively present new decision situations. This is particularly important for instance in medicine where specific emergency situations can be created, in military strategic cases in which correct decisions must be taken, in aeronautics, fire-fighters training and other situations which require a decision making process. Simulation environments can be enhanced by life-like animated agents such as Cosmo (Lester, et al, 1999) that provides customized advices to support students' problem solving. A key problem posed by these life-like agents that inhabit artificial worlds is deictic believability and for that they have to move through their environment, pointing judiciously to objects as they provide problem solving advice. These types of simulations have a strong contribution to learning.

## Important Scientific Research and Open Questions

Simulation-based learning should increase in the future resulting from improvements of technology and software. Important questions remain such as what is the impact of virtual reality environments on human behaviour and decisions? Visualization process is more and more important and a particular effort is driven on facilities to produce a simulation.

To increase the realism of simulation (believability), affective considerations begin to be introduced and tested with affective agents or avatars. They mimic emotional reactions, an important part of human behaviour. Several works are under way on this topic.

Other research is focusing on the introduction of learning through a large variety of games (funny games, 3D real time game of strategy and adventure). As it becomes more easy and funny to learn through these subtleties a lot of work try to investigate ways to introduce learning into games or games into learning programs.

Other works are focusing on the introduction of intelligence into games. This can take into consideration the learning style or the motivation of the learner, but also several cognitive components such as attention, focus, speed, spatial reasoning, problem solving, stress or reaction time. This aspect of intelligence means that the game should adapt to each user not only at the beginning of the game but also dynamically along the game.

## Cross-References

Similarity learning

Learning with games

Imagery and learning

Visual perception learning

Spatial learning

Simulation and learning: the role of mental models

Visualizations and animations in learning systems

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