10-2019

Chapter 6: Designing and Learning from Modeling and Simulations

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Instructional Message Design:
Theory, Research, and Practice

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Citation:

Saylor, T. (2019). Designing and learning from modeling and simulation. In M. Ramlatchan (Ed.), *Instructional Message Design: Theory, Research, and Practice* (Vol. 1). Norfolk, VA: Kindle Direct Publishing.

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Key Points:

- The affordance of technology has made the design of simulations a much more practical application of instructional message design
- Augmented and virtual reality applications have become affordable and practical message design options to enhance learning
- Well designed, high-fidelity simulations allow for the authentic practice of skills that learners will need to perform in the real-world

Figure 1. Modern simulations evolved from early post World War II computer simulators, such as the digital AKAT-1 used for thermodynamic simulations (https://commons.wikimedia.org/wiki/File:AKAT-1.JPG (CC BY-SA 3.0)

Abstract

Instruction message design with simulations is the use of technology to create virtual environments for cost-effective, safe, and authentic learning. This chapter presents a condensed history of simulation learning, an introduction to several approaches to design instructional simulations, and research based best practices that can be used to guide instructional designers. These best practices include the attention to fidelity or realism of the simulation, the removal of extraneous distractions from the design, and the inclusion of sight, sound, and haptic details that the learner will encounter in the real world. Augmented reality, or the blending of virtual and physical environments, as well as virtual reality, or the immersion of learners in synthetic environments, are also two related areas that will allow for innovative message design opportunities. Advances in technology have allowed for the use of simulations in a wider variety of instructional applications including K-12, higher education, and military training. This chapter describes several of these intriguing avenues.

Introduction to Modeling and Simulation Systems: A Historical Perspective

Computer simulations date back to World War II when two mathematicians, Jon von Neumann and Stanislaw Ulam, were asked to solve the simulate and predict the behavior of neutrons (Pritsker, 1986; Shinde, 2000). The previous experimental methods of trial and error were proving to be too ineffective. While mechanized flight simulators had existed since the 1930s, von Neumann and Ulam's worked was among the first to begin virtualizing the physical environment with statistical analysis (National Museum of the US Air Force, 2015). They considered many different options and decided to utilize "the Roulette Wheel" or the "Monte Carlo" method, a technique for finding approximate solutions to problems by means of doing many random samples (Shinde, 2000). Since basic data regarding the regularity of various events were known, the mathematicians merged probabilities of individual events into a step by step analysis to attempt to predict the end result of the complete

sequence of events. von Neumann and Ulam's (and others' work at the Los Alamos National Laboratory) pioneering work using early computers for advanced statistical modeling would influence and inspire a new generation of researchers (Wood, 1985). With the remarkable success of the techniques on the neutron problem, it soon became popular and found many applications in business and industry. Through the use of electronic computers, this method became widespread throughout the sciences. Ulam also improved the flexibility and general utility of computers (Banks, 1998). Ulam worked at Los Alamos, New Mexico, where he used his simulation methods to help design the hydrogen bomb, the fusion bomb, the fission bomb, and the atomic bombs used to stop World War II. In the late 1940s his team used the legendary ENIAC computer system to simulate and create the functional design of the first hydrogen bombs (Haigh, Priestley, & Rope, 2014; Wood 1985).

Post-war world, new technological advances that were being developed for military uses during the war, were emerging in the private sector as new problem-solving tools. The beginning of computer technology was broken into two approaches: analog and digital. Commercially designed digital computers began to see uses during the late 1940s and early 1950s in a number of organizations (Shinde, 2000). During this period programming languages such as FORTRAN and COBOL were being developed for early computer systems and the field was beginning to differentiate between the construction of a simulation and the use of the simulation (Sammet, 1981; Wexelblat, 1978). The interesting part was with new technology came new problems. Who would use these expensive computers and what would they utilize these tools for? Historically, it became the senior engineer's responsibility to figure out how to use these electronic behemoths and utilize them to solve the problems of the day. This period of simulation history also saw the evolution from human computers to specialized computer programmers who used electronic computers for calculations and modeling (Shetterly, 2016).

Computer simulation would not see any major advances for years due to the cost and processing power of technology not advancing far enough to make the technology a widely useful tool. This lack of advancement was due to how long it took to get results, and the requirement of an excessive amount of resources to program, design, and execute the simulations (Shinde, 2000). The lack of sufficient computer power negatively impacted early modeling and

simulation programs (Wood, 1985). It was not until 1961 when IBM's General Purpose Simulation System (GPSS) was created and released to assist in the design of various simulations did results begin to be used to rapidly inform decision making (Thesen, 1978). IBM's GPSS was easier to use than previous systems and was also applied to simulate stock exchange, traffic control, manufacturing, data center, telephone, and airline reservation systems (Gordon, 1978). IBM shortened the time it took to model, simulate the problem, and receive results from months down to weeks. The interesting part was that the system was designed so that the engineers could input information into the program, but engineers commonly preferred to have specialized programmers interact with the system (Reitman, 1988).

Now the world had the beginnings of simulation but how would we move forward from here? The one thing that all programs require is a language to utilize. This programming language is the basis for all of the computer simulation's inner workings and calculations. It was decided in the late 1960s that a group needed to be established to address the standardization of these languages and to suggest how to best move forward (Shinde, 2000). This group was comprised of SHARE, the Joint User's Group of the Association for Computing Machinery (ACM), and the Computer and Systems Science and Cybernetics Groups of the Institute of Electrical and Electronics Engineers (IEEE).

In the 1970s, simulation was taught to industrial engineers in school but unfortunately rarely applied due to practical limitations (Shinde, 2000). Industrial engineering graduates viewed simulation as long hours wasted at a computer terminal with endless runs to discover an obscure bug in a language.

Two main misnomers about simulations in the 1980s was that simulations were expert based and took what felt like forever because of programming and debugging. Also, the simulation software only concentrated on material requirements planning (MRP), this only takes into account the timing and sizing of orders and could not account for capacity limitations. Then the Simulation Language for Alternative Modeling, or SLAMII, was developed in 1983 and was popularly used on the cost effective and widely available IBM PC (Pritsker, 1986). SLAMII provided three different cost effective modeling approaches that were Network, Discrete Event (the simulation state changes at specific times or points), and Continuous (simulation state can change at any time or point during the

simulation) and you could utilize any combination together. This program was the modern predecessor of many of today's simulation software (Knill, 2000; Shinde, 2000).

Now jumping forward to 1998, simulation software could provide automatic data collection, optimization, a new user interface, and did not require the user to write in any proprietary programming languages. Today a user is able to model, execute, and animate nearly any manufacturing system in any level of detail in minutes versus weeks. Advanced versions of simulation software in the 2000s now supported the following features (Knill, 2000; Muhammad, 2014; Schank, 1997; Shinde, 2000):

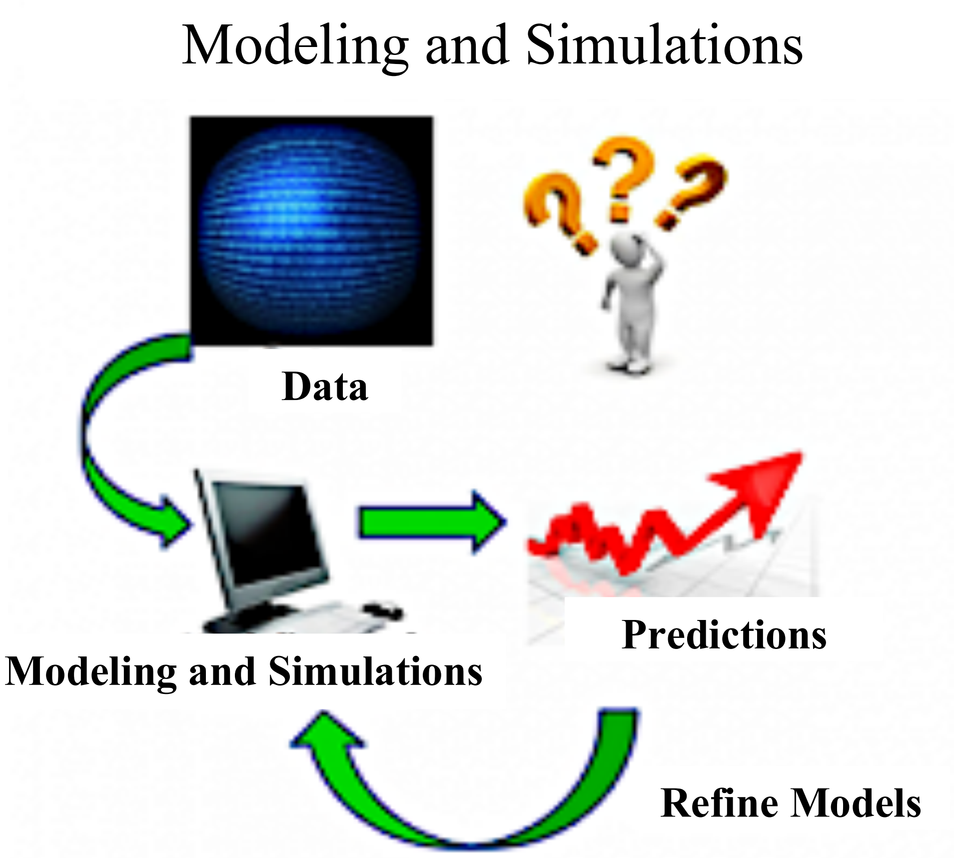
- Uniquely structured environments and graphical user interfaces let the user quickly enter the geometry and production requirements of a model.
- Expert system technology generates details automatically while windows and pop-up menus guide the user through the modeling process.
- Changes can be made quickly and easily with far less chances of errors.
- Built-in material handling templates make the user more productive, so users do not waste time programming.
- The user can verify and test designs, answer "what if" questions, explore more alternatives, and catch system glitches in 3-D animation, all before implementation.
- 3-D graphics are automatically created as the user enters data.
- Results can be communicated in real time or near real time.

Today's modeling and simulation is arguably one of the most multifaceted fields of study to undertake as an instructional systems designer. With the constant advances in technology that occur every day and the cultural change across the planet that welcomes the affordances of technology into their lives, many crave technology in their daily lives and this desire increased the demand for more advances from corporate markets. With this demand driving industry

to create faster, stronger, more versatile technology, has made simulation and modeling a much more achievable goal.

The benefits of modeling and simulation are too many to name, regardless of the industry. Quality, safety, productivity, and improvements can all be affected by modeling and simulation, whether the change occurs in the office, or on the industry floor, or in the warehouse (Reitman, 1988). Today, simulation is extensively being used as a tool to increase production capacity in many fields and industries. Visualization and graphics have undoubtedly made an enormous impact on all simulation companies. Easy-to-use modeling has resulted in low-priced packages that would have been unthinkable just a few years ago. The Simulation technology has shot up in value to other related industries. The Simulation industry is coming of age and is no longer just the domain of academics.

Introduction to Modeling and Simulation Systems:
A General Overview



https://www.quora.com/What-is-modeling-and-simulation-1

Figure 2. Data serves as inputs to simulation systems designed to model reality, the systems create predictions based on these models, the accuracy of these predictions are used to further refine the models

Modeling and simulation is a rapidly evolving field that is integral in science, technology, engineering, mathematics, health science, business, education, and numerous other fields of application. With the ever-changing technological advances that occur today, modeling and simulation has immeasurable potential for sparking a student's interest in any science, technology, engineering, and mathematics (STEM) field. Modeling and simulation fields can

include various disciplines that can interest young adults that includes gaming, animation, virtual reality, augmented reality, medical and scientific imaging, engineering drawing, automation and transportation, and architectural drafting.

Today's modeling and simulation is arguably one of the most rapidly expanding fields in an industry that is being extensively utilized as a vital tool to increase industrial production capacity while limiting waste by designing systems in the virtual world. For instance, our military is committing millions of dollars in funding research projects to help augment our troops' abilities and to limit our losses during conflicts. Advances in visualization and graphics have undoubtedly made an enormous impact on all simulation companies.

Simulations have become instrumental in industrial research and development throughout the world. This amazing tool provides the end user the ability to create real world situations without the extreme cost involved in building full scale models, staffing the models with real people, and running the model through several different evolutions to ascertain the effectiveness of the design model. By using this tool, the end user will be able to evaluate how their designs perform in the industry and it will also allow them to collect and review the data that they gather to ascertain its usefulness in industrial applications.

Modeling and Simulation Presentation Methods

Computer-Based Simulations (CS) use computers to predict the fluid responses of a system through the behavior of a system modeled after it (Gould, Tobochnik, & Christian, 2017). Simulations use the mathematical models of a working system in the form of a computer program. The simulation is composed of mathematical equations that recreate the real system. Once the simulation program is run, the output from the simulation will result in mathematical data that represents the behavior of the real system. Not all simulations are programs, some can be in the form of a computer-graphics image which will be a direct representation of a process with an animated sequence. Computer simulations are most useful when it would be difficult or unsafe to study an object or system in real life. Take for example, an asteroid coming straight for earth. How can we find the actual flight path of such an object? By

creating simulations we can create a mathematical model that incorporates such variables as heat, velocity, and gravity to estimate the impact of near earth objects.

Virtual Reality **(**VR**)** implies a complete immersion experience that shuts out the physical world (Merchant, 2014). Using VR devices such as the HTC Vive, Oculus Rift, or Google Cardboard, learners can be transported into a number of real-world and imagined environments such as the middle of a squawking penguin colony or even the back of a dragon. VR open doors to a new realm of instructional message design by immersing learners in artificial environments where they can manipulate objects in 3D spaces.

https://elearningindustry.com/virtual-reality-training-vr-changes-ld-4-ways

Augmented Reality (AR) is the blending of interactive digital elements such as dazzling visual overlays, buzzy haptic feedback, or other sensory projectors which adds digital elements to a live view often by using the camera on a smartphone (Gorman, 2016). This versatile delivery method allows the educator to assign educational locations and virtual field trips to visit during break time and school time to augment the students' educational goals. The additional resources available during physical or virtual field trips ares especially interesting. Examples of augmented reality experiences include Snapchat lenses, Google glass, and the game Pokemon Go (which alerts and encourages players to visit historical locations and sites around them). While Pokemon Go occupies a place in history as the first widely adopted augmented reality experience on mobile devices, there are (and will be) many instructional applications:

Mixed Reality **(**MR**)** combines elements of both AR and VR, real-world and digital objects interact. Mixed reality technology is just now starting to take off with Microsoft's HoloLens as one of the most notable early mixed reality apparatuses. As a result, today's military are including as much technology as possible to better protect our troops. For instance, combinations of mixed reality technologies are being used to remotely pilot drones and to send critical information and communication to soldiers in real-time:

https://www.military.com/video/logistics-and-supplies/field-equipment/us-army-tactical-augmented-reality/5453063309001

Immersive Simulations (IS) are technology supported by VR and allows us to learn skills just like we did when we were children, through observation and emulation (Lateef, 2010). This type of learning plays a huge role in why it is so effective for learning new skills. As you see below, a Naval Research Engineer demonstrates an infantry Immersion Trainer using VR technology:

https://www.navy.mil/view_image.asp?id=48945

Role-Play Simulations (RS) is when an individual portrays a role with other participants, with or without the specific reliance on technology (Joyner & Young, 2006). Best practices include involving all learners, allowing adequate time, providing feedback, and allowing for reflection (and schema creation) at the end of the role play activity. Participants are given a situation plus a task or problem, but they are not acting as themselves but as though they are someone else. The learner assumes the role of the character in the scenario they are provided. An example would be if you are given the role of a manager and you need to discuss a behavioral issue with an employee. Another example would be medical role-play simulations, such as a cardiopulmonary resuscitation (CPR) first-aid learning workshop. Learners are able to practice and refine their new skills on functional models:

How to use Modeling and Simulation Theories

A simulation can be defined as a model of reality reflecting some or all of its properties. Robert Gagne's conditions of learning theory stipulates that there are several different types or levels of learning (Gagne, 1972). The significance of these classifications is

that each different condition type requires several types of instruction. Gagne identifies five major categories of learning: verbal information, intellectual skills, cognitive strategies, motor skills, and attitudes. Different internal and external conditions are necessary for each type of learning. In terms of message design for simulations, Gagne identified the following properties of a simulation as crucial:

- A simulation represents a real situation in which operations are carried out.

- A simulation provides the user with certain controls over the problem or situation.

- A simulation omits certain distracting variables irrelevant or unimportant for the particular instructional goals. Simulation = (Reality) - (Task irrelevant elements)

Simulation-based education today often relies on the usage of computers, programs, and advanced technologies to present a near perfect (or as perfect as possible) representation for the users and enhances the learning environment. There are several tools in use today that can be employed to create effective simulations. Instructional message design using simulations includes five main components that are common despite applications of simulations in different fields (Jefferies, 2005). Characteristics of the students are built into the specifics of the simulation. The message design includes a teacher or facilitator that guides the learner through the activity, provides assistance, and debriefs students after the simulation. Educational practices that are supported by the simulation, including how students work together, should be included in the design. The implementation of the design should consider the authenticity and realism of the design, as well as the exclusion of extraneous content but the inclusion of relevant intrinsic aspects of what the simulation is meant to model. The intended outcomes are also part of the design, including learning effectiveness as well as the instructor and student perceptions and satisfaction with the design. Figure 3 illustrates these instructional message design considerations:

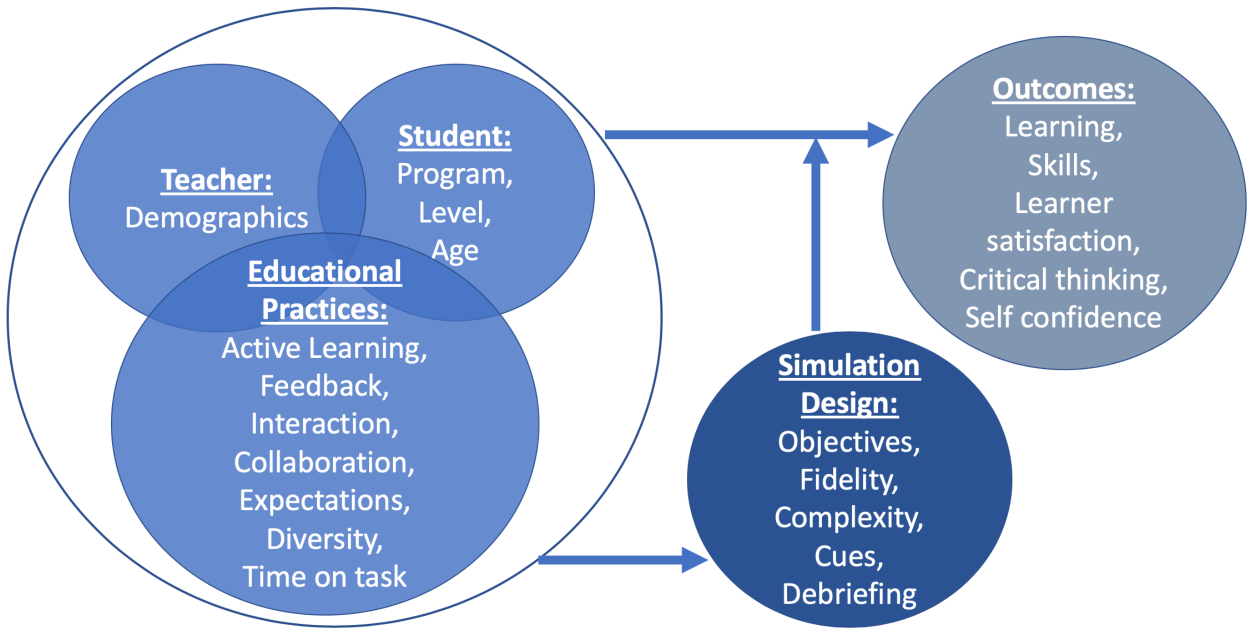


Figure 3. A model for designing simulations starts with the characteristics of the teacher and student and applied educational practices, which informs the design of the simulation, which should result in effective outcomes (Modified from Jefferies, 2005)

Modeling and simulation are effective techniques that can be used to save thousands of hours of work and prevent tragedies. The instruments we have available to use today are improving every day. Where we used to make physical prototypes to represent our processes, which took weeks to create with a large amount of resources exerted, now we can create virtual models in a few short hours with much more accurate results. One of the most important part of an effective virtual simulation process is that it should be continuous in nature (today's technology allows for the cost effective generation of continuous modeling, which in many cases are preferred over discrete models). Once you create a model and place it online you can always improve upon the model and constantly receive data to ascertain the current operating parameters that the system is operating under. For instance, an environment can be simulated during training sessions before the actual facility is built or available and revised during construction of the physical environment:

As will all instructional interventions, the message design of simulations requires a thorough learner and learning objective analysis. Simulation-based learning presents a specific problem in that system designs can be made too complex and difficult for new, novice students. It has been shown that novice learners are routinely unable to retain information from overly complex simulations (Lateef, 2010). The ability for students to understand a simulation is limited by the student's prior knowledge of the topic. Human cognitive structure (i.e., considerations for cognitive load, see chapter two in this book) should be routinely taken into account while designing a simulation. It is also worth noting that the use of simulations is often only part of the over-all learning process. For instance, an instructional program would first consist of online or in-class work with an instructor, then guided learning on a simulator, then learning in the real-world.

Historically, previous research studies have documented that, at least for novice learners, simulation-based learning can be difficult. Learners have problems in establishing goals and results in learning through simulations, or that they have problems with verbalizing results and gained knowledge (Glaser, 1992). The end result is that the more detailed the information, the more chunking is required for the student to retain learning. In a simulation this

chunking involves breaking complex scenarios in simpler modules that comprise the overall larger learning objective. Breaks and debriefing sessions can be designed into the simulation as the simulation progresses from simpler modules to more complex, larger scope challenges.

Instructional Design Best Practice When Designing Simulations

Instructional designers can rely on and apply a set of evidence-based best practice when designing simulations, especially immersive experiences that prepare learners for skills they will need to use to perform in the real-world. For instance, cognitive load theory and multimedia learning theory strongly suggest the reduction of extraneous distractions and a focus on relevant content (Sweller, Ayers, & Kalyuga, 2011; Mayer, 2014). Other best practices include defining clear learning objectives, briefing learners before the simulation, focusing on the fidelity or realism of experience, ensuring practical learner evaluation, and debriefing of learners after the simulation (Sittner, Aebersold, Paige, & Lioce, 2015). The fidelity of the experience is an important point to consider; the simulation must be authentic (ideally as authentic as reasonably possible) such that skills practiced and refined in the simulation can be applied in the real-world (Reigeluth & Schwartz, 1989). For instance, if the control wheel of a vehicle moves in a certain way, then in terms of instructional message design the control wheel in the simulation should move in that exact same way providing that exact same level of feedback to the learner. Several best practice design guidelines can be derived from this previous research:

Simulation Design Best Practice:

1. In terms of instructional message design, focus on the fidelity of the experience

2. The simulated experience should mimic as closely as possible the real-world experience

3. Remove extraneous, unrelated distractions from the design

4. Include the intrinsic details (e.g. sights, sounds, movement, and haptics) that the learner will experience when transferring skills to the real-world

Summary

The effective use of simulation and modeling techniques and technologies is a growing field of educational research and instructional message design. It is an innovative avenue that allows the designer and the user numerous opportunities to lay out their plans and work together to create instructional message designs that transcend previous technology constraints. Simulation technology, including evolving augmented and virtual reality applications, can be used in training applications to increase access, reduce costs, and reduce the danger of training in the physical environment. Simulations and modeling give instructional message designers the power to create virtual worlds to accomplish learning objectives in a very wide variety of industries.

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