Simulating Knowledge: Computational Simulation as a Cultural tool and New Literacy

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Abstract:

Computer simulations have become an important means for generating knowledge in the social, behavioral, physical, and biological sciences, engineering, and medicine. To develop a sense of what this way of knowing does and how it works, I start by briefly exploring two examples of simulations in practice; an economist modeling the arrangement and organization of business in a city; and a physicist surprised by his simulated experiment of the atomic interactions between a gold sheet and nickel tip. These two examples articulate the process by which simulation facilitates the construction of knowledge. With this model articulated, the paper then discusses a variety of problems that arise in simulations—the way they can seduce professional communities and the public at large into seeing issues in a particular way. The power and potential problems involved in simulation suggest the need for a broader public understanding of simulation, what I refer to as 'simulation literacy'. The paper concludes by briefly outlining what that literacy would entail and a call for study of simulation designers "in the wild" to begin building a rich understanding of how experts in simulation understand the process.

The Archimedes simulation brings together more than 10,000 variables about the human body. Its developer, David Eddy, believes he has put “everything we know about physiology” into the model (Kahn, 194), which has proved to be very accurate at anticipating the results of clinical trials for untested drugs. Eddy touts that the model can even reproduce and demonstrate aspects of a clinical trial, which aren't readily measurable, like the quantity of plaque a person has accumulated in their arteries. Approximately 200 times cheaper than conducting a clinical trial, there is a real chance that Archimedes, or some software like it in the future, may begin to take the place of some clinical trials. Originally developed by Kaiser Permanente, the Archimedes simulation is now owned and operated by an independent company. The business is doing quite well. Different medical studies have booked Archimedes a year out. The role of simulations like Archimedies is no longer simply an issue for academics. As the United States works to reformulate its health care system, it is becoming essential that citizens have a basic literacy about the nature and process of simulation.

This story is not unique to medicine. In a wide range of fields, simulations are transitioning from the cutting edges of science into the daily life of citizens around the world. As more and more medical knowledge and knowledge in other fields is generated and created through simulation, it is paramount that the citizenry be equipped to understand the nature, power, and problems that arise in simulation.

The Emergence of Computer Simulation

Over the last forty years, computer simulation has become a central way of understanding the world, a way of understanding which is becoming even more important in the 21st century. Computer models and simulations have become a major means for generating knowledge in the social, behavioral, physical and biological sciences, engineering, and medicine. As sociologist of science Shery Turkle explained "in the past twenty years, researchers have gone from using simulations for discrete, tactical purposes to working almost full time in simulation" (Turkle, 2009). Simulation is rapidly becoming one of our primary methods for generating knowledge.

In 2009, the National Science Foundation funded the International Assessment of Research and Development in Simulation-Based Engineering and came to similar conclusions. They suggest that simulation "is changing the way disease is treated, the way surgery is performed and patients are rehabilitated, and the way we understand the brain" as well as "changing the way materials and components are designed, developed, and used in all industrial sectors; and aiding in the recovery of untapped oil, the discovery and utilization of new energy sources, and the way we design sustainable infrastructures" (Glotzer et al., 2009). The panel ends their report by expressing a need for better training and education to prepare the global workforce to use, create, and understand computer simulations.

As simulation becomes ubiquitous across this wide range of disciplines, the need for a broad base of understanding of how computer simulation works is becoming something much more widespread than the need for competent scientists and engineers. The need for a citizenry that can interpret and understand the process is becoming critical. I propose that these changes are significant enough that it is valuable for us to begin thinking about simulation itself as literacy. This approach to simulation as a literacy is grounded in the broader notions of new literacies which have emerged in literacy studies (Lankshear & Knobel, 2006). While some researchers have casually suggested this notion (Turkle, 2009; Collins, 2003), suggested related ideas like systems literacy (Wilensky, 1999), and broader ideas like computational literacy (diSessa, 2000), this paper offers a warrant for the need to think of simulation as an viable literacy in its own right. After articulating that need, I then offer the beginnings of an argument for how we might start to develop this literacy. In order to accomplish those goals, the paper begins by isolating some of the characteristics of simulation through two case studies. An example from economics and from physics will help outline the process of simulations as tools for thought. From there I will discuss some of the ways in which simulations are being misunderstood, which demonstrate the need for framing understanding of simulation as a literacy.

Simulations Are Another Tool For Thought

There is an extensive technical literature on the theory behind different kinds of simulations, on building simulations and models, and on how to validate experiments conducted using simulations. While this literature is important, it does not directly articulate some of the broader questions about simulations, which this paper endeavors to answer. We need to begin thinking about how simulations amplify, enhance, alter, and reorient the act and process of thinking. We need to develop a critical understanding of how the process of simulation facilitates the creation of knowledge and the structure of the knowledge that simulation generates.

How Tools For Thought Work

To begin exploring this process, it is important to start with the recognition that simulations are tools for thought and as tools for thought, simulations should be understood in relation to what we know about the complex interactions between thinking and other tools more generally. While this might seem like a detour from the overall goal of understanding simulations, it is crucial to establish a baseline for comparison in the relationship between tools and thought in other contexts. It is important to establish this relationship in order to reinforce the fact that most of our thinking is enabled, facilitated, shaped, and otherwise mediated through an irreducible connection between cognition and physical and cognitive tools (Werstch, 1998).

The best way to explain some of the complex interactions between cognition and tool use is to work through a concrete example. For this case, I will briefly present an example offered by Roy Pea of two ways to measure the diameter of a tree. With a conventional measuring tape, a forest ranger would follow the following 6 cognitive and physical steps:

1. Measure the circumference of the tree (6 feet);
2. Remember that the diameter is related to the circumference of an object according to the formula circumference/diameter equals 22/ z (or pi);
3. Set up the formula, replacing the variable circumference with the value of 6 feet;
4. Cross-multiply, getting 22 (diameter-unknown) = 42
5. Isolate the diameter by dividing 22, obtaining 42/22
6. Reduce the fraction 42/22 1.9 feet (Pea, 1997, p. 70)

After completing this process, the ranger has thought through the work required to come to the conclusion. Now consider the same ranger using a different measuring tape, one where the "numbers have been scaled so that the algorithm for these calculations is *built* into the tool" (Pea, 1997, p. 70). In this situation the ranger simply wraps the tape around the tree and reads off the correct measurement, 1.9-foot diameter. Beyond simply augmenting or enhancing the process of thinking, this tool has fundamentally transformed it. One would not say that the tool is thinking, but it has embedded inside it a set of algorithms which allow its user direct access to answer a specific question without even understanding the processes required to otherwise answer the question.

While this case may seem interesting in itself, I bring it the context of thinking about simulations for two reasons. First, it demonstrates the complex kinds of interactions that happen between thinking and tools. Second, I report it because it can be used as a means for understanding the very process of simulation. The measuring tape is designed to facilitate direct access to an answer through the tool. In a similar way, a simulation can reify a set of ideas, practices, and models and explicate their interactions. As the simulation creator lays out the features of the system and watches them interact they can engage with a phenomena in a fundamentally different way than viewing it in a static form.

More Fundamental Tools For Thought

As the previous section explained, all tools have a dynamic interaction with the process of thinking in action, but there is another class of tool that has a still more transformative impact. Things like writing, reading, and mathematical computation can all be understood as tools. Each has a history. Each was invented. Through various studies each has been demonstrated to have a powerful impact on the very process of thought and conceptions about what valid thinking is. (For literacy see Ong, 1988, for the printing press see Eisenstein, 1979). The appearance of simulation in a wide range of fields and the necessity of simulation for understanding the problems facing those fields in the 21st century, it is worth conjecturing that simulations themselves may fall into this category of tool. This must, however, remain pure conjecture at this point as the prominence of simulation is a relatively recent phenomenon.

Simulations In Practice:

To develop a sense of what this way of knowing does and how it works, it is important to briefly explore a few examples of simulations in different fields; a physicist surprised by his nano-sized simulation and a political scientist's approach to simulation cooperation. In each of these examples I will isolate a few of the key similarities and differences which I can then use to articulate a larger framework by which simulations facilitate the construction of knowledge.

Simulations and Agent Based Models

A common use, and one of the most powerful applications of simulation, is to define the behavior of individual agents; particles, amoebas, shoppers, local businesses, or multi-national corporations and examine how those behaviors interact to generate emergent behavior across a system. An example can help clarify this process and make explicit the way in which simulations are being deployed to facilitate understanding.

Economist Paul Krugman's work in *The Self Organizing Economy,* provides a useful means to understand this process (1996). He starts with a relatively simple question: why do businesses arrange themselves in the "poly centric, plumb pudding pattern of the modern metropolis." (p. 24-25). Instead of starting from the structure of a city, he begins by articulating a model of the individual actors which make up cities. For the purpose of the simulation, Krugman simplifies the structure of a city into a city with only businesses. He then assigns two forces which effect the business owners' decisions, a force that attracts businesses to aggregate in a single area which explains business's needs to share a local customer base, and some forces driving businesses to establish themselves further apart from each other representing things like competition for land, labor, and in customers. From there, he sets two rules. First, there is an ongoing tension from being close to other businesses and further away from other businesses, and second, that the range of the two forces is different, in other words businesses like having other businesses very close by but dislike them being a little ways away. By moving the model of the individual agents into a simulation, Krugman can experience the results of the interactions between those agents and sit back to appreciate any forms of emergent behavior and organization.

With that model in place, Krugman explains the results of a simulation running with any initial random placement of businesses. He finds that, “any initial distribution of businesses across the landscape, no matter how even (or random), will spontaneously organize itself into a pattern with multiple, clearly separated business centers.” (p. 25) In other words, a model based on individual agents (the businesses) which follows the simple rules he set out will very quickly stabilize in a pattern that mirrors the patterns of modern American cities.

This example provides a site to unpack the process of simulation. In this case Krugman began with an idea about how individual actions of business owners could potentially shape the landscape of cities. He then abstracted the complex world of a modern city into a simplified model of individual cities filled with only businesses and established a mechanism by which those individual businesses make decisions about and reshape the landscape through those individual decisions. From there he could program a computer simulation to run through the interactions of a thousand individual businesses over any number of time frames, at which point he found that those rules did indeed develop a image of something that looks very much like a modern city. I have used this relatively simple case to underscore the processes at the heart of a wide range of models. By specifying behavior of abstracted components in a model, the simulation enables its creator to tinker with the rules governing individual agents and components of the model and quickly see the implications of those changes to the entire system.

Simulations as experiments

Alongside facilitating agent based models, simulations are also being used to conduct something akin to much more traditional scientific experiments. In situations where it is either impossible to conduct physical experiments, either because of ethical issues, like nuclear weapons, situations where it is cost prohibitive or dangerous to use experiment in the real world, like experimental aircraft, or in situations where information is simply unobservable in the traditional sense, like nanoscience, simulations have become important tools for conducting experiments.

In the late 1980's physicist Uri Landman developed a sophisticated computer model of the forces between atoms. Landman's team at Georgia Tech started their process by developing models of gold and nickel atoms based on well-known physical laws at the atomic level (Landman, 1990). Using this model, Landman began conducting what he calls "computer experiments, where the evolution of a system of interacting particles is simulated with high spatial and temporal resolution by means of a direct integration of the particles' equations of motion" (p. 454). While Landerman did not have the ability to directly view the interaction between nickel and a piece of gold, he was able to use the information he had gathered about each substance to simulate an experiment of the interaction between the nickel and gold. When he conducted this simulated experiment, he was surprised to discover that at a close distance the gold atoms "jump-to-contact, " creating a tiny nanowire between the gold sheet and the nickel tip. Landerman's surprise at the results of the simulation offers a crucial insight into the potential power of simulations for thinking.

Landerman had a solid grasp of physical laws he used to build his model, and a robust understanding of how the models were put together. Yet, when he introduced the simulated nickel tip to simulated gold sheet, the jumping behavior which the simulation produced surprised him. The simulation had demonstrated behavior which he had not anticipated and that later more sophisticated tools would demonstrate to be experimentally valid.

Philosopher of science, Johannes Lenhard, has argued that this case demonstrates something about computer models which differentiates them from theoretical models, like Krugman's theoretical city. Lenhard argues that where traditional approaches to understanding models in science "can be conceived as an instrument for gaining insight (though in a highly idealized model world), simulation modeling presents an instrument for gaining control over model behavior by becoming acquainted with the model and developing an orientation within it" (Lenhard, 2006, p. 615). Landerman's model allowed him to conduct an experiment, and the process showed him something completely unexpected.

The process of simulation

Across two different sites of simulation, the arrangement of businesses in cities, and the atomic interactions between gold and nickel, some general trends emerge about the process of simulation. In this section, I will use those trends to set a general outline of the process by which simulation facilitates the creation of knowledge. Banks, a computer scientist, identifies twelve stages in the process of simulation as a research method: problem formulation, setting of objects and overall project plan, model conceptualization, data collection, model translation, verification, validation, experimental design, production runs and analysis, additional runs, documentation and reporting, and implementation (Banks, 1998 for other similar presentations see Pegden et al. 1995; Law & Kelton 1991). For the purpose of this discussion, these steps can be simplified into a broader cyclical understanding of the process of simulation. I characterize the process of simulation as (1) isolating characteristics to simulate, (2) developing a model of the interactions between those characteristics, (3) running the simulation to uncover the emergent behavior of the simulation, and (4) evaluating the results. The process then frequently returns to the beginning, using the results of the process to alter the characteristics or the model to then rerun the simulation. I present these stages here in a linear fashion, but this is not necessarily the case in practice, and the stages iterate and return to each other over time. However, each of these characteristic moments are crucial pieces of the process, and they each build on each other.

Problems with Simulation

The power of simulations, to create engaging, robust, and visually compelling models of pieces of the world, is also the source of the largest problems in pitfalls to the understanding which they facilitate. As simulation becomes more and more prominent, it becomes all the more critical that people understand the way in which simulations can be seductive. It is essential for both creators and consumers of simulations to understand the kinds of abstraction, assumption, and approximation that enter into the process of the design, development, and computation operating in any given simulation.

Understanding Simulations As The Thing Itself

Anthropologist Shery Turkle provides a valuable case study in the seductiveness of simulation (2009). Turkle reports about a power player of the game Sim City who told her about the "Top Ten Rules of Sim City." One of the adolescent's rules was that "raising taxes leads to riots." While there is some validity to a rule like this, particularly in light of the recent "tea party" movement in the United States, it is not an iron-clad rule of society. It is, however, a fundamental truth in the abstraction that is *Sim City*. Now, if the adolescent had simply understood this as a rule in the model, it would be fine, but Turkle insists that the adolescent did not understand that the simulation was a simplification. Turkle claims that this adolescent had uncritically extrapolated a set of rules she used to understand society from *Sim City*. While it might seem that this is simply a problem for the public, research in the sociology of science suggests that the same kind of seductiveness of the models can happen in the laboratory (Lahsen, 2005). Lahsen suggests that the seductiveness of simulated models makes it difficult for researchers who develop the models to evaluate their quality. Traditionally sociologists of science have suggested that the closer a scientist is to the work the better they are at evaluating it. Lahsen suggests that the power of the simulation to seduce requires new modes for review of these kinds of models. This seductiveness makes it all the more critical for both citizens and scientists to develop a critical eye for simulation.

The Black Box Problem

As simulations are increasingly used as stand-ins for the physical world, it is crucial for the validity of simulation based research to have as high a fidelity as possible to the processes and events they are modeling. Berendsen, a chemist, states this problem quite well, “There is a danger…that applied scientists will use ‘standard’ simulation methods, or even worse use ‘black-box’ software, without realizing on what assumptions the methods rest and what approximations are implied” (Berendsen, 2007, p. 6). The specialization which has taken place in the process of developing simulations, between researchers and developers means that those interested in simulations must be all the more diligent in validating the outcomes of their simulated work through a wide range of methods and processes.

Simulation Requires A New Literacy

Both critics and proponents of the effects of the growing reliance on simulations in the creation of knowledge should agree that with every passing year simulation is becoming an even more potent and widespread process for the creation of knowledge across a wide range of fields. While simulation has been casually suggested as a literacy (Turkle, 2009), and related ideas, like dynamic systems, have been framed as a literacy (Wilensky, 1999), and some broader ideas, like computational literacy (diSessa, 2000) to some extent address this notion, I propose that the evidence presented here about both the importance and process of simulation warrants consideration as a literacy in its own right.

It is important to clarify exactly what I mean by defining simulation as a literacy. The primary reason to frame it as a literacy is to stress the importance of the process to being a citizen. In this sense, I am using the word literacy in much the same way that proponents of scientific literacy use the term. In the case of science, the educational community has largely come to believe that understanding the process and nature of science have become such critical components of being a citizen in a democracy that they science should be cast as a essential, like textual literacy. Like reading, scientific literacy intends to suggest understanding aspects of science is essential for any individual to fully participate in the democracy.

With that core purpose noted, there is another sense in which the term literacy does useful work in this context. To be literate in the textual sense is to be able to both read and write text. This opens an important question for defining simulation as a literacy. Clearly, creating simulations provides substantial inside information about the process of simulation, but should the concept of literacy here suggest that a fully simulation literate individual would be both ‘reading’ and ‘writing’ simulations?
Some current research on communities of simulation game players suggests that there are significant reasons to understand reading and writing simulations as much more of a continuum than how we understand reading and writing in texts. Squire and Giovanetto’s documentation of the process and thinking which players of the simulation video game *Civilization* demonstrate in communities of gamers underscore the sophisticated ways in which these players are beginning to analyze the game as simulation designers (2008). Similarly, my own research on the habits of mind and values of *Civilization* modders suggests that these game players have very sophisticated understandings of the trade-offs and models that undergird their gameplay (in press). While it is clear that there is a need for more research to understand how simulation users interact with and understand the models in the simulations they engage with, this research does demonstrate that the

difference between reading and writing in simulations is complicated enough to offer no simple answers.

With that noted, the idea of simulation literacy provides another argument for projects like Northwestern's NetLogo tools, which allow students to author their own simulations. While projects like this have been operating for quite some time, it is important to begin to highlight not only their value in transmitting ideas about the scientific process and scientific thinking, but also the very real way in which a tool like this encourages students to develop a broader simulation literacy. We need to know more about how these kinds of tools can be leveraged to help transfer lessons about the process and nature of simulation to the results of simulations in the wide range of disciplines which citizens are now called upon to make decisions about on a near daily basis.

Taking into account some of this initial understanding of how individuals understand simulation games, and some of the successes of simulation authoring tools like Netlogo, I want to point to a final crucial gap in our understanding. While I have done my best to lay out the process of simulation and some of the pitfalls that exist in the ways in which simulations generate knowledge, we still need a considerably larger body of information about the process and habits of successful simulation creators to be able to have a fully realized understanding of what simulation literacy entails. We need to know more about the process and kind of cognitive work that skilled professionals creating and consuming simulations engage in.

Recent work in educational psychology has established a need for a deeper understanding of the ways professionals use their knowledge. In particular, as cognition is both situated and distributed in environments, it is valuable to see how experts navigate and construct knowledge "in the wild" (Hutchens, 1994). We need to know more about how experts develop, critique, communicate, and analyze simulations, and the best mode for understanding that is through ethnographic work with simulation creators.

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