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LEARNING SIMULATION MODELS THROUGH PHYSICAL OBJECTS

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ABSTRACT

We traditionally learn how to model systems through texts, either online or in published form, but is it possible to learn about models by interacting directly with physical objects? Imagine taking a walk in a museum where objects reveal their modeling nature. A fossil in a science museum may indicate a process model for mineralization of bone, or the museums' cafe, although a large object, may indicate a queuing model reflecting how customers wait in line and obtain service. Such informal learning outside of the classroom augments formal learning in instructor-led, syllabus-based courses. We cover recent work in a class where students were instructed to explore museum objects through the *lens of modeling and simulation*. We link to an outdoor sculpture that contains physical web access to modeling information. Students are able to see models through objects rather than strictly through classroom instruction. Models become new interpretations of art objects.

1 INTRODUCTION

Simulation education has taken on many forms in the past: papers, tutorials, videos, and demonstrations to name a few. The classical instruction of simulation within a university setting is to have an instructor conduct a semester-long course on some aspects of computer simulation. These aspects may focus on an encompassing discipline, such as operations research, or aspects may be more conceptually oriented such as when the emphasis is on agent-based, discrete-event, or hybrid simulation. These modes of education are primarily based on a curriculum centered on topics relevant to the field. A class where verification and validation of models are covered would be conducted by breaking down verification and validation into sub-component areas. These areas usually involve case studies or the use of a specific software tools, allowing the student to learn the field by way of practical examples.

Though effective at delivering education, these methods have significant problems when considered "in the large." If the goal is to reach many diverse students, this goal is unlikely to be realized purely within classroom settings or by narrowly focusing on the discipline independent of a variety of application contexts. Our goal is to bring modeling and simulation to the widest possible audience. The pedagogical approach used to achieve this goal is through *object-based learning*. Object-based learning, as suggested by its name, involves pedagogy and learning that *centers on physical experience*. Object-based learning is therefore empirically driven. This type of learning is fairly common in museums since museums are home to unique, and often rare, objects. By linking modeling to objects, we are also able to better connect with other disciplines since these same disciplines can be presented by way of the object. An object becomes a gateway or catalyst for simultaneously learning many subjects. Interaction with the object includes a wide variety of potential approaches, but certainly includes the usual experience of *seeing*—often where a museum object is frequently located within a vitrine for purposes of preservation and to avoid touching the object.

Hybrid simulation within the context of the simulation literature has generally meant a combination or integration of event-based and time-based approaches to modeling. At one time, this practice was termed *combined modeling*. A traditional example of hybrid simulation is integrating discrete event modeling with the time-slice approach in Systems Dynamics (Zulkepli et al. 2012). Another example is integrating discrete event and agent-based modeling (Brailsford et al. 2013). Our interpretation expands the qualification of "hybrid" to include physical context as well as model type. The object-based approach situates models of every variety "within" physical objects, thus making the objects physical/logical artifacts. Within Section 2, we broaden modeling to include non-dynamic models such as the concept map. The hybrid nature of our modeling is defined not only by (1) physical/logical but also by (2) integrating non-dynamic/dynamic modeling with other forms of modeling such as those defining models of knowledge and geometry.

The paper is organized into five sections. The first section contains a general discussion about how to see models in objects, by using the example of a bronze Japanese sculpture from the 19th century. In the second section, we present an object from a recent Inca exhibition at the Dallas Museum of Art in Dallas, Texas. To a modeling and simulation theorist or practitioner, it may seem peculiar to examine an ancient cultural object as a means to learn about modeling and simulation. In our experience, though, this type of experiential learning is received well by students, and encourages many different types of students to explore multi-disciplinary knowledge. An art historian is drawn to an Inca artifact for reasons of culture and history, but is then introduced to modeling and simulation *as a new mode of object interpretation*. Our focus on interpretation needs highlighting: modeling and simulation are defined not in terms of methods or tools, but rather as fundamental ways of seeing the world and all of its experiences and objects. This approach was informally surfaced in the *Models of X Project* (Fishwick et al. 2016a). The third section introduces the most recent project where a class of students brought multiple interpretations, including those of modeling, to a contemporary sculpture located at the University of Texas at Dallas. The interpretations can be browsed on a smartphone or tablet. The final sections of the paper present related work, summary conclusions and areas for future research.

2 INTERPRETING OBJECTS USING MODELING

Since our strategy involves learning models directly from objects, we observe that objects are ubiquitous in our experience. While one can learn an operations research model by examining the workflow in a manufacturing plant, a large object in its own right, our goal is to allow any object, regardless of size, to convey models, not limited to a specific discipline, relevant for the simulation learner. Our focus will be mainly on works of art for the following reasons: (1) art seems an unlikely place to find modeling and simulation and yet art museums and artworks are widely experienced, making them novel vessels for model-based education, and (2) art, and objects within museums, tend to be rare and unique, making these objects interesting targets of investigation.

Figure 1 is a picture of a Japanese sculpture in bronze and glass within the Dallas Museum of Art. It is traditional in art appreciation to begin to experience this object with contemplation at first, followed by a series of questions asked by the viewer. For instance, these questions arise: What is happening in the sculpture—what is being represented? Who are the figures? How was the glass sphere made? How was the sculpture made? These questions lead to numerous others about the role of samurai in Japanese society, the nature of the weapons, and the identification of sea creatures at the base. While the set of questions is virtually limitless in size, many of the questions have answers that are models or model-based.

Modeling is an activity where we represent things that we experience in the world by creating other objects—which we call *models*. Therefore, modeling is a core approach of the act of representation. The modeling and simulation community has tended to focus on models of behavior (i.e., dynamics). However, our view on modeling is extended to two other categories: knowledge and geometry. Models of knowledge have documentation and history within artificial intelligence (AI) and cognitive science

(Brachman and Levesque 1985), but can also be found in the form of mind maps, concept maps, and ontologies. Ontologies have transitioned from the AI literature to the semantic web literature over the past 20 years. There are also other forms of knowledge representation such as frames and schemas (Shank and Abelson 1975). Within modeling and simulation, knowledge representation is often discussed in concept modeling and ontology. We begin with terms and then transition eventually to dynamics. For Figure 1, we could construct a semantic network by identifying the objects, their roles and attributes, and how the objects are related. The semantic network or concept model is one of the most natural types of modeling possible for the modeling and simulation practitioner. Even natural language, without the aid of diagrams, serves as a way of modeling.

Figure 1: Takenouchi no Sukune Meets the Dragon King of the Sea, Date: 1879-1881. Designer: Sanseisha Company. Medium: Bronze and Glass, Courtesy of the Dallas Museum of Art, Public digital media collection. Additional Information: DMA Connect (DMA-Takenouchi 2016).

The second type of modeling is geometry. How can we represent the shape and form of Figure 1? Depending on the type of design it is possible to think of Figure 1 first as a digital image of a specific resolution. Then, one can create a 2D design and then a 3D design. For this sculpture, each of the three human figures would be designed through rigging an armature and then fine-tuning the anatomy and the clothing.

The third type of model is dynamics, which is most familiar to the modeling and simulation audience. One can model many facets of the sculpture: 1) the sequence of states and events in the story where the dragon King of the Sea presents the jewel of the tides to Takenouchi for having rid the sea of a dangerous creature to humans and sea dwellers, 2) the pipeline required to achieve lost-wax casting of the bronze, 3) how the sphere was made (from solid quartz), and 4) the dynamics of tides.

3 INCA TUNIC MODELING

Words such as *system* and *model* evoke different reactions and interpretations depending on discipline and context. For our purposes within the modeling and simulation area, we define a system as an abstract mathematical structure that contains sub-components, each of which may contain further sub-components. Each component is connected with other components. By “mathematical,” we observe that it is sufficient for the model to be built from abstractions independent of the syntax used to capture how we perceive the model. Therefore, mathematical notation is one approach to language; however, other more widely understood abstract formalisms (e.g., model components and syntax) tend to be visual and diagrammatic.

The art museum was chosen as the venue for considering systems thinking in a Fall 2015 class in Modeling and Simulation. Students were each given a choice of an object at the DMA. With some guidance, they interpreted these objects through thinking of them from a systems perspective. The guidance consisted of heuristics such as: (1) represent knowledge about the objects and their representations, resulting in a concept map; (2) consider any processes or techniques associated with the object, what is represented in the object, or in the object's material; and (3) model the object with digital or physical materials. Systems thinking is atypical in an art museum, which is why it was chosen. The goal was to illustrate variety in object interpretation that ventured beyond art history explanations. Consider the Inca tunic in Figure 2, which was highlighted within a recent exhibit (DMAInca, 2016). Some of the following discussion in this section was recently edited for, and presented to, a museum audience (Fishwick 2016b).

Figure 2: Tunic with checkerboard pattern and stepped yoke. Courtesy of the Dallas Museum of Art, Public digital media collection. Additional Information: Inca Tunic (DMA-Tunic 2016).

For this tunic, there are many possible questions we may ask:

- How was the tunic originally woven?
- How would the tunic be woven today?
- Can a computer program reproduce the tunic pattern?
- How was the red fabric dyed?
- What are the population dynamics of the alpaca or llama?

- Can the colored, square motifs be used to encode information?
- What were the behaviors or rituals of the tunic wearer?
- How was the tunic exhibit installed within the museum?
- What workflow process can be used to obtain a list of all tunics?
- What is the global timeline for Inca tunics across all museums?

These questions can be answered through dynamic models of the sort employed in the simulation field. We will cover example dynamic models, but first couch the study of the tunic in a concept map (Novak and Gowin 1984). The concept map is a directed graph of concepts linked by relations. For example, "Inca is a *type_of* culture" and the tunic is *processed_with* a loom, with two types of loom indicated: upright and backstrap. The concept map is a type of semantic model (Sowa 1983). A concept map of the tunic is depicted in Figure 3.

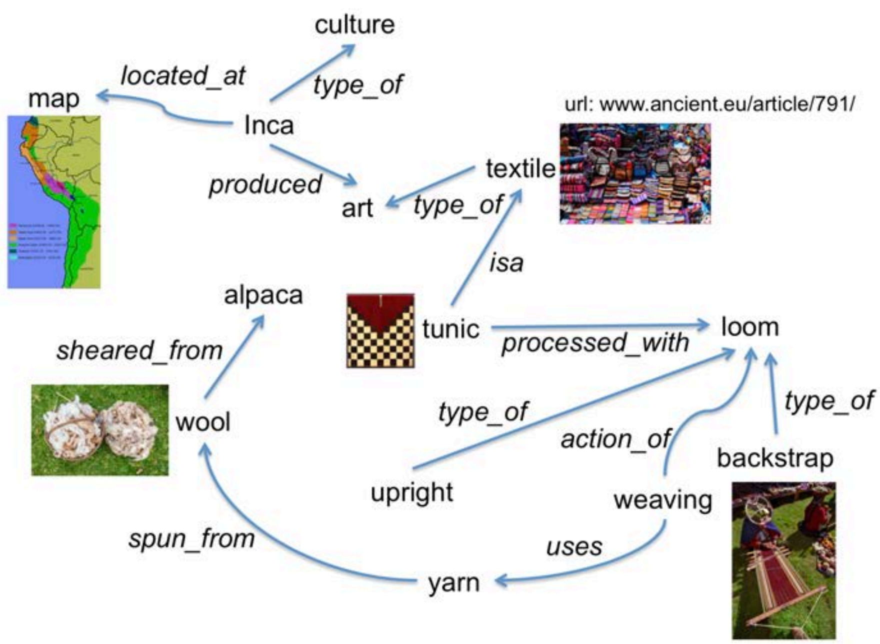

Figure 3: Concept map of knowledge about the Inca tunic. Images: tunic image is from the public DMA digital media collection. Map in the upper left is from Wikimedia Commons: public domain. Remaining images from Shutterstock, Inc., standard license.

The next step in seeing the tunic from the lens of systems thinking is to map out the dynamic relations. We do this by focusing on verb-based relations in English. The diagram in Figure 4 represents a finite state machine (Fishwick, 1995), as it is termed in computer science (FSM 2016). Each state has a participle verb form indicating state. For example, to craft a tunic, we begin by shearing an animal from the camelid family, such as an alpaca. Thus, the system that indicates how the tunic is made can be seen as a sequence of activities (i.e., states) of different people in a sequence-based pipeline.

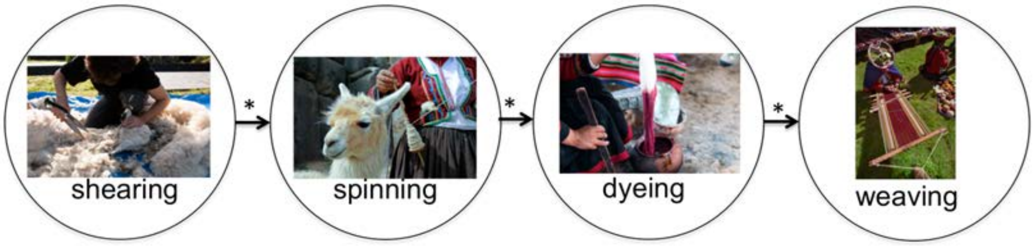

Figure 4: Four connected states comprising a finite state machine (FSM) for the tunic process. Images: Shutterstock, Inc., standard license.

Figure 5 presents the dynamics of making the tunic using a data flow graph. For data flow, information is processed from one functional node (e.g., *spin*) to the next. Starting on the left of Figure 5, an alpaca is sheared. In a more detailed model, there would be an arrow input to “shear,” but this is left out for simplifying the diagram. There are two outputs from shear: one going to the wool, which subsequently must be spun, and another representing the alpaca minus the sheared wool: the shorn alpaca. Spinning can be done in one of two directions termed *S ply* versus *Z ply*.

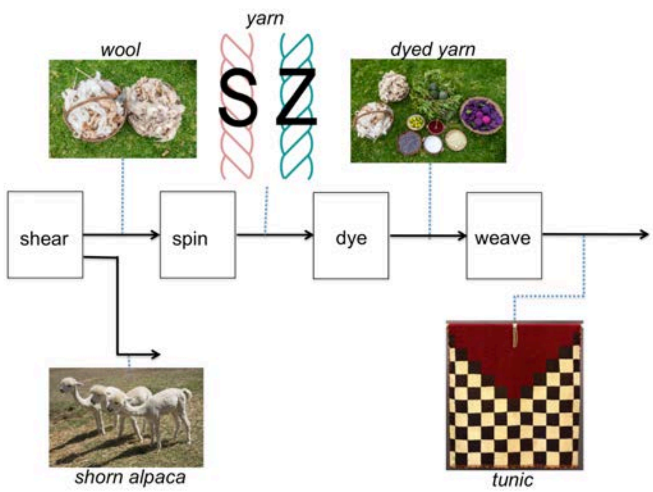

Figure 5: A data flow graph that represents material flowing from left to right. Each node is a function or process, as indicated by a verb. Images: Shutterstock, Inc., standard license, with the exception of the S/Z image (public domain, Wikimedia Commons) and the tunic (courtesy of DMA).

Figures 3 through 5 illustrate three model types, where there is a design effort to ensure that each model component is denoted by text and some graphical cues, such as photographs. This approach to model design is deemed necessary where the visitor is from a general population, rather than from a highly technical domain such as engineering.

Figure 6 shows how programming can be considered modeling (of a decision procedure). A partial Processing program (Greenberg 2008) on the left side indicates a piece of the program, with the synthetic tunic image on the right side obtained from executing the program. The code is a textual model that captures *a computer science type of interpretation* of the original tunic.

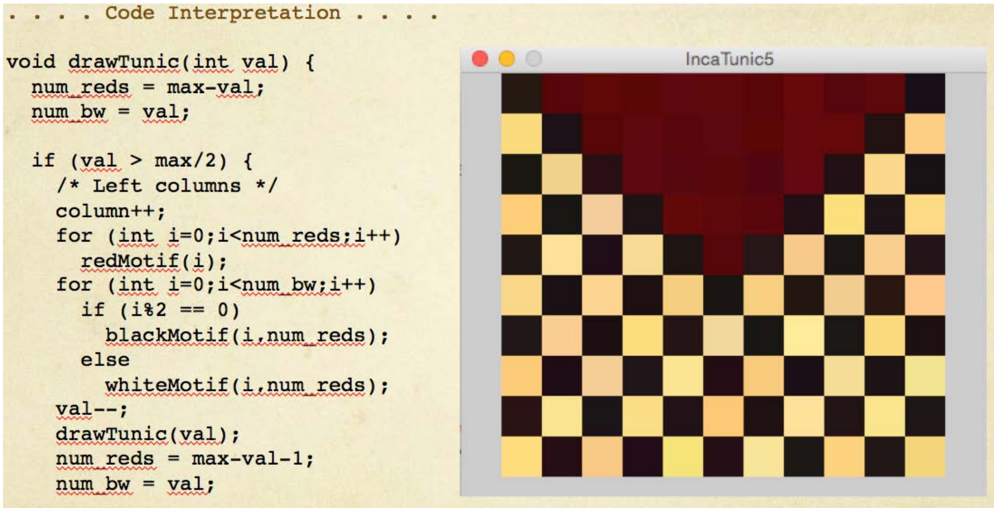

Figure 6: A Processing program (left) which produces an image similar to the Inca tunic (right).

Numerous other models are possible for the tunic such as the one in Figure 7 where a data flow model takes the original tunic image on the left and then applies this image, through a left-to-right flow via functional image filters.

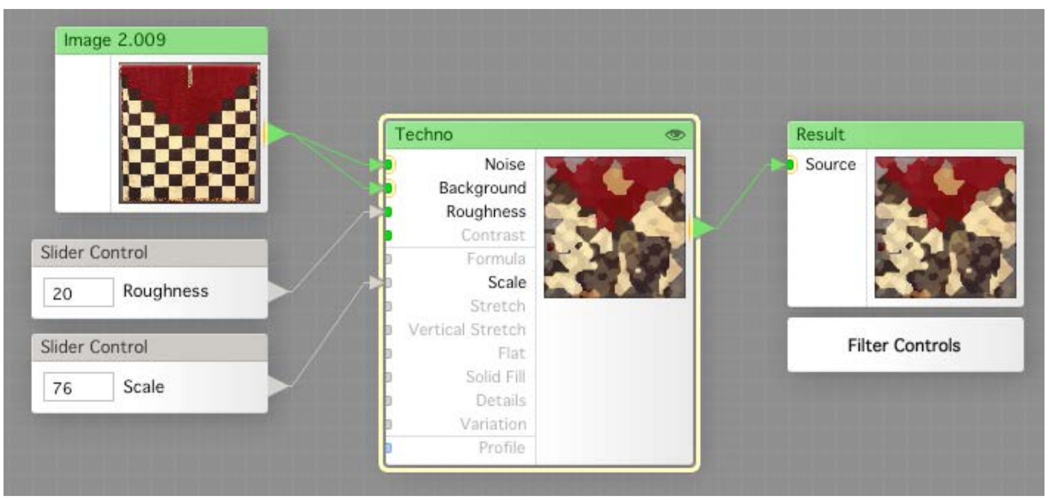

Figure 7: A data flow model that processes images using filter nodes. Program: Filterforge (Filterforge 2016).

4 RED JACK SCULPTURE MODELING: THE PHYSICAL WEB

The two figures in Figure 8 show different perspectives of the ten foot tall red sculpture called “Jack” by artist Jim Love in 1971. While not focused solely on modeling, the purpose of this experiment was to create an object-based way to learn about Jack, with some of these ways being related to modeling knowledge, geometry, or dynamics. A smartphone app was created for Android and iOS. By using a Bluetooth beacon near the sculpture, the user can see different models of Jack (Jack, 2016) across five different categories (Science, Technology, Engineering, Art & Humanities, and Mathematics, or STEAM).

Figure 8: The red jack, called “Love Jack” by Jim Love (side view, left), (end courtyard view, right).

The physical web (Jenson et al. 2015) involves a network, potentially of global proportions, of “smart” objects. An object is smart by virtue of having a microcontroller-based circuit nearby or attached to it. The objects can be in motion or installed in a fixed location. Mobile object tracking in conferences and other venues is achieved by having a *smart tag*. For instance, a conference attendee would wear the tag, and then a network of base stations could track the tags. The tags are fairly simple in design and “advertise” an ID of some sort. In the case of the physical web, with Google’s Eddystone protocols, the tag can also advertise a URL. In contrast to moving conference attendees, the other use of the physical web strategy is to attach the tag to a motionless object. This is the approach we have used with the Jack sculpture. A small (about 2 centimeters in diameter) tag is placed underneath one leg of Jack and is unnoticeable. This tag contains a microcontroller and a Bluetooth radio operating at 2.4Ghz, along with other basic components such as clocks, resistors, and capacitors all located on a printed circuit board. We are using the Eddystone URL protocol where the tag is set to advertise (about 3-6 times per second) the URL. This advertisement is picked up by a custom app, or by the Chrome physical web app by Google on a client machine—usually a smartphone, although a tablet or laptop are also possible. The URL points to any information desired. For modeling and simulation, models are shown and discussed within the web page. For Jack, there are conceptual and geometric models, but also numerous dynamic system models possible: the process of weathering on the sculpture’s surface; the process used to lift and place the Jack during its installation, and the process of making a Jack replica with 3D modeling or using digital fabrication methods such as laser cutting and 3D printing.

Figure 9 (left side) shows the app we have developed for use with the Bluetooth beacons. The app has functionality that is shown with features identified with arrows. The app is called *SnooP* and Figure 9 shows what occurs when a user in front of the Jack sculpture. The app can be refreshed either through an active text-button or a pull-down swiping gesture. The first line of text is the title of the object (Love Jack). The second line is a question that is created to foster inquiry and contemplation by the viewer. This particular line is a play on words (i.e., “You Don’t Know Jack”) inviting the viewer to touch the smartphone Jack image, which results in being transferred to a web page where multiple STEAM perspectives are available for browsing. The user can choose any perspective and learn more about that perspective. Some of the perspectives are models either of knowledge, dynamics, or the shape and geometry of the sculpture. The web page snapshot is shown in Figure 9 (right side).

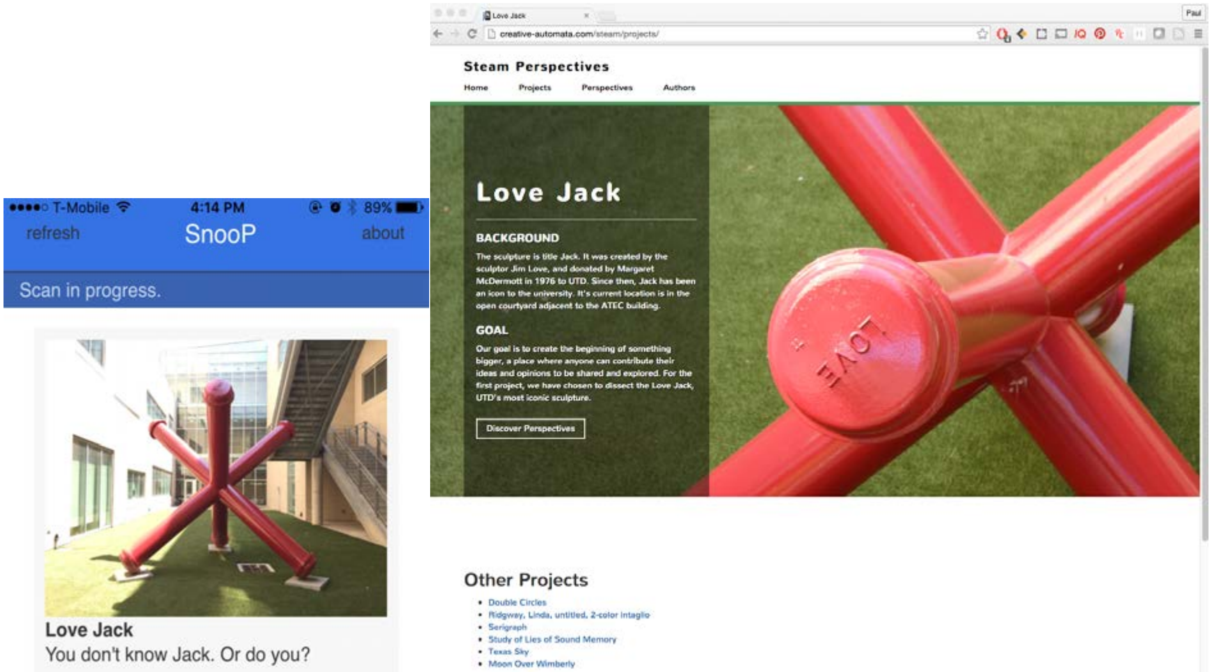

Figure 9: Left: Screenshot of the app, *SnooP*, while located physically at the Love Jack sculpture. Right: Screenshot of the web page opened when the touches the SnooP image on the phone.

5 RELATED WORK

Our work is a combination of hybrid modeling and simulation, in addition to focusing on education using objects. For related work in both hybrid modeling and education, our goal within the paper lay outside the norm. We are augmenting the study of hybrid combination to include those where the model and a physical object can be joined, via a Bluetooth beacon or through some other tagging approach. Also, the described system is hybrid because the presented material for an object may include multiple disciplines; one might learn geology, mathematics, art history, and modeling from the same object. On learning, our discussion is focused mainly on learning through experiencing objects (Fishwick 1998, Cubert and Fishwick 1999). The task of educating students on simulation is as old as the field, and the literature is vast. In particular, the Winter Simulation Conference has convened a Simulation Education track. However, previous work has focused on learning simulation through a specific discipline, or using a new type of environment or language. There are some notable outliers in terms of broader perspectives on education independent of specific software, modeling methods, or domains of application. For example, Jain (2014) covers the practice of teaching of simulation in business schools. Gogi et al. (2014) detail a study performed for models to generate insights and enhance discovery. General coverage of simulation in textbook form includes Fishwick (1995), Law and Kelton (2000), and Banks et al. (2000). Zeigler et al. (2000) present a mathematical system-theoretical account of the field. Taking these broader perspectives into the realm of physical objects requires rethinking how we can educate large numbers of people about our discipline. In terms of beginning with knowledge-based structures as a gateway to dynamic modeling within simulation, this was included in early hybrid artificial intelligence/simulation research (Elzas et al. 1989, Fishwick 1991).

The closest literature on education for objects can be found within museum culture and scholarship. Learning through objects (Turkle, 2007; MacGregor, 2011; Chatterjee & Hannan, 2015) is fundamentally different than learning through a discipline. Disciplines are typically vertically oriented. This verticality matches the intellectual architecture of school curricula and the physical buildings found at universities. Connections are made between disciplines, but the student's primary exposure to knowledge is by way of discipline rather than through personal experience. An object can be interpreted through a variety of lenses or disciplinary angles even though a museum may align itself with a particular one.

6 CONCLUSION AND FUTURE WORK

The goal of our work is to surface the richness of modeling through interaction with physical object such as the Inca tunic and the Jack sculpture. By using the technology of low-energy Bluetooth, one can tie a web URL to a small beacon which is placed next to the object. This URL then points to information to be conveyed to a person with a smartphone, while attending to the object. We posit that models of objects such as the tunic and sculpture represent unique interpretations of the object. Therefore, modeling is viewed as *a way of knowing the world* using a well-crafted modeling language with formal syntax. We are constructing a model to assist with informal learning, using objects. During the Fall 2015 class, where students made models of Jack, emphasis was placed on making the models easy to understand for a general university-level student in any area. Students also made models for six artworks in the ATEC building from a donated collection of art (Davidow 2016). We are fine-tuning the app, and designing analytics so that we may study how objects are used, and which model-related questions are of the most interest. We hypothesize that a guided path toward object and model discovery is ideal. This guidance would allow people using the smartphone app to learn about an object through a guide or a facilitator. We plan on including analytics with the app, so we are able to produce data on use. We would like to know which models and interpretations are found to be most useful. We are planning on opening up the model-based interpretation of physical objects by using a Wiki-based community approach, allowing shared archival knowledge to be surfaced by the app. The approach used to date was based on a coordinated web page, since students provided the model interpretations. For a more scalable solution, a collaborative editing method will be employed since contributors may be physically, and institutionally, distributed.

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