

On the Epistemological, Ontological, Teleological and Methodological Currents in Modeling and Simulation: An Overview

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ABSTRACT

Modeling and Simulation (M&S) has been used to solve problems, make decisions, and understand complex phenomena. Scholars have tried to understand and formulate the epistemic value of gained insights through models and simulations. Questions such as how insights are considered knowledge, what the tradeoff between perspectives and objectivity is, what kind of purpose models and simulations fulfill, and how M&S is used within a research methodology paradigm are a starting point of discussing the philosophical underpinnings. The epistemological, ontological, teleological and methodological (E/O/T/M) considerations of M&S is the main motivation of this paper. A comprehensive literature review on E/O/T/M considerations provides an initial roadmap to study the nature of M&S leading to the following questions: How can the authors define canons of research for M&S based on E/O/T/M? How can they define an E/O/T/M-based meta-model to characterize models and simulations? And how can the authors study validation of models and simulations based on E/O/T/M considerations?

Keywords: Epistemology, Knowledge, Modeling, Ontology, Philosophy, Simulation, Teleology

1. INTRODUCTION

Modeling and Simulation (M&S) has been used in various contexts; it has been considered to be a tool, a methodology, and a discipline. Pragmatically, the usefulness of insights obtained using

M&S applications cannot be denied. However, the increasing use of M&S in numerous disciplines, such as political science, meteorology, oceanography, economics, and healthcare, among others, calls for finding what common challenges and advantages exist across these disciplines. We suggest that one way of looking

DOI: 10.4018/jats.2013010101

at those commonalities is by looking at E/O/T/M foundations (premises and assumptions) of the use of M&S across disciplines.

From a high-level perspective, M&S uses models to represent a phenomenon of interest and simulates these models to gain insight or to predict. Gaining insight or prediction suggests that knowledge is generated from the modeling and/or simulation activity. This knowledge-generation activity has been under deliberation on questions such as: Can simulations generate knowledge? What kind of knowledge do simulations generate? Does simulation need its own epistemology? Although these are epistemological questions, they are not separate from ontological, methodological, and teleological issues regarding the modeler's perspective, approach, and intent. Frigg and Reiss (2009), for instance, argue that despite simulation creating parallel worlds on more ideal conditions than the "real world", this is not unique to simulation; ergo it does not warrant a new philosophy of science. Humphreys (2009), on the other hand, states that with the introduction of computational science new issues also have arisen within the discipline of philosophy of science, namely: epistemic opacity, semantics, temporal dynamics, and practice not principle. *Epistemic opacity* refers to cognitive agents' limited access to knowledge; *semantics* refers to how simulations are applied to real system given the detachment of simulations from reality, how computer simulations are limited by syntax of computer code, and how semantics are subsumed under that syntax; *temporal dynamics* refers to the temporal representations of dynamic processes involved in simulation is an essential element for philosophy of science in terms of the speed of prediction, as opposed to deduction; and finally *practice, not principle*, refers to how computational methods have forced researchers to differentiate between what is practically applicable, and what can only stay as principle.

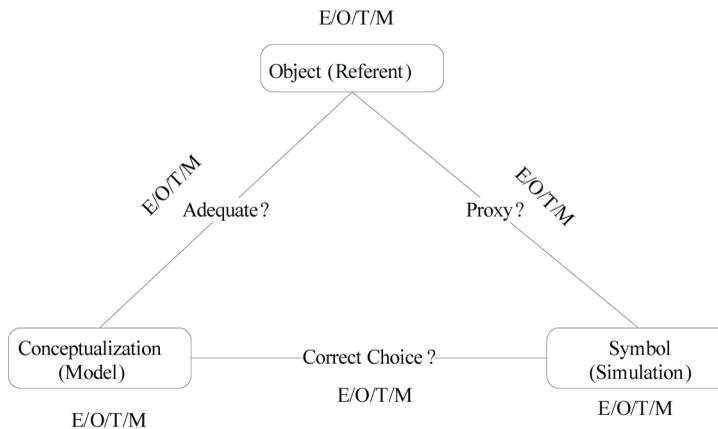
As it can be inferred, the gap between simulations and reality and how it is bridged in a manner that knowledge can be established has epistemological, ontological, method-

ological, and teleological implications. These implications include issues such as validation (Klein & Herskovitz, 2005), simulation model formulation and characterization (Lenhard, 2007), and ultimately, whether or not simulation generates and/or applies knowledge. In order to gain insight in these issues, we propose to look into how models and simulations can be characterized using E/O/T/M considerations. Turnitsa, Padilla, and Tolk (2010) have made an introduction into this proposition by overlapping E/O/T considerations with the *semiotic triangle* idea introduced by Ogden and Richards (1923). Their model is modified in this paper, as seen in Figure 1.

The following discussion also sets the grounds for the definitions of "object", "model" and "simulation", which will be used throughout the paper. The starting point of M&S is an object/phenomenon that can be real or imaginary. The *model* then becomes a *conceptualization of this object*. In other words, a model should capture the understanding of an object/referent/problem and facilitate its computer implementation. As such, a model can have many forms ranging from the informal to the formal: mental models, UML diagrams, ontologies, or mathematical equations. It is noted that the model does not have to be computable, but it should facilitate its computer implementation. This position is consistent with Robinson (2008) and Zeigler, Praehofer, and Kim (2000). This position of model as a conceptualization of an object/problem/ can also be traced back to Systems Science (Mitroff et al., 1974). In this instance, the model did not result in a simulation but in another model for which an analytical solution could be obtained.

The simulation is the computer implementation of the model (it is another model) and allows the study of a phenomenon overtime. As such, it has to be formal in nature in order to be executed in a computer. It is noted that we are referring to constructive simulations. There are simulations that are needed but are not computable. In those cases, live simulations are used. Assuming that the model is a representation of the object and the simulation

Figure 1. Semiotic triangle for M&S (Adapted from Turnitsa, Padilla and Tolk (2010))



a representation of the model; then the simulation is also a representation of the object. These definitions are consistent with those by Gilbert and Troitzsch (2005), where a model is defined as a simplification of a structure or system, or as a specification, and simulation is a different type of modeling, where instead of controlling the actual object, the focus of interest is on the model, rather than the phenomenon itself. It is noted that these are working definitions. If the reader is interested in formal definitions of these and other related terms please refer to Tolk et al (2013).

Notice that these definitions reflect Humphreys' issues when computational simulations are introduced, especially semantics. Semantics importance to M&S has been addressed by Zeigler, Praehofer, and Kim (2000) and Tolk, Turnitsa, and Diallo (2008) among others. The overall goal of semantics in M&S is to capture theories of a referent which can be represented using models whose syntactical representation is simulations. The difficulty of this semantics increases when different models/simulations need to be combined in order to solve questions individual models/simulations were no designed for. The semantics issue then is extended to how one simulation is interoperable to another and to which level; semantics being one of them (Tolk & Muguira, 2003).

Just like one differentiates object from model and simulation and establishes the processes of conceptualization, implementation, and adequateness, we need to establish that E/O/T/M issues take place at each state and process as they should not be overlooked or assumed. For instance, the ontological question for the object would be "what is reality?" During the conceptualization phase, whether the process is adequate or not and whether it captures and generates knowledge becomes an interesting epistemological/methodological discussion. For the model itself, an ontological question could be "What perspective is the model built upon?" and a teleological question could be "What is the purpose of the model?" Similar to the conceptualization phase, the simulation process prompts epistemological questions such as "what is the appropriateness of the process in reference to the modeling question?" The simulation also generates teleological questions similar to the model such as "what is the purpose of the simulation?" Finally, whether or not the simulation is a considerable proxy for the object, and how it generates knowledge, is another epistemological question. In other words, E/O/T/M issues take place at each state and process; they just need to be identified and made explicit as to better understand the model's philosophical DNA.

Since this paper is focused on providing an overview, one of the interesting results that emerged is that in the literature covered, philosophical discussions happen on different nodes of the semiotic triangle; i.e. an epistemological discussion may focus on the model, whereas another paper may suggest that epistemological issues are related to simulations. It is the purpose of this paper to provide an initial roadmap for E/O/T/M considerations and seek to clarify these positions for M&S.

2. EPISTEMOLOGY

According to Steup (2011), epistemology is the study of knowledge - concerned with questions related to the necessary and sufficient conditions of knowledge, its sources, its structure, and limits – and justified true belief – concerned with questions related to the concept of justification and if justification is internal or external to one's mind. These questions, in terms of M&S, are currently under debate by philosophers of science.

In the late 1950's, Helmer and Rescher (1959) were discussing the epistemology of "inexact sciences". According to them, the construction of a model and conducting of experiments ("pseudo-experiments") in the model is epistemologically significant. They have stated that applying simulation techniques seem to be a promising approach; indeed they have been proven right.

Part of the discussion when answering epistemological questions leads to how much researchers are able to study the system of interest through simulation; in other words, to what extent simulation can "reliably mimic" the real world. This may also corresponds to the three processes in the semiotic triangle; the conceptualization process (from object to model), the implementation process (from model to simulation), and the inference process (from simulation to the object). When discussing how and why knowledge is obtained, as well as the type and quality of knowledge that is obtained, the issue of validity is usually called

into question within the M&S world. Simulation modeling in any discipline will lead to certain results; there should be some standards as to measure the degree of reliability of these results (Winsberg, 1999). This is the reason Winsberg argues why simulation requires an epistemology. When used successfully, each of the techniques and methods used in simulation, such as choosing which parameters to include and what assumptions to make add reliability to the simulation (Winsberg, 2003).

Winsberg (2009) has set forth the question of the "nature of the epistemological relationship between the artifact and nature" (p. 576), addressing how simulations are epistemologically different from "experiments." He disputes the claim that traditional experiments have more epistemological power because they can tie the results back to the real world, thus establishing external validity. He states that computer simulations may establish stronger reliability and validity in some instances. Within simulations, the fact that the behaviors of the object and the target are very similar can be traced to different aspects of model building. In other words, the epistemic power of a computer simulation, according to Winsberg, will depend on the quality of the background knowledge and the ability of the researcher. It is, therefore, crucial to establish the strength of both the underlying theory behind the assumptions and the input parameters, and the capability of the researcher (or the modeler) in order to satisfy epistemic credibility of a simulation. Bolinska's definition of a model (or "vehicle") being an epistemic representation relies highly on two conditions: (1) the model has to be informative about the target system in question, and (2) the user should have the aim of faithfully representing a system, which depends on the previous knowledge of the user (Bolinska, 2012). The question of the user (or the modeler) will surface again when teleology is discussed later on.

The design of the model being accurate will depend on the verification process. According to North and Macal (2007, p. 222), verification is necessary from an operation and

implementation aspect, which makes sure that the model “performs the correct calculations according to its intended design and specification”. Balci (1997, p.1) defines verifying a model as “substantiating that the model is transformed from one form into another, as intended, with sufficient accuracy”. In other terms, it makes sure that the model is built right. According to Sargent’s definition (Sargent, 1999), verification of a model ensures that the computer program of the model and the implementations are running correctly. According to Sargent (1999), a simulation language is used within the computer programming, model verification makes sure that the simulation language is error free, has been properly implemented, and has been correctly programmed. The knowledge obtained from the model and the simulation of the model will greatly depend on how accurate the model is. The semiotic triangle suggests that the model should be an adequate conceptualization of the object, or the phenomenon being studied, and the correct way of simulation should be chosen according to the model. Following this, whether or not the simulation is a good proxy for the object itself should be studied. Adequate verification process ensures that all the initial premises, the assumptions and rules are captured in the model as intended. Unlike validation, the focus of verification is on ensuring that the model does what it is supposed to do; the “truth” of simulation results is beyond the scope of verification, but crucially impacted by accuracy of the process of verification.

When comparing experiments with simulations, inevitably the issue of validity is faced. In the natural sciences this is not a problem as simulation becomes an extension of experimentation. Simulation is used in order to reduce costs, have more experiments in a reduced timeframe, or reduce human risks. Mathematical models, with agreed upon variables and metrics that capture the phenomenon are now programmed in a computer and the computer provides that experimental environment. In the social sciences, on the other hand, models depend highly on proposed theories, there are no agreed upon mathematical models that

capture these phenomena, and variables are usually constructs or artificial variables that ‘facilitate’ measurement but convolute effects. In this sense, simulation in the social sciences is not an extension of reality, but seemingly the creation of a reality, which puts into question the idea of validity. The validity discussions have already been prevalent when comparing quantitative and qualitative research methods. It seems that now it has been extended to consider simulations.

Kuppers and Lenhard (2005), for instance, argue that validity (in the classical, traditional sense) is not an adequate measure in simulation applied to the social sciences. This lack of adequacy comes from different fronts. One is the issue of simplifications due to necessary abstractions. Bossel (1994), for instance, states that the construction of a model will always include simplifications, aggregations, omissions and abstractions, therefore further distancing the model from the actual phenomenon under consideration.

Another front posits the awareness of how truth is established using simulations. Schmid (2005) states that the application of the philosophical truth theories, namely correspondence, coherence, and consensus, enables the researcher to gain more insight and therefore acquire increased understanding on certain assumptions and parts of the simulation process. Instead of considering the adequacy, efficiency, or practicality of simulation, he states that discussing philosophical truth can offer a deeper epistemological discussion on simulation. Briefly, from a *correspondence theory of truth* perspective, a simulation model is true if and only if it corresponds to a matter of fact in reality; from the *coherence theory of truth* a simulation model is true if and only if it is a member of a coherent system of believes; and from a consensus¹ theory of truth, a simulation model is true if it is commonly agreed upon. The awareness of this differentiation is important because it allows us to establish validity in each perspective and identify the demands of validation that fall under each. The issue, however, is that simulation models, although

based on coherence via abstractions, seek to establish correspondence to phenomena. That connection of system of beliefs (notwithstanding the nature of those beliefs) to matter of facts is one of the points of contention in the epistemology of M&S.

Yet another perspective on the discussion of truth within M&S relates to the origin of acquired knowledge: Empiricism and Rationalism. Empiricism is the theory of knowledge which emphasizes those aspects of scientific knowledge that are closely related to *experience*, especially as formed through deliberate experimental arrangements; it is strongly tied to scientific method. Solem (2003) has defined the positivistic epistemological debate as consisting of hard knowledge, which is real and is capable of being transferred and transmitted in a tangible format. The use and application of M&S within disciplines such as natural sciences is through the empirical worldview, where the “real world” is a phenomenon that can be observed, and the results from M&S experiments can be empirically validated against that real world. The empirical attachment to the world that is modeled is sometimes emphasized in M&S. For instance, Bailer-Jones (2003) starts her paper by stating that “scientific models are *about* phenomena in the empirical world” (p. 59).

Rationalism, on the other hand, is the philosophical belief which asserts that the truth can be best discovered by reason and factual analysis. It is the epistemological theory that is based on the premise that significant knowledge of the world can best be achieved by a priori means; therefore it is in contrast with empiricism. Rationalistic epistemology is characterized mainly by a deductive process of argumentation, that all knowledge could be derived deductively. The rationalists agree that knowledge may come from (physical) experience; however they disagree with empiricists in the fact that it *must* (Haserot, 1947).

One could argue that M&S, in most cases, is an empirical-rationalist activity where one tries to capture a phenomenon from reality in a conceptualization that can be computer implemented in order to facilitate not only the

inductive inference from data but also the deduction of new insights. Consider an ontology (computer artifact) for instance. An ontology can capture what is known and/or assumed about a phenomenon of interest and use this information to deduce new information using first order logic. This deductive process from a model does not require a computer implementation, but it can be used as a formal conceptual model to facilitate the computer implementation from which data is generated. This empirical-rationalist perspective of M&S is consistent with Axelrod’s (1997, p. 3-4) agent-based modeling (ABM) categorization of the third way of doing science:

Like deduction, it starts with a set of explicit assumptions. But unlike deduction, it does not prove theorems. Instead, an agent based model generates simulated data that can be analyzed inductively. Unlike typical induction, however, the simulated data come from a rigorously specified set of rules rather than direct measurement of the real world.

It is noted that simulations do not need to correspond to observable phenomena. Researchers can build models and simulations that suggest how phenomena take place and gain insight about them. Cognitive architectures, for instance, are theories about how the brain works that can be implemented in simulations. They are based on empirical research, but not fully, as the mechanisms of how the brain works are not completely known. This is consistent with Krohs (2008) who argues that a correlation need not exist between the simulation and the real (“material”) system, like engineering where simulations are conducted for the purposes of testing and improving design of systems.

3. ONTOLOGY

Ontology, in a very simplified sense, deals with the nature of things. Smith (2003) provides a concise definition of what an ontology is: “Ontology as a branch of philosophy is the science

of what is, of the kinds and structures of objects, properties, events, processes and relations in every area of reality” (p. 1). Therefore, as Solem (2003) puts it, ontology is “our picture of how the world looks; our worldview” (p. 439).

There are different views as to what it is for an item to be accepted into ontology. For some, it is merely a matter of existence or being; for others, it is a matter of real existence or being, where this is something that stands in contrast to ordinary existence or being (Fine 1991). Fine further elaborates that an item is accepted into ontology because it should be there, not because someone put it there; ontology is total; it includes everything that is accepted; ontology is actual; it includes everything that is correct to accept.

There have been different attempts at categorizing ontological currents. Klemke (1960), for instance, discusses a phenomenalist philosophy, which includes the particulars/universals ontological discussion. He defines *universal* as “the repeatable character, whose instances are commonly called qualities of individuals or relations among individuals; hence, that which is never wholly contained in any one presentation, unless it exists only in that one presentation (which could never be known with certainty to be the case)” and *individual* as “that about which a quality or qualities may be predicated, or that which may stand in a relation to other individuals” (p. 256). From an empiricist stance, he states that an individual cannot perceive or sense or directly know the universals. If the universals exist, then for the individual to have any information or knowledge about them, there should be another way other than direct acquaintance.

Another account is that of *subjective/objective* perspectives. Solem (2003), modifying the concepts that were discussed in Morgan and Smircich (1980), discusses these two ontological positions as *Realism* and *Nominalism*. Realism is the school of thought in which reality is defined as being external to the individual; it is objective by nature, and is “out there”, which means that the individual can reach the reality that is outside him or herself. Reality defined by the realists is a hard and concrete structure.

Nominalism, on the other hand, advocates that reality is produced by the consciousness of the individual, that it is a product of one’s own mind, and is therefore subjective by nature.

In an ontological classification by Becker, Niehaves, and Klose (2005), the relationship between the researcher and the place of cognition is under consideration. If the real world is assumed to be independent of cognition, of thought and speech, then the ontological position is realism, or objective. If the researcher chooses to define reality through the cognitive lenses of one, then the ontological position is one of idealism, or subjective. Giere’s view that the modeler is representing the real world and not the model is closer to subjective ontology, where the scientist is a part of the world that is being modeled. A similar argument is also made by Bailor-Jones (2003), where the focus is on the model *user*; it is noted that only through these users the model and different aspects of the model are under consideration. Giere (2004) further elaborates on this point by taking a realist approach to modeling, in discussing that what ordinary human beings can and cannot observe is not an important issue; the important issue is whether they can “observe enough to practice science” (p. 750). As it can be noted, epistemology and ontology rely on one another in order to study the nature of knowledge based on our position of what is. Knowledge and the position in which knowledge is generated and/or valid are of crucial importance in M&S.

In M&S, all models are considered to be abstractions of reality. Gilbert and Troitzsch (2005) have stated that building a model entails the researcher to understand the world. A model is defined by them as “a simplification—smaller, less detailed, less complex, or all of these together—of some other structure or system” (p. 2). The nature of these abstractions is important as some scholars account for an agreed upon abstraction, while others consider them conceptualizations subsumed to the perspective of a modeler generating different accounts of the same referent. In that sense, the position of ontological assumptions in M&S are consistent with the subjective/

objective argument; assumptions are placed in the context of what the *real world* is, and the relationship between the *modeler* and the *model*. Therefore, how a *model* is defined and the link between objective, observable reality and the represented reality is a starting point of ontological discussions. Further, in a realist/nominalist perspective, models can be seen as their own realities which we try to reconcile with the “real” reality through validation.

Offering another perspective when looking at how scientists use models to represent aspects of the real world, Giere (2004) argues that the model is not in itself a representation; the scientist using the model is in fact doing the representing, i.e. the modeler is responsible of how the model is formed with respect to what is being modeled. Through use of existing similarities to the real system, it is made possible that the model can be used to represent a real world. This view is also present in studies conducted by Parker (2009) and more recently, Maki (2011). The justification of inferences from results of experiments to conclusions about the target system should be done by analyzing whether the model and the target system are similar to each other (Parker 2009). Maki also reiterates this point when arguing that since models represent target systems, the “resemblance aspect” between the surrogate and target system will define the adequacy of the model functions. Giere (2004) also uses the notion of *similarities* to explain the relationship between the model and the aspect of the world the model is being used to represent. Due to the existence of these similarities, the simulation model can be used for the purposes of representing a particular reality. The model being similar to, or resembling, reality, also brings forward the argument of non-similarities; i.e. what happens when the model is not similar to what is being modeled? Even when there are “falsities”, insights can still be gained. Zagzebski (2001) noted this issue, stating that from falsities we arrive at insight. Since simulations are abstractions, they are also falsities (in the empirical sense), that can also create insight.

4. TELEOLOGY

Teleology is an area of philosophy which explains the future in terms of the past and the present based upon the study of purpose, ends, goals and final causes. Historically the term “teleology” has been subject to considerable ambiguity, being used within three contexts (Weber & Rapaport, 1941):

The first may be called the descriptive sense in which the term is regarded as synonymous with purposive or having a purpose. It is used to describe a common mental attitude in which some plan is projected for the future. In the second sense, the term is taken to mean that the goal or end towards which a process is directed is itself a determinant of the process. The third sense, which may be called the metaphysical sense, is nothing more than a systematic extension of this same principle to the entire universe. Reality is conceived to be a hierarchy of ends, exhibiting varying degrees of systematic completeness and tending toward a single end, which thus to the extent to which all other things are instruments in its service determines their existence and character (p. 70)

Stacey et al. (2000) poses a similar framework with two components: The assumption of what the future looks like (known state or unknown state), and the reason for movement into the future. The reason for movement is in itself divided into five perspectives: The *Natural Law Teleology*, in which the future is a repetition of the past, and the purpose of movement or change is to sustain an optimum state, and there is no self-organization; the *Rationalist Teleology*, in which there is a chosen goal in the future, and the movement is towards realizing that goal, however, similarly to Natural Law Teleology, self-organization does not exist. The decision maker points to the chosen goals, and designs a system of rules and procedures to achieve them. In *Formative Teleology*, there is an implication towards a form of self-organization, though without significant

transformation; the final state (or the future) can be known in advance, and the movement is to realize or sustain a final form which is already there. In the *Transformative Teleology*, the future is unknowable yet recognizable; an iterative process sustains continuity. Finally, the *Adaptionist Teleology* is different than all others in a way that the environment is a part of the teleology; adaptation to an environment which may change in unknowable ways is the base of the teleology. Since simulation is the implementation of the model, and most of the time a temporal component is also involved in the simulation, the idea of the state of the future, the goals, and movement towards those goals becomes important. From the semiotic triangle, it can be seen that teleology relates to the purpose of the conceptualization, and also the purpose of the simulation. Within the teleological perspective, the questions “Why are we modeling?” and “Why are we simulating?” should be answered.

Perlman (2004), in his efforts to develop a taxonomy of teleological theories, has noted that since teleology has been included in various fields, it becomes difficult to establish a full grasp of the relevant teleology literature, which may be the reason why many theories on teleology have been proposed yet not completed. Purpose can be related to active behavior (Rosenbueth et al., 1943) towards the attainment of a goal. Given that teleology is purposive and goal oriented (Weber & Rapaport, 1941; Rosenbueth et al., 1943), purposeful active behavior represents the inherent sense of teleology. However, Rosenbueth et al. (1943) goes a bit further to define the concept; a teleology is based on feed-back to be predictive (extrapolative) and non-predictive (non-extrapolative). This predictive vs. non-predictive classification will be the starting point of teleological assumptions within M&S. According to the spectrum constructed by Bridewell and Langley (2010), theory-driven (analytical) models are at opposite ends with data-driven (inductive) approaches. They note that purely descriptive

models can be built from data, but in terms of variable selection and data collection, theoretical constraints are still valid.

Simulations, as Weirich (2011) notes, have many purposes since they are very diverse. The teleological assumptions in this case will start with answering the question what is the purpose of M&S. Bossel (1994) provides two main perspectives on the reasons why simulation is used. The first is *description of behavior*. This particular simulation model consists of an output that is a function of some input, which can be mathematical equations. This type of simulation can be considered to be a black box, where only the inputs and the outputs can be observed. What happens within the box, “how” the inputs turn into the outputs cannot be observed; therefore insight gained from this process is limited. This is similar to the *predictive* purpose of simulation, as discussed by Gilbert and Troitzsch (2005). This is useful if a model that faithfully reproduces the dynamics of some behavior is successfully developed, then the passing of time can be simulated, and thus the model can be used to ‘look into the future’. So the idea of the state of the future discussed above is applied to both the modeling and the simulation aspect by Gilbert and Troitzsch. According to Feinstein and Cannon (2003), simulation models either represent preexisting systems, or systems that are under consideration. In order to use simulation for the purposes of assessing the characteristics of a real-world situation, the model should effectively replicate the system. Once this replication is in place, however, Feinstein and Cannon start discussing the issue of how to make sure this replication correctly represents the real world. So the teleological discussion leads to an epistemological one. The relationship between the model and the process of simulation is also under consideration. Even when there is no analytical solution to be obtained from a theoretical model, the goal of running simulations is to predict the behavior of a system (Krohs, 2008). Models that are useful in making predictions are defined as *phenom-*

enological models by Bokulich (2011), and are constructed through empirical data. These models only possess “instrumental value”, according to Bokulich, and do not provide genuine insight into the real world.

The second perspective on why simulations are used is *explanation of behavior*. This simulation model is conducted for the purpose of modeling actual processes. Questions such as “what parts?”, “how are they connected?”, “how do they influence each other?” can be answered. The box in this case can be similar to a glass box, or an opaque box. The main purpose of explanatory models, Bokulich (2011) argues, is to provide insight into the world that is being analyzed. This purpose is similar to what Gilbert and Troitzsch (2005) call *understanding*. Simulations of this purpose help researchers obtain a better understanding of some features of the social world, as well as the relationship between the ‘micro’ level, which represents the attributes and behavior of individuals, and the ‘macro’ level, which is a representation of the properties of social groups. Together with investigation of emergence, this understanding is amplified. The different kinds of explanations (specifically for Agent-Based Modeling) have been recently discussed in Elsenbroich (2012), with the conclusion being that a mechanistic explanation (where no causality is established) as opposed to functional or partially causal explanations is sufficient for studying social sciences. The explanatory powers of simulations have also been discussed by Weirich (2011); he notes that simulations with the purpose of explaining a natural phenomenon will use a dynamic model of the natural system of interest. The relationship between the model and the simulation becomes more apparent in Weirich’s study; he states that the model has to be explanatory in order for the simulation to be explanatory. He states that the model’s assumptions are “inherited” by the simulation as well. Therefore, the epistemological link between the model and the simulation in the semiotic triangle (“Is the simulation used for this model a correct one?”) is further intertwined with the teleological arguments.

The questions of where the target system will be in the future, why the system behaves in a particular manner, how certain conditions would affect the behavior of the system, are all questions that a computer simulation model intends to answer (Parker, 2008). In order to ensure that any one of the purposes of simulation is achieved, the issue of validity should be discussed. When discussing the models and whether they are true, or contain any truth, Maki (2001) suggests that in addition to the *resemblance* aspect discussed previously, we also should look at the pragmatic aspects; which contains the notion of *usefulness with respect to a purpose*. According to Maki’s discussion, a model is said to be true if it is successful in serving a specific purpose. Sargent (1999) establishes a direct link between teleological assumptions and validity when he states that developing a model should be based on a specific purpose, and the validity of that model needs to be considered with respect to that purpose. Bossel (1994) had argued the same point when he stated that a simulation model cannot be discussed in terms of its *correctness* but only in terms of its validity with respect to the model purpose. The simulation should be valid, so that the researchers can be sure of its accuracy and soundness. Parker (2008) defines the activity of discovering how adequate the target system is represented by the computer simulation, with respect to the goals of the modeling study, as *model evaluation*, and equates this definition with validity. This teleological perspective results in four types of validity according to Bossel (1994). *Behavioral validity*, in which the model system produces the same dynamic behavior as the original system under the same initial conditions and exogenous influences as the original system; *structural validity*, where the influence structure of the model corresponds within the constraints of the model purpose to the essential influence structure of the original; *empirical validity*, where the results obtained from the model need to correspond to the empirical results from the original system under the same conditions, and *application validity*, in which the model and its simulation capabilities correspond

to the model purpose and the requirements of the model user. Application validity is similar to Maki's (2001) suggestion discussed above, that models should be considered with respect to their purpose. What Bossel adds to this idea is the model user. The logical assumption would be that the user is the one conceptualizing the model; therefore the purpose of the model is the same as the purpose of the user. However, this may not necessarily be the case. Going back to the semiotic triangle, the starting point is always the object (referent) under study. The user wanting to study this object may be different than the user wanting to study the model. Furthermore, the actual modeler can be different from the person studying the model. Therefore, the assumptions and the purpose of the user may be different at each corner of the triangle.

The discussion of validity also merges the epistemological currents together with the teleological currents. Schmid (2005) defines rational validation of a model if the model is true due to its membership of a coherent system of beliefs, in this sense a simulation must be consistent and non-contradictory in that system of beliefs. Schmid says that a model may be wrong in what regards to its correspondence with reality, but truth using coherence if it satisfies its subjective purpose. He presented two concepts in validation, *specific purpose* and *sufficient accuracy*; a model can be valid from one perspective (serves its purpose), but inaccurate on the other (lack of empirical data). In this case, the model is accurate and true (ergo valid) from the viewpoint of coherence while invalid from the viewpoint of correspondence.

Making assumptions and designing the model in form of a computer program is one of the stages of simulation-based research (Gilbert & Troitzsch, 2005). It becomes increasingly difficult to decide what to leave out and what to include, especially when what is being modeled is a complex phenomenon. The more that is left out, the greater the conceptual leap required between the conclusions drawn from the model and interpretations in relation to the target. The more that is put in, the more precisely the parameters have to be measured or

assumed, each have effect in validity. Axelrod (1997) in Gilbert and Troitzsch (2005, p. 19) has noted that "accuracy is important when aim is prediction; simplicity is an advantage if the aim is understanding". Therefore, the teleological assumptions will lead to epistemological decisions the researcher has to make.

5. METHODOLOGY

Methodology, unlike epistemology, ontology or teleology, does not initially seem like it is part of a philosophical discussion because of its common, daily use. However, the older meaning of the word, as Marney and Tarbert (2000) state is "a philosophical discourse on method" (pg. 1), and should be considered as the fourth underlying theme within the philosophical underpinnings of M&S. The main purpose of a methodology is to provide a solid foundation so that a robust research method can be developed. In any research, the overall research paradigm and the research approach should set the grounds for a research methodology, which is then followed by a detailed research method. It is important to establish the boundaries of the research methodology that is going to be adapted in any study, so that proper guidelines can be presented. This serves two main objectives. The first objective is to establish *repeatability* and *traceability* of research. It is the duty of the researcher to layout the specific steps taken in order to establish methodological repeatability. The second objective of the research methodology serves a more high-level purpose, which is to introduce a more formalized approach for the research method. Within this research hierarchy, M&S can be used in different manners.

Axelrod (1997) has stated that simulation is "a new way of conducting scientific research" (p. 17). In addition to induction and deduction, he states that simulation is the *third research methodology*. Similar to deduction, the starting point of simulation is a set of explicit assumptions. However, instead of proving a theorem, data is generated through simulation that can be *analyzed inductively*. This property provides

the simulation with the characteristic of aiding intuition and understanding. Gilbert and Terna (2000) note that the reason why social sciences have not benefitted enough from computer simulation as a methodological approach may be that the main value of simulation in the social sciences is for theory development rather than for prediction. As Gilbert and Troitzsch (2005) have stated, building a model entails the researcher to understand the world.

As discussed in the Teleological currents, M&S will serve different purposes, from prediction to explaining behavior, from understanding to repetition of behavior. According to Gilbert and Troitzsch (2005), there are three main uses of simulation: (1) *Understanding*, where simulation helps researchers obtain a better understanding of some features of the social world, as well as the relationship between the 'micro' level, which represents the attributes and behavior of individuals, and the 'macro' level, which is a representation of the properties of social groups. Together with investigation of emergence, this understanding is amplified. (2) *Prediction*, where if a model that faithfully reproduces the dynamics of some behavior can be developed, then the passing of time can be simulated, and thus the model can be used to 'look into the future'. (3) *Substitution*, in which simulation can be used to develop new tools to *substitute* for human capabilities. For instance, expert systems simulation can be used by non-experts to carry out diagnoses. In all three uses, both models and simulations are used as part of the definitions. The reason for this "mixed" approach may be because methodology, by its nature, is a more comprehensive and inclusive concept. Therefore, in this section, we look at methodological uses of M&S as a discipline, and not "models" and "simulations" separately.

How M&S is used methodologically, and the type of knowledge and the way this knowledge is acquired will be different according to different purposes, as discussed above. This connects the Epistemological, Teleological and Methodological currents.

One of the major methodological perspectives is using simulation to develop theory. Bertrand and Fransoo (2002), Davis, Eisenhardt, and Bingham (2007), and Diallo, Padilla, Bozkurt, and Tolk (2012) among others have proposed methodologies for the use of simulation in theory development. These methodologies have different departing points and assumptions, but they are focused on generating new knowledge through simulations. Bleda and Shackley (2012) captures best the combined 'complexity' of these methodologies in their study of modeling risk perceptions using systems dynamics. Their methodology transforms theoretical approaches into a formal model, especially in the case of no or very little empirical data. They do state the limitations of empirical validity and calibration due to lack of empirical data; however they also state that this does not prevent researchers from gaining understanding about the phenomenon at hand. The theory development approach is one of the main threads of methodological currents.

M&S, used as a methodology, significantly varies according to the context of the research. For instance, within Operations Research (OR), real-life operational processes are explained, cause and effect analysis is conducted, and empirical data is validated. A common example of computer simulation within OR is testing heuristic methods to solve combinatorial optimization problems (Bertrand & Fransoo, 2002). This brings the focus of the research methodology into an objective reality where epistemic certainty is dominant. When dealing with social sciences, the level of epistemic uncertainty increases as problems and phenomena under consideration become more complex. For every study that emphasizes empirical grounding within social sciences (see Boero & Squazzoni, 2005), there can be found another study that offers alternative solutions (see Windrum et al., 2007).

Within social sciences, the lack of empirical data, lack of decomposable systems and presence of *wickedness* encourage and necessitate

the use of M&S in a different structure. Sousa-Poza, Padilla, & Bozkurt (2008) proposed a rationalist/inductive methodology to deal with these wicked issues. Their methodology consists of building premises from generalizations made in the first step and putting these premises together in a coherent system. This coherence is given structure and formalization via M&S. The *coherence theory of truth* was discussed previously in the Epistemology section. This is further evidence on how methodology and epistemology are connected to each other; what type of knowledge is being obtained is directly related to how that knowledge is reached. Within the rationalist/inductive methodology, Sousa-Poza, Padilla and Bozkurt have proposed that the strength of the methodology lies in its traceability. In this sense, traceability results by the linkage of the resulting theory (generated via M&S) to the originating systems of premises and because these premises are derived from theories of real phenomena, the model/simulation is considered to be a good explanation of phenomena.

Shifting the discussion from general use of M&S within different research methodologies, to the particular methodologies, it is important to note that within the Semiotic M&S triangle, Methodology is present in all three nodes (Referent, Model and Simulation), and the three links (whether the model is an adequate representation of the referent, whether the correct choice of simulation was made, and whether the simulation was an adequate proxy for the referent). "How" each of these processes are conducted, i.e. the methodology, will significantly impact the results obtained in studying the subject at hand.

6. DISCUSSION

The E/O/T/M issues discussed in this paper have been studied within the context of M&S for some time, across many disciplines. The main purpose of providing an overview of available literature in these four topics is to emphasize

the growing necessity of considering them when using M&S in research or researching about M&S.

Within considerations about the actual system of interest (the "object"), all four philosophical arguments bring forth valid questions. Epistemological discussions should be on what is currently known/assumed, and what is true about the object. Ontological discussions will consist of how what is known should be framed and from what perspective the researcher looks at the object. As for teleological discussions, what the purpose of the object is, why it exists, and why the researcher is studying it should be asked. In all three discussions, it can be seen that the personal predisposition of the researcher plays an active role. From the methodological aspect, the question can be on how the researcher knows what he/she knows about the actual system.

When it comes to the conceptualization (the "model"), the four E/O/T/M considerations remain, but the focus of the questions now change. Epistemological discussions can be split into two parts: one looking at what knowledge from reality is captured in the model and a second that considers what new knowledge is obtained from the model (and if it is indeed knowledge). In other words, while one side considers the model as subsumed from reality the other seems to consider a reality subsumed to the model as the model (and corresponding simulation and its results) is applicable to 'a' reality that hopefully matches the 'real' reality. Ontological arguments ask what perspective of reality the model captures and how the model is similar/different from the object it represents. The assumptions and the simplifications that were made to construct the model should also be considered here, since through these assumptions the model is being brought to reality. Teleological questions will include what the purpose of the model is, why there is a model in the first place, and why that particular model. It can be seen that the last question is also related to the process of conceptualization, i.e. the

link between the object and the model, instead of focusing merely on the model itself. From a methodological standpoint, how the model was developed, and how the model works will be important. Because simulations are models, E/O/T/M considerations of models apply to simulations as well.

There are three main discussion points that are crucial in tying together the threads discussed above: Defining canons of research, a philosophy of science-based framework, and the process of validation. The canons of research dictate that every research should begin with a specific paradigm, and everything else within the research (methodology, tools and techniques chosen, etc.) should be based on this paradigm; this can also be called the research philosophy. This overall research philosophy should dictate the specific canons that the research is based on. Certain disciplines (or methodologies) may come with established canons; e.g. if research is positivistic, validation is empirical. While useful and necessary for rigor of research, these canons contain two major traps: (1) each researcher may have a different idea on what these canons mean, i.e. no standard definition; and (2) certain canons come with their own historical baggage, i.e. validation is associated with “empirical” validation. For modeling and simulation, Sargent (1999) describes sixteen different validation techniques that include internal validation, face validation, traces, parameter variability, sensitivity analysis, predictive validation, and historical data validation, among others. As such, a discussion of canons of research for M&S is needed as we mostly rely on extensions of quantitative and qualitative research methods that vary by discipline. These extensions, it can be said, are valid if one considers M&S a set of techniques that enhances a person’s research in a particular field. However, if one considers M&S a discipline on its own that, like statistics, can be used by many disciplines, we need to understand its nature and one way to start can be by exploring if it requires unique canons of research or a unique specification. M&S, as a discipline, should be domain-independent, so that it can be used by all fields and in all types

of studies without any issues arising as to what a particular researcher meant when he/she used the term “validity”, etc.

Another reason of considering E/O/T/M together is to be able to categorize models. Usually, philosophical considerations are limited to epistemological, or epistemological and ontological issues at most. By including teleology and methodology, a framework could be developed that researchers can ‘catalog’ their models in terms of these four arguments; i.e. the model and the simulation of that model can be defined in terms of its empirical, objectivity, predictive, and experimentation-through-simulation or empirical, subjective, explanatory, system-of-premises leanings/assumptions among others.

Lastly, it has been suggested in this paper that along validation, areas such as modeling, as a form of conceptualizing an object/phenomenon and as a form of architecting a simulation, and simulating, as creating a corresponding computer implementation to a model, are major issues in M&S. They are intertwined, either because of convenience or practice, and they need to be untangled in order to provide better E/O/T/M insights. In the philosophy of science and M&S literatures strong emphasis is put into the validity of models/simulations and validation processes. Further, it seems like everyone has an answer that fails to address other people’s questions. However, reaching a consensus on validity/validation without E/O/T/M considerations at each node and link in the semiotic triangle will prove a major and perhaps unsolvable challenge.

7. CONCLUSION

The main purpose of this paper was to present a literature review within the boundaries of the following philosophical issues: epistemological, ontological, teleological, and methodological. Presenting these arguments with respect to the semiotic triangle gave us a way of scoping and organizing the literature available on the topics mentioned.

Discussing the object, the model, and the symbol (the nodes of the triangle), and the process of conceptualization (from object to model), the process of simulation (from model to symbol), and the inference (from symbol to object) from the perspective of E/O/T/M gave us a discipline-independent, and tool-independent map of M&S. Further elaboration on these issues, and the development of a formal framework that may provide the basis of better understanding on how M&S is used in research, and research on M&S itself.

REFERENCES

- Axelrod, R. (1997). *The complexity of cooperation: Agent-based models of competition and collaboration*. Princeton, NJ: Princeton University Press.
- Axelrod, R. (1997). Advancing the art of simulation in the social sciences. In R. Conte, R. Hegselmann, & P. Terna (Eds.), *Simulating social phenomena* (pp. 21–40). Berlin, Germany: Springer-Verlag.
- Bailer-Jones, D. M. (2003). When scientific models represent. *International Studies in the Philosophy of Science*, 17, 59–74. doi:10.1080/02698590305238.
- Balci, O. (1997). Verification, validation and accreditation of simulation models. In S. Andradottir, K. J. Healy, D. H. Withers and B. L. Nelson (Eds.), *Proceedings of the 1997 Winter Simulation Conference* (pp. 135-141).
- Bealer, G. (1999) A theory of the a priori. *Nous*, 33(Supplement: Philosophical Perspectives, Epistemology), 29-55.
- Becker, J., Niehaves, B., & Klose, K. (2005) A framework for epistemological perspectives on simulation. *Journal of Artificial Societies and Social Simulation*, 8(4). Retrieved March 1, 2012, from <http://jasss.soc.surrey.ac.uk/8/4/1.html>
- Bertrand, J. W. M., & Fransoo, J. C. (2002). Operations management research methodologies using quantitative modeling. *International Journal of Operations & Production Management*, 22, 241–264. doi:10.1108/01443570210414338.
- Bleda, M., & Shackley, S. (2012). Simulation modeling as a theory building tool: The formation of risk perceptions. *Journal of Artificial Societies and Social Simulation*, 15(2), 1–25.
- Boero, R., & Squazzoni, F. (2005). Does empirical embeddedness matter? Methodological issues on agent-based models for analytical social science. *Journal of Artificial Societies and Social Simulation*. Retrieved March 1, 2012 from <http://jasss.soc.surrey.ac.uk/8/4/6.html>
- Bokulich, A. (2011). How scientific models can explain. *Synthese*, 180, 33–45. doi:10.1007/s11229-009-9565-1.
- Bolinska, A. (2012). Epistemic representation, informativeness and the aim of faithful representation. *Synthese*. doi:doi:10.1007/s11229-012-0143-6 PMID:23426094.
- Bossel, H. (1994). *Modeling and simulation*. A K Peters, Ltd.
- Bridewell, W., & Langley, P. (2010). Two kinds of knowledge in scientific discovery. *Topics in Cognitive Science*, 2, 36–52. doi:10.1111/j.1756-8765.2009.01050.x.
- Churchman, C. W., & Ackoff, R. L. (1950). *Methods of inquiry: An introduction to philosophy and scientific method*. St. Louis, MO: Educational Publishers.
- Davis, J., Eisenhardt, K., & Bingham, C. (2007). Developing theory through simulation methods. *Academy of Management Review*, 32, 480–499. doi:10.5465/AMR.2007.24351453.
- Diallo, S., Padilla, J., Bozkurt, I., & Tolk, A. (2012). Modeling and simulation as a theory building paradigm. In A. Tolk (Ed.), *Ontology, epistemology, and teleology of modeling and simulation - Philosophical Foundations for Intelligent M&S Applications*. Springer Publishing.
- Elsenbroich, C. (2012). Explanation in agent-based modeling: Functions, causality or mechanisms? *Journal of Artificial Societies and Social Simulation*, 15(3), 1–9.
- Feinstein, A. H., & Cannon, H. M. (2003). A hermeneutical approach to external validation of simulation models. *Simulation & Gaming*, 34, 186–197. doi:10.1177/1046878103034002002.
- Fine, K. (1991). The study of ontology. *Noûs (Detroit, Mich.)*, 25, 263–294. doi:10.2307/2215504.
- Frigg, R., & Reiss, J. (2009). The philosophy of simulation: Hot new issue or same old stew? *Synthese*, 169, 593–613. doi:10.1007/s11229-008-9438-z.
- Giere, R. N. (2004). How models are used to represent reality. In *Proceedings of the 2002 Biennial Meeting of the Philosophy of Science Association Part II: Symposia* (pp. 742-752).

- Gilbert, N., & Troitzsch, K. G. (2005). *Simulation for the social scientist* (2nd ed.). Buckingham, UK: Open University Press.
- Harrison, J. R., Lin, Z., Carroll, G. R., & Carley, K. M. (2007). Simulation modeling in organizational and management research. *Academy of Management Review*, 32, 1229–1245. doi:10.5465/AMR.2007.26586485.
- Haserot, F. S. (1947). The meaning of rationalism. *The Journal of Philosophy*, 44, 205–216. doi:10.2307/2019571.
- Helmer, O., & Rescher, N. (1959). On the epistemology of the inexact sciences. *Management Science*, 6, 25–52. doi:10.1287/mnsc.6.1.25.
- Hochberg, H. (1965). On being and being presented. *Philosophy of Science*, 32, 123–136. doi:10.1086/288032.
- Hofer, B. K. (2002). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, 13, 353–383. doi:10.1023/A:1011965830686.
- Humphreys, P. (2009). The philosophical novelty of computer simulation methods. *Synthese*, 169, 615–626. doi:10.1007/s11229-008-9435-2.
- Kakol, P. (2002). A general theory of worldviews based on Maghyamika and process philosophies. *Philosophy East & West*, 52, 207–223. doi:10.1353/pew.2002.0027.
- Klein, E. E., & Herskovitz, P. J. (2005). Philosophical foundations of computer simulation validation. *Simulation & Gaming*, 36, 303–329. doi:10.1177/1046878104273437.
- Klemke, E. D. (1960). Universals and particulars in phenomenalist ontology. *Philosophy of Science*, 27, 254–261. doi:10.1086/287744.
- Krohs, U. (2008). How digital computer simulations explain real-world processes. *International Studies in the Philosophy of Science*, 22, 277–292. doi:10.1080/02698590802567324.
- Kuppers, G., & Lenhard, J. (2005). Validation of simulation: Patterns in the social and natural sciences. *Journal of Artificial Societies and Social Simulation*, 8(4), 1–13.
- Lenhard, J. (2007). Computer simulation: The cooperation between experimenting and modeling. *Philosophy of Science*, 74, 176–194. doi:10.1086/519029.
- Maki, U. (2011). Models and the locus of their truth. *Synthese*, 180, 47–63. doi:10.1007/s11229-009-9566-0.
- Marney, J. P., & Tarbert, H. F. E. (2000). Why do simulation? Towards a working epistemology for practitioners of the dark arts. *Journal of Artificial Societies and Social Simulation*, 3(4). Retrieved March 2, 2012 from <http://jasss.soc.surrey.ac.uk/3/4/4.html>
- Mitroff, I., Betz, F., Pondy, L., & Sagasti, F. (1974). On managing in the systems age: Two schemas for the study of science as a whole systems phenomenon. *Interfaces*, 4(3), 46–58. doi:10.1287/inte.4.3.46.
- Morgan, G., & Smircich, L. (1980). The case for qualitative research. *Academy of Management Review*, 5, 491–500.
- Moss, S., & Edmonds, B. (2005). Towards good social science. *Journal of Artificial Societies and Social Simulation*, 8.
- Nonaka, S., & Takeuchi, N. (1995). *The knowledge-creating company. How Japanese companies create the dynamics of innovation*. Oxford, UK: Oxford University Press.
- North, M. J., & Macal, C. M. (2007). *Managing business complexity: Discovering strategic solutions with agent-based modeling and simulation*. Oxford, UK: Oxford University Press.
- Ogden, C. K., & Richards, I. A. (1923). *The meaning of meaning* (8th ed.). New York, NY: Brace & World, Inc..
- Parker, W. S. (2008). Franklin Holmes and the epistemology of computer simulation. *International Studies in the Philosophy of Science*, 22, 165–183. doi:10.1080/02698590802496722.
- Parker, W. S. (2009). Does matter really matter? Computer simulations experiments and materiality. *Synthese*, 169, 483–496. doi:10.1007/s11229-008-9434-3.
- Perlman, M. (2004). The modern philosophical resurrection of teleology. *The Monist*, 87, 3–51. doi:10.5840/monist20048711.
- Rescher, N. (1996). *Process metaphysics: An introduction to process philosophy*. Albany, NY: State University of New York Press.
- Robinson, S. (2008). Conceptual modeling for simulation Part I: Definition and requirements. *The Journal of the Operational Research Society*, 59, 278–290. doi:10.1057/palgrave.jors.2602368.

- Romer, H. (2006). Complementarity of process and substance. *Mind and Matter*, 4, 69–89.
- Rosenblueth, A., Wiener, N., & Bigelow, J. (1943). Behavior, purpose and teleology. *Philosophy of Science*, 10, 18–24. doi:10.1086/286788.
- Sargent, R. G. (1999). Validation and verification of simulation models. In P. A. Farrington, H. B. Nemhard, D. T. Sturrock, G. W. Evans (Eds.), *Proceedings of the 1999 Winter Simulation Conference* (pp. 39-48).
- Schlimm, D. (2009). Learning from the existence of models: On psychic machines, tortoises, and computer simulations. *Synthese*, 169, 521–538. doi:10.1007/s11229-008-9432-5.
- Schmid, A. (2005). What is the truth of simulation? *Journal of Artificial Societies and Social Simulation* 8(4). Retrieved March 2, 2012 from <http://jasss.soc.surrey.ac.uk/8/4/5.html>
- Smith, B. (2003). Ontology. In L. Floridi (Ed.), *Guide to the philosophy of computing and information* (pp. 155–166). Oxford, UK: Blackwell.
- Solem, O. (2003). Epistemology and logistics: A critical overview. *Systemic Practice and Action Research*, 16, 437–454. doi:10.1023/B:SPAA.0000005490.12249.7a.
- Tolk, A., Diallo, S., Padilla, J., & Herencia-Zapana, H. (2013). Reference modeling in support of M&S – Foundations and applications. *Journal of Simulation*, 7, 69–82. doi:10.1057/jos.2013.3.
- Tolk, A., & Muguira, J. (2003). The levels of conceptual interoperability model. In *Proceedings of the 2003 Simulation Interoperability Workshop*, FL.
- Tolk, A., Turnitsa, C., & Diallo, S. (2008). Implied ontological representation within the levels of conceptual interoperability model. *International Journal of Intelligent Decision Technologies*, 2(1), 3–19.
- Turnitsa, C., Padilla, J. J., & Tolk, A. (2010). Ontology for modeling and simulation. In *Proceedings of the 2010 Winter Simulation Conference* (pp. 643-651).
- Weber, A. O., & Rapaport, D. (1941). Teleology and the emotions. *Philosophy of Science*, 8, 69–82. doi:10.1086/286670.
- Weirich, P. (2011). The explanatory power of models and simulations: A philosophical exploration. *Simulation & Gaming*, 42, 155–176. doi:10.1177/1046878108319639.
- Windrum, P., Fagiolo, G., & Moneta, A. (2007). Empirical validation of agent-based models: Alternatives and prospects. *Journal of Artificial Societies and Social Simulation*, 10(2), 8. Retrieved March 2, 2012, from <http://jasss.soc.surrey.ac.uk/10/2/8.html>
- Winsberg, E. (1999). Sanctioning models: The epistemology of simulation. *Science in Context*, 12, 275–292. doi:10.1017/S0269889700003422.
- Winsberg, E. (2003). Simulated experiments: Methodology for a virtual world. *Philosophy of Science*, 70, 105–125. doi:10.1086/367872.
- Winsberg, E. (2009). A tale of two methods. *Synthese*, 169, 575–592. doi:10.1007/s11229-008-9437-0.
- Zagzebski, L. (2001). Recovering understanding. In M. Steup (Ed.), *Knowledge, truth, and duty: Essays on epistemic justification, responsibility, and virtue*. Oxford, UK: Oxford University Press.
- Zeigler, B. P., Praehofer, H., & Kim, T. G. (2000). *Theory of modeling and simulation* (2nd ed.). Academic Press.

ENDNOTES

- 1 Consensus theory of truth is not widely discussed in literature. It can be speculated that it relates to activities such as Accreditation in that a simulation model is considered useful and usable for a particular purpose even if it is not considered empirically valid.

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