Validation and Verification in Social Simulation: Patterns and Clarification of Terminology

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Abstract. The terms 'verification' and 'validation' are widely used in science, both in the natural and the social sciences. They are extensively used in simulation, often associated with the need to evaluate models in different stages of the simulation development process. Frequently, terminological ambiguities arise when researchers conflate, along the simulation development process, the technical meanings of both terms with other meanings found in the philosophy of science and the social sciences. This article considers the problem of verification and validation in social science simulation along five perspectives: The reasons to address terminological issues in simulation; the meaning of the terms in the philosophical sense of the problem of "truth"; the observation that some debates about these terms in simulation are inadvertently more terminological than epistemological; the meaning of the terms in the technical context of the simulation development process; and finally, a comprehensive outline of the relation between terminology used in simulation, different types of models used in the development process and different epistemological perspectives.

Keywords: Verification, validation, pre-computerized, post-computerized models, terminology.

1 Introduction: On the Reasons to Address Terminology

Verification and validation are two extensively used terms in simulation. They are widely used in science in general, both in the natural and the social sciences. They have plethora of different methodological significances, in diverse epistemological perspectives, upon different beliefs, and expectations. They are used often with the same or interchangeable meanings. They are the subject of numerous scientific and philosophical debates, and connected to diverse disciplinary, interdisciplinary and multidisciplinary contexts. In spite of recalcitrant debates, a standard meaning is unlikely to emerge. The terms carry an ineluctable relationship to the problem of "truth". In simulation, their affirmative character, alluding to a positive result claim, is often criticized (e.g. see Oreskes et al. 1994). Terminological disputes seem unlikely to be useful. Consensus in meaning seems improbable. In effect, it would seem reasonable to ask: Would it be useful, or even reasonable, to discuss these terms on strict terminological grounds without discussing their epistemological underpinnings?

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There are, however, methodological contexts where the terms acquire an increased pragmatic semantics. While scientific practice tends to lead scientific communities towards using common methods, as well as common languages and meanings, the use of these terms tends to become considerably pragmatic. Particularly in disciplines that make use of computerized models, like in simulation, the terms verification and validation are associated with the need to evaluate models in different stages of the software development process. In social science simulation, common definitions are usually imported from computer science, as well as from numerical and technical simulation, having intended distinct – but not infrequently conflated – meanings. In the strict context of the simulation development process, it would not be unsafe to say that the purposes of verifying and validating a simulation have become reasonably consensual:

> *Verification* – Most researchers define verification as referring to the performance of the program code, for instance, as "the process of checking that a program does what it was planned to do" (Gilbert and Trotzsch, 1999, p.21), or "checking that the representation is faithful to the simulator's intentions" (Edmonds, 2003, p.108);
> *Validation* – According to Gilbert and Troitzsch (1999, p.22), "While verification concerns whether the program is working as the researcher expects it to, validation concerns whether the simulation is a good model of the target", or, according to Edmonds (2003, p.108), that "the expression of the simulation in terms of outcomes is faithful to the relevant social phenomena."

Comparable definitions abound in the literature. At any rate, given the strong epistemological character of both terms it is always possible to perceive differences among similar definitions. Consider for instance the term *validation*. Whereas Gilbert and Troitzsch seem to define it with reference to the process of simulation as a whole, Edmonds emphasises the expression of the simulation in terms of its outcomes. However, as Küppers and Lenhard (2005) have shown, it is not unusual to construct useful simulations with faithful outcomes even when new assumptions that contradict the intended conceptual model are introduced in the specification and the corresponding programs. Whereas the simulation program may not be a good model of the target, the resulting data output model may reflect a good model of it. There is in fact more than one model involved. Could we say that in Gilbert and Troitzsch's sense the simulation would not be validated, but that it would be so in Edmonds' sense?

Although useful in specific contexts, terminological debates would not seem useful if the attempt was to confront or falsify definitions of terms on comprehensive contexts. In effect, as it is widely recognized, several chains of intermediate models are developed before obtaining a satisfactory simulation. Moreover, given the multi-paradigmatic character of the social sciences, many kinds of models will be used in different simulations. And this begs the question: Is it useful to discuss patterns of terminology without outlining the specific methodological context of a simulation and its intrinsic epistemological ambiguity?

Epistemological significances are, after all, the fundamental ingredients to outline a logic of the method of simulation.[1] Indeed, the significances of these terms are often

[1] Previous work on the analysis of intentional and empirical adequacy of computer programs in social science simulation is such an example (see David et al. 2005).

built over tacit assumptions, which tend to evolve as a cultural aspect of the discipline, as a function of paradigmatic diversity and change – there are not and there should not be strict rules about it. On the other hand, if the issue is methodological clarity there may be reasons to address a terminological analysis. If the goal is delimiting peculiar concepts for particular terms, relative to particular methods – or, in other words, if the goal is to disambiguate the mapping between pragmatic terminological use and ontological/epistemological significances – there may be room for useful argument. Why would that be interesting? Essentially because in social science simulation there are two distinct senses in which the terms *verification* and *validation* are used, which support the reasons for writing this article: *verification and validation in the computational modelling sense* and *verification, validation and confirmation in the traditional philosophical sense*. I will often call the former VERIFICATION AND VALIDATION IN THE SIMULATION DEVELOPMENT SENSE and the latter VERIFICATION, VALIDATION AND CONFIRMATION IN THE BROAD SENSE.

2 On the Goals and the Structure of This Article

The lack of consensus with respect to the nature of scientific knowledge suggests that the terms represented by 'verification' and 'validation' will never be completely free from a certain degree of ambiguity. The ambiguity seems somehow more salient in social science simulation insofar as researchers conflate the meanings of both terms along the simulation development process with other meanings found in philosophy of science and the social sciences. The goal of this article is the clarification of terminology. I will suggest that the identification of distinct phases along the construction of a simulation contributes to clarify the use of the terms. Particular emphasis will be given to the importance of recognizing the construction of two distinct kinds of conceptual models in the simulation development process, one before the implementation and execution of the simulation programs – THE PRE-COMPUTARIZED MODEL – and another after the implementation and execution – THE POST-COMPUTARIZED MODEL.

This somehow obvious distinction among pre-computational, post-computational and actual computerised models does not appear to be methodologically relevant in computer science or technical simulation, but its tacitness contributes to increased ambiguity in usage of the terms in social science simulation. The consideration of different kinds of intermediate models in the logic of the method of simulation helps us situate the roles of the terms in the development process and thus into the real epistemological debate. Additionally, the consideration of the meaning of both terms in the development process sense, on the one hand, and in the broad sense, on the other hand, helps us describe the different categories of knowledge involved in building simulations. It will further allow us to observe that many debates around the problem of "truth" in simulation are inadvertently more of a terminological nature than of an epistemological nature.

3 On the Meaning of Verification, Validation and Confirmation of Models in a Broad Sense

The well known paper of Oreskes et al. (1994) is arguably the reference of criticism to an alleged misleading use of terms in simulation. For some researchers, it is actually a criticism to simulation as method. The paper emphasised the role of numerical models in the earth sciences and its influence on public policy. Today, in the era of global warming, no one would deny the importance of computers and simulation in the natural sciences for public policy. In any case, the claim is their abstract is undoubtedly the following: "Verification and validation of numerical models of natural systems is impossible" (Oreskes et al. 2004, 641). More than ten years after the publication of this article, refutations abound in the literature. In a widely accessed lecture on the internet,[2] Tetsuji Iseda, a philosopher and former research assistant of Frederick Suppe[3], confronts Suppe's and Oreskes' ideas on the value of simulation. A debate which, according to Iseda, should converge to a central question: "Can simulation models yield knowledge about the real world?" And the answers of Suppe and Oreskes, in the view of Iseda, are the following:

> "Oreskes et al: We can not *verify* simulation models, so scientists cannot obtain knowledge from simulation modelling."
> "Suppe: Simulation models can be *verified* in some sense, so we can obtain knowledge from them."

The common term at stake is the word "verification". For Iseda, however, there are various degrees of certainty on the problem of "truth". These are identified by the terms verification, confirmation and validation, recalled by Oseda in the light of Oreskes' critique of simulation:

> Firstly, VERIFICATION stands for absolute truth, "To say that a model is verified is to say that its truth has been demonstrated, which implies its reliability as a basis for decision-making" (Oreskes et al. 2004, 641). Models cannot be verified insofar as the real world is never a closed system, and so there cannot be a logical proof that a model is true. Closed systems come up only in purely logical structures, such as proofs in formal logic. Secondly, VALIDATION stands for a "model that does not contain known or detectable flaws and is internally consistent" (*ibidem*, 642). Models can be validated by comparing different solutions, or by calibrating models to adjust known data. But this does not mean that models have been verified, insofar as "the agreement between measures and numerical outputs does not demonstrate that the model that produced the output is an accurate representation of the real system" (*ibidem*, 642). Finally, CONFIRMATION stands for plausible theories in terms of evidence. "If empirical observations are framed as deductive consequences of a general theory and these observations can be shown to be true, then the theory is confirmed and remains in contention for truth" (*ibidem*, 643). Hence, as Iseda remarks, models may be confirmed but this means only the model is probable, not that the model is true.

In summary, for Oreskes et al., simulations can be validated and confirmed but never verified. The primary value of simulation would be to "offer evidence to strengthen what may be already partly established, or to offer heuristic guidance as to further research, but never susceptible to proof." For Oreskes, a simulation is thus more like a

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[2] Iseda (1997), see http://carnap.umd.edu/phil250/oreskes/oreskes.html (retrieved March 2007).
[3] The author, among others, of the "Semantic Conception" of scientific theories.

fiction: “A model, like a novel may resonate with nature, but it is not a “real” thing” (*ibidem*, 644). Conversely, for Iseda, verification is possible in some sense. A simulation is a representation of aspects of the real world and thus yields knowledge about the real world: Oreskes’ way of defining “verify” would be too strict – “it would make empirical knowledge impossible” (Iseda 1997). Arguably, it may not be unsafe to say that Osedas’ view is shared by many researchers doing simulation. However, rather than an epistemological debate, this seems to be a terminological discussion. My objection to Isedas’ interpretation about Oreskes essay would be the following:

> (i) Oreskes’ view is not incompatible with Suppe’s; Oreskes’ criticism is mainly on the use of terminology, claimed to be misleading; (ii) Oreskes criticism to terminology does not show that simulation models cannot be validated and/or confirmed; (iii) it is true that Oreskes sense of the term verification is strict and thus simulations cannot be verified in the sense defined, but whether Oreskes has suggested or not that simulation cannot yield knowledge about the real world is by no means clear in Oreskes’ paper.

Rather than questioning if simulation yields knowledge, there is another question, which has not been addressed by Oreskes or Iseda, which would be perhaps more illuminating: What *kind* of knowledge can simulation yield about the real world?

Not only this question is more pertinent from an epistemological point of view, but we argue to be useful for clarifying the mapping of terminological usage to epistemological significances, avoiding what could be a mere debate around the use of the same terms in distinct contexts. The simulation development process involves the construction of several models, built according to different methods, serving different purposes, ultimately embedded in the simulation and eventually yielding different kinds of knowledge to the researcher. And this brings us back our central remark: the terms verification, validation and confirmation of models are usually discussed in the broad philosophical sense, but are often conflated with their use in the development process sense. An ambiguity that led Oreskes to state the following contentious sentence about verification:

> “Numerical models may contain closed mathematical components that may be verifiable, just as an algorithm within a computer program may be verifiable.” (Oreskes et al., 1994, p.641).

And further suggesting that the following definition of validation, given by the International Atomic Energy Agency, is erroneous:

> “A validated model is one that provides a good representation of the actual processes occurring in a real system.” (Oreskes et al., 1994, p.642)

However, outside the traditional sense of computer science, the first quoted sentence may also be erroneous. Whether an algorithm within a computer program is verifiable or not depends on whether the program may be qualified as a pure logical structure or as a causal model of a logical structure that instantiates a particular algorithm (see Fetzer, 1999 and also David et al. 2005). Even the simplest program may not be verified in Oreskes' sense. Moreover, whereas the second quoted sentence may be misleading when interpreted in the light of the philosophical sense of validation, it would be actually consensual in the strict computational modelling sense of simulation, in which the goal is to evaluate whether the specification and the results of a simulation are good models of the target, which are two well defined steps in the simulation development process. In short, whether validation in the computational modelling sense stands for verification, validation or confirmation in the broad philosophical sense, it may well be a relevant terminological debate, but not necessarily a useful epistemological debate. For someone not familiar with simulation and from an epistemological point of view the terms may indeed lead to confusion, but are not necessarily erroneous.

4 On Four More Examples of Terminological Dilemmas in Social Science Simulation

Isedas' note on Oreskes *vs.* Suppe is mostly related to simulation in the natural sciences. Likewise, not considering terminological and epistemological traditions in the computer and the social sciences may yield misleading methodological analyses of social science simulation. Apart from the conflation of the terms in the development sense with the philosophical broad sense, there are other relevant ambiguities that may have a terminological rather than an epistemological origin. This observation is not a criticism of the methodological literature in the field. It is rather a natural consequence of an intense interdisciplinary field with exciting new methodological challenges. In any case, the clarification of terms and the resultant emergence of epistemological debates is a positive contribution to the field. The following topics are examples liable to terminological dilemmas, with potential influence on epistemological debates – or simply epistemological misunderstandings, mostly arising as a product of the encounter of the computer and the social sciences:

Experimental vs. Empirical vs. Quasi-empirical Methodology. To the extent that simulation is an experimental methodology, it has been considered as a quasi-empirical approach (e.g. Küppers and Lenhard, 2005, paragraph 2.2). Moreover, insofar as it is programs that are executed and tested, and not the phenomena that they presumably represent, the term "quasi-empirical" has replaced the term "empirical." Both terms used in this sense seem to be borrowed from the natural sciences, and not from the sense of building and evaluating social science simulations with gathered empirical data. If the intention is to indicate that simulation resembles empirical research to some degree, in the sense that gives a quasi-access to a real experiment with the social phenomena, the term may become highly controversial, and indeed may be claimed misleading. Rather than stating that simulation is quasi-empirical, consider the ambiguity in stating that simulation makes "quasi-experiments" with the social phenomena. Moreover, just like the use of hypotheses confirmed by observation does not necessarily imply using experiments, there may be not any reasons to suggest that simulation, as a definitive experimental exercise with computerized models, resembles empirical science in the sense of experimental science. At the very least, if the term empirical is used to characterize the logic of the method of simulation, its intended meaning should be clarified.

Formal inference in the classical computer theory sense vs. inference in the discursive intentional sense (for more details, see David et al. 2005). Epstein (1999), among others, has used the "formal symbol manipulation" conception of the classic theory of computation, which describes computers as formal inference machines, to characterize generative simulation as necessarily deductive. The terms "generative" is now widely adopted in social science simulation. However, to understand simulation according to such formal conception of computation requires understanding the inference mechanism in the exclusive grounds of first-order logical sentences. But there are not reasons to suppose that the semantically rich social phenomena represented in simulations can be expressed simply with first-order logical sentences. The building and evaluation of simulations involve the use of rhetorical and intentional discourse, usually acquired in the context of limited consensus. While those simulations may be formally described in the sense of being abstract, it should be remarked that the term formal in such a sense does not necessarily translate to the sense of "formal symbol manipulation" utilized in classic computer science.

Deduction in the formal sense vs. deduction in the empirical sense (for more details, see David et al. 2007). While Axelrod characterised simulation as a contrast to both induction and deduction, induction was defined as the "discovery of patterns in empirical data" and deduction as the specification of a "set of axioms and proving consequences that can be derived from assumptions." Deduction, in this sense, seems to refer to pure mathematical-logical demonstrations, as opposed to deduction as a kind of ampliative reasoning in an empirical sense. Yet, there is no strong reason for not viewing deduction as a kind of empirical enquiry. Popper, like many other deductivists in the philosophy of science, would say that there is no such thing as induction. Indeed, to define the epistemic specificities of simulation based on the contrast between induction and deduction does not seem to be methodologically informative. Whether the epistemic conception of empirical enquiry may be understood as inductive, deductive or even abductive is by no means a specific dilemma of simulation.

Abduction vs. generativism. The notion of "generative" was initially posed as the specific epistemic characteristic of simulation that contrasts with deduction and induction, a sort of new methodological conception of doing science, often described as a "third way of doing science".[4] At any rate, the term "generative" seems to be just a synonymous of "abductive". Indeed, what the term generative has been characterising seems to be similar to Pierces' second conception of abduction, in which hypothetical explanations are inquired in order to explain a given explanandum. If that is the case, from an epistemological point of view the term "generative" does not seem to describe a new methodological conception in science. Moreover, "generativist" claims may well run the risk of being considered overenthusiastic or even misleading.

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[4] See Epstein (1999). See also Axelrod (1997).

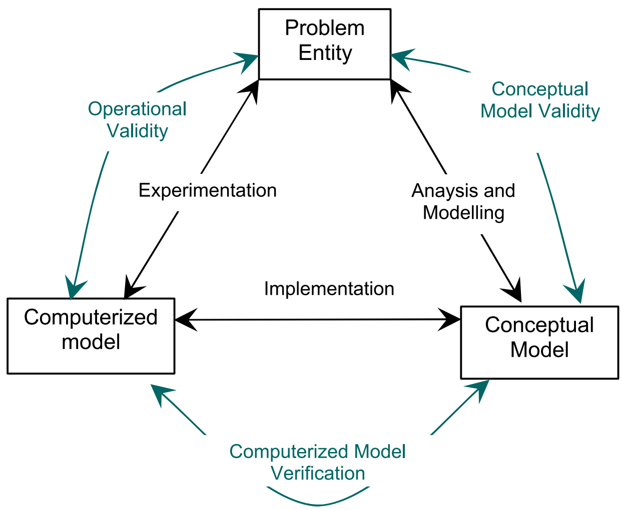

Fig. 1. Simplified version of the development process in technical simulation, according to Sargent (1998)

5 On the Relation of Verification and Validation to the Simulation Development Process

In the strict context of the simulation development process, could verification and validation acquire a less contentious meaning? Rigorously speaking, none of the terms can avoid acquiring significances dissociated from the philosophical problem of "truth". In social science simulation, other terms are sometimes used to refer to the verification step, such as "internal validation"[5] or "program validation"[6]. Notwitstanding, the usual terminology adopted from computer science and technical simulation seems to prevail, and is adopted by most researchers. References from simulation in computer science and engineering, such as Sargent (1998), are often used as the inspiration to define the terms. Whether the terminological mapping from technical to social science simulation is appropriate depends on how well the development process of technical simulation can be mapped to the development process of social science simulation. I will argue that this mapping can only be partial. However, I will argue that the usual terminology will remain.

In technical simulation, verification and validation are usually defined in terms of two kinds of models: the conceptual and the computerised model. That is, according to the simplified development process of Figure 1, a single conceptual model mediates between the problem entity and the computerized model. The problem entity is the ultimate subject of inquiry. The conceptual model is usually a mathematical/ logical/ verbal representation of the problem entity. Meanwhile, whereas the evaluation of technical simulations is essentially a quantitative analysis of the outputs, the evaluation

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[5] Axelrod (1997, p.27).
[6] Richiardi et al. (2005, paragraph 4.28).

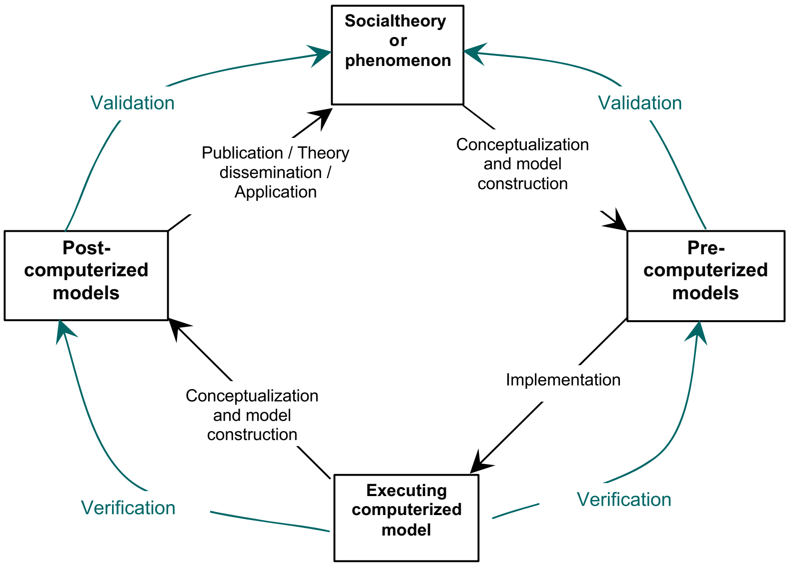

Fig. 2. The development process in social science simulation: representing explicit post-computerized models

of complex social models is also qualitative and highly conceptual. A fact that requires recognizing the construction of two distinct kinds of conceptual models during the simulation development process, one before the implementation and execution of the simulation programs – THE PRE-COMPUTARIZED MODEL – and another after the implementation and execution – THE POST-COMPUTARIZED MODEL. This requires recognizing that two subjects of inquiry exist in simulation, rather than one: the target theory or phenomenon and the executing computerized model, represented in Figure 2. In short, two conceptual models mediate between two subjects of inquiry.

The conceptual model on the right, designated here as the *pre-computarized model*, is a representation in the minds and writing of the researchers, which presumably represents the target social phenomenon or theory. This model must be implemented as a computerized executable model, by going through a number of intermediate models such as textual programs written in high-level programming languages. The inquiry of the executing model give rise to one or more conceptual models on the left, designated here as the *post-computerized* models. They are constructed based on the observation of execution behaviours and output data, often through graphing, visualisation and statistical packages. The whole construction process results in categories of description which may not have been used for describing the pre-computerized model. This gives rise to the usual idea of *emergence*, when interactions among objects specified through pre-computerized models at some level of description give rise to different categories of objects at different levels of description, observed in the executing model and specified accordingly through post-computerized models.

As a canonical illustration, consider the well known culture dissemination model of Axelrod (1997b) whose goal is to analyse the phenomena of social influence. At a certain level of description, the pre-computerized model defines the concept of *actors* distributed on a grid, the *culture* of each actor is defined as a set of five features and *interaction mechanisms* are specified with a bit-flipping schema.[7] The executing model gives rise to other categories of objects like the concepts of *regions* and *zones* on the grid, resulting from the interaction of several individual cultures, associated with properties of interest and conditions in which they form. A great deal of the simulation proposed by Axelrod concerns inquiring properties of *regions* and *zones* in the context of a new conceptual model proposed, such as the relation between the size of a *region* formed and the number of features per *individual culture*. These concepts are later interpreted in relation to the target social phenomena of social influence.

I will now situate the role of verification and validation in the simulation development sense. The goal is not to establish any kind of standard definition for these terms. Rather, the intention is to show that once the full set of different kinds of models are denoted explicitly in the development process, the mapping to the problem of "truth" in the philosophical sense is facilitated, insofar as the epistemological underpinnings of each model involved may be analysed – and thus run fewer risks of reducing epistemological debates to terminological ones. Recall that the reason for distinguishing the terms verification and validation in the development process is pragmatic, related to the need to determine the adequacy of several kinds of models against two distinct subjects of inquiry. In this context, consider the following definitions:

COMPUTERISED MODEL VERIFICATION is defined as checking the adequacy among conceptual models and computerized models. It is primarily concerned with ensuring that the pre-computerized model has been implemented *adequately* as an executable computerized model, according to the researcher and/or stakeholders' intentions in the parameter range considered, and also that the post-computerized model *adequately* represents the executing model in the parameter range considered. You may now interject, What is the meaning of *adequate*? Indeed, this would return us to the epistemological debate, considered elsewhere, where adequateness can be explained according to a number of epistemological perspectives, such as the notions of formal, empirical and intentional knowledge.[8] Our goal is essentially terminological. A minimal definition could be the following: adequateness means that the execution behaviours of the computerized model coincide with the semantics of both the pre- and the post-computerized models, in accord with the researcher's intentions.

Finally, CONCEPTUAL MODEL VALIDATION is defined as ensuring that both the pre- and post-computerised models are *adequate* models of the target social theory or phenomenon. The term adequate, in this sense, may stand again for a number of epistemological perspectives, such as empirical or arbitrarily interpretative. Given the difficulty in establishing standards for the construction of social theory or the surveying of social facts, it is an epistemological issue beyond simulation with no easy solution. From a practical point of view, adequateness may be established according to the intuition of the researchers or the stakeholders involved in a participative-based simulation. In any case, the interest of validation is to assess whether the target social theory or phenomenon is adequately represented by relevant micro-levels of description of the pre-computerised model and relevant micro and macro-levels of description of the post-computerised model.

[7] In which the probability of interaction between two actors is set proportional to a measure of similarity between two cultures.

[8] See David et al. (2005). See also David et al. (2007).

Table 1. Some examples of common techniques and approaches for verifying or validating models in the simulation development process sense. Corresponding methodological perspectives are referenced as footnotes.

	Pre-Computerized Models	Post-Computerized Models
Validation	Formal Modelling Theory-driven Discourse Empirical Methods[9] Participative-based Approaches	Statistical Signatures Stylised Facts[10] Participative-based Approaches Cross-Model Validation ("Model-to-Model")[11]
Verification	Structured Programming (e.g. modularity, object-oriented programming) Model Embedding[12] (e.g. compilation, software reuse of components) Static Methods (e.g. code walk-throughs)	Dynamic Methods (program testing, sensitivity analysis) Replication for Alignment Participative-based Approaches

Table 2. A mapping between terminology and epistemological perspectives on simulation, related to validation and verification

Terminological and Epistemological Perspectives in Oreskes' (1994) Sense	Epistemological Perspective in Isedas' (1997) Sense	Subject of Inquiry	Terminological Perspective in the Simulation Development Process Sense	Conceptual Models Involved	Epistemological Perspectives in Terms of Kinds of Knowledge Involved
Can models be verified, validated or/and confirmed (in the broad philosophical sense)?	Can simulation yield knowledge?	Executing computerized model	Verification	Pre- and post-computerized models	Formal knowledge; Intentional and empirical knowledge (in David's sense, 2005)
		Social theory or phenomenon	Validation		Multiparadigmatic

Given the simulation development process described, are there any crucial differences between verification and validation in the simulation development process? From an epistemological point of view there are certainly differences, but from a terminological

[9] See Boero and Squazzoni (2005).
[10] See Bernd-O et al. (2005).
[11] See Hales et al. (2003).
[12] See David et al. (2005).

point of view it is a distinction that results from the computational methodology. Whereas *verification* is essentially a form of evaluating the logical inferences established between micro and macro concepts with reference to the computerised model, *validation* is essentially a form of evaluating the adequateness of *both* those logical inferences and concepts with close reference to the target social theory or phenomenon.

6 On Epistemological Perspectives

Can simulation yield knowledge about the social world? This is a philosophical question in the social sciences, but it is by no means the only important question. Whereas the body of research that simulation in the social sciences provides has been intense in the last two decades, the increase in philosophical literature came to the surface much more recently. Philosophical interest is an indication that simulation has become a consolidated discipline, with its influence on society, contributing with knowledge and critical thinking, with its own eclectic dilemmas, methods and techniques. Once we look into Figure 2, we may realize that a number of approaches and techniques can be identified for each quadrant of the simulation development process, described in Table 1. Details on these approaches and techniques are out of the scope of this essay, although some references on methodological and epistemological perspectives are indicated as footnotes. The point is that if simulation is to be analysed as a method, its established tools and techniques are to become ingredients of analysis, together with their role in the simulation development process. This will preclude us from running the risk of driving epistemological debates by means of terminological ambiguities.

What kind of knowledge can each model and technique provide? What is the range of purposes for these models and techniques, their methodological limits, ranges of application, what type of consensus can they achieve or provide? Once we realize that simulation is a complex type of model embedding[13], and realize the meaning of verification and validation in the development process sense, the mapping from terminology and types of models to different categories of knowledge may become easier to investigate. Whether the question is whether simulation yields knowledge or the kind of knowledge that simulation provides, that is a philosophical debate that can be stated in the terms of Table 2, which illustrates a mapping between terminology and examples of epistemological perspectives, such as Oreskes et al. (1994), Iseda (1997) and David et al. (2005). An indication that acknowledges the consideration of explicit post-computerized models in the logic of the method of simulation, which helps us situate the roles of the terms verification and validation, and thus into the real epistemological debate.

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[13] In the sense of David et al. (2007).

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