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## A Framework for Epistemological Perspectives on Simulation

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### Abstract

Simulation is a widely-used research method going back to a long history in numerous disciplines and in many research communities. But the epistemological status of simulation remains unclear and very much depends on the individual propositions of the researcher. At this juncture, we develop a reference framework which allows structuring and systematizing (often hidden) epistemological assumptions made by researchers when applying simulation as a research method. Afterwards, we show how to apply the reference framework by analysing the influence of the consensus-oriented approach (as one possible epistemological position) on simulation research.

### Keywords:

Simulation, Epistemology, Reference Framework, Ontology, Consensus-Oriented Approach

### Introduction

#### 1.1

Simulation as a research method has a long history in numerous disciplines and in many research communities. Physics, electronics, robotics, economies, logistics and production planning and control ([Krüger 1975](#); [Oakshott 1997](#)) apply simulation, for instance. Furthermore, simulation is used worldwide as a method for explanation and prediction in different research and practitioner groups. In this context, several epistemological questions arise: What are the assumptions made when researches from different academic disciplines, communities and countries apply simulation? How does knowledge researches already gained about the "real world" influences the conduction of the research and the interpretation of the results? Are the basic assumptions made always the same?

#### 1.2

In fact, we find evidence that different academic disciplines and different research communities tend to develop distinct approaches and tend to make distinct assumptions ([Chen, Hirschheim 2004](#)). Chen and Hirschheim have conducted an empirical study analyzing eight major IS publication outlets between 1991 and 2001. The examination of 1893 articles published in US journals or European journals shows that the vast majority (89%) of US publications is influenced

by a positivist paradigm. Though European journals also publish 66% research based on positivist principles, they tend to be much more receptive to interpretivist research (34%) than US journals are. Those paradigms are based on distinct epistemological assumptions. The differences on a paradigmatic level consequentially lead to an epistemological difference in alignment ([Hirschheim, Klein 1989](#); [Chen, Hirschheim 2004](#); [Niehaves 2004](#)).

### 1.3

Thus, the research questions to be answered are:

- a. What are the relevant epistemological aspects when conducting simulation and how can they be systematized?
- b. What are the consequences of possible epistemological positions for simulation (research)?

Section 2 will point out where the assumptions about the "real world" (ontology) and about human cognition processes (epistemology) come into play when building up simulation models and conducting the simulation process. In Section 3 we will discuss the term epistemology and analyse in what way it is related to other terms commonly used in this context: research methods and research paradigms. Section 4 will then formulate central questions addressing epistemological issues relevant in the context. An epistemological framework developed will comprise those questions and corresponding answers commonly made. Section 5 will give the example of the consensus-oriented approach in order to show how to apply the epistemological framework. Furthermore, impacts of the consensus-oriented approach are discussed. The conclusion (Section 6) will sum up this paper's result and the outlook for future research will show fruitful avenues to continue research taking into account the epistemological perspectives on simulation.



## Simulation as a Research Method

### 2.1

Simulation is used in many application areas such as physics, electronics, robotics, economies, logistics and production planning and control ([Krüger 1975](#); [Oakshott 1997](#)). It is an ambiguous term and definitions vary:

- "A Simulation is an experiment performed on a *model*. " ([Korn, Wait 1978](#))
- "Simulation is the modelling of a process or system in such a way that the *model* mimics the response of the actual system to events that take place over time. " ([Schriber 1987](#)).
- "Simulation is the process of designing a *model* of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system. " ([Pedgen, Shannon et al. 1995](#))
- "... the term 'simulation' describes a wealth of varied and useful techniques, all connected with the mimicking of the rules of a *model* of some kind. " ([Morgan 1984](#)).

In all cases, simulation are based on models ([Morgan 1984](#)). Models are used as the core of the method, to – at least partly – representing and/or aiming at a "real world" object system or problem ([Bossel 1992](#)). In fact, here, models are used in two ways. At first, researchers try to identify universal principles and processes of the "real world" which they formalize in the forms of models. Afterwards, the models derived, are in turn used within the simulation process in order to receive new cognitions. Obviously, the construction of the simulation model is a fundamental step for the validity of the simulation results ([Morgan 1984](#); [Law, Kelton 1991](#)).

### 2.2

So far, there are only few generally accepted statements when and how to use simulation. Reasons are the existing complexity and diversity of simulation problems itself ([Krüger 1975](#)). As a result, a broad variety of simulation types has been developed. Figure 1 illustrates these types in the form of a morphologic box.

<b>Criteria</b>	<b>Specifications</b>	
<b>Time Reference</b>	statistic	dynamic
<b>Intention</b>	descriptive description   explanation   prediction	pragmatic-normative decision support
<b>Change of State</b>	deterministic	stochastic
<b>Time Model</b>	discrete	continuous
<b>Procedure Control</b>	event-driven	time-driven

**Figure 1.** A morphologic box for a classification of simulation as a research method

### 2.3

Thus, at the beginning of simulation project, it is necessary to verify the applicability of simulation (or the simulation type chosen) to the given real world problem represented in the problem definition (cp. in the following Figure 2). At this very early point of time in the simulation process, researchers already make several (sometimes hidden) assumptions (e. g. about the structure of the system which is going to be represented in the simulation model).

### 2.4

After establishing necessary preconditions for the use of simulation (e. g. existence of human resources and suitable Hard- and Software), the simulation model is constructed. The construction phase of the simulation model on the one hand depends on the type of model that is to be built. Some models need complex mathematical equations and others don't. On the other hand the application of the model is an important factor. A model e. g. used for strategic purposes may use different techniques than a models used for day-to-day planning ([Oakshot 1997](#)). Moreover, the design of the model is influenced by the availability of data. Thus, model construction and data collection take place simultaneously. Afterwards the constructed model needs to be validated. Finally, planning, conduction and interpretation of simulation runs are to be supposed to solve the problem initially formulated.

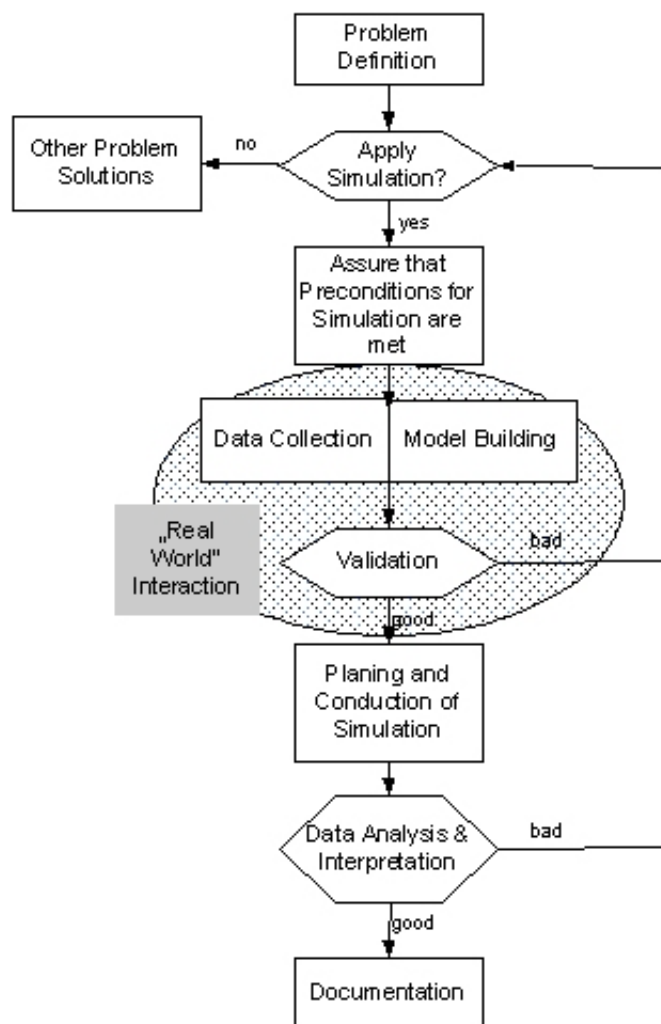


Figure 2. Simulation Process (Krüger 1975)

## 2.5

In summary, in all parts of the simulation process, assumptions about the "real world" (ontology) and about human cognition processes (epistemology) come into play. The construction of a simulation model and the interpretation of the simulation results, primarily depend on the researcher, his research area, his experiences and for the most part his inherent epistemological perspective. In turn, the epistemological assumptions that underline the simulation model used significantly influence the quality and validity of the research results.

## Epistemology

### 3.1

Epistemological assumptions are those about the nature of human cognition. Epistemology can be understood as the science of analyzing the way human beings grasp knowledge about what is (perceived to be) existing (Burrell, Morgan 1979; Niehaves 2004). It addresses the question of how a person can come to true knowledge, while simulation can be seen as a research method intending to produce knowledge. At this juncture, epistemology has a great affect on the enterprise to apply simulation in order to produce "true", "valid", or "useful" knowledge. In order to analyze the way and the extend to which epistemology has such impact, we will first seek to specify the relationship between the terms "research method" and "epistemology" (Section 3) and secondly attempt to structure and systematize the epistemological issues relevant to this discussion (Section 4).

### 3.2

Thus, we seek to provide a framework based on the phenomenon of research culture in order to differentiate the terms "research method" and "epistemology". This framework is also applicable to other research methods apart from simulation and can, thus, be understood as a general

framework. Different disciplines and different research communities provide a different research culture. Drawing upon the theory of culture which was strongly influenced by Edgar Schein ([Schein 1992](#)), we can differentiate three levels of culture: the level of artefacts and symbols, the level of norms and values, and the level of basic assumptions (see Figure 3). These levels are distinguished by the degree of visibility to an observer. Applying this schema on research culture, we can classify the terms relevant to the discussion: research methods [m], research paradigms [p], and epistemological assumptions [e].

(A) Level of Artefacts & Symbols	Visible, but have to be interpreted	<u>Research methods [m]</u> , research results, language, rituals, etc.	➔ <i>For example:</i> Simulation, Statistical data analysis, etc.
(B) Level of Norms & Values	Visible in parts; unconscious	<u>Research paradigms [p]</u> , ideologies, ethics, maxims, guidelines, etc.	➔ <i>For example:</i> Positivism, Interpretivism, etc.
(C) Level of Basic Assumptions	Mostly invisible; unconscious	<u>Epistemological assumptions [e]</u> , assumptions about: nature of man, time, etc.	➔ <i>For example:</i> Origin of knowledge, Influence of the subject, Possibility of truth

**Figure 3.** Distinct levels of (research) culture

- A. We find research methods as well as research results on the level of artefacts and symbols, the most visible part of research. In most cases, these entities, for instance data, results, and languages, have to be interpreted. Thus, the visible parts of simulation are found here, including the simulation model, the simulation process description, the data generated, and so forth. Their interpretation (with regard to "truth", "validity", "usefulness" etc.) is thus depending on further underlying issues.
- B. The word paradigm refers to a thought pattern in any scientific disciplines or other epistemological context. Kuhn defines a (scientific) paradigm as ([Kuhn 1970](#)):
  - i. what is to be observed and scrutinized,
  - ii. the kind of questions that are supposed to be asked and probed for answers in relation to this subject,
  - iii. how these questions are to be put,
  - iv. how the results of scientific investigations should be interpreted.

Research paradigms can be found on the level of norms and values. They are visible in some parts, for example when certain paradigms are questioned because they did not seem to take into account significant influencing factors. The growing belief in subjectivity as a main influencing factor on research, for example, led to the broad discussion of positivism and interpretivism over the last years ([Lee 1991](#); [Fitzgerald, Howcroft 1998](#); [Falconer, Mackay 1999](#); [Mingers 2001](#); [Weber 2004](#)). In recent Information Systems (IS) literature an extensive discussion on research paradigms and their assumptions can be found. Epistemological assumptions were alongside ontological and methodological ones, those mainly taken into account in order to identify and to describe distinct paradigms as well as to differentiate them from each other (see Figure 4).

Author	Criteria	IS research paradigms
G. Burrell & G. Morgan (1979)	a. Ontology, b. Epistemology, and c. Methodology	Functionalism, interpretivism, radical humanism, and radical structuralism
A. S. Lee (1991), W. Chen & R. Hirschheim (2004)	a. Ontology b. Epistemology	Positivism, interpretivism
B. Fitzgerald & D. Howcroft (1998)	a. Ontology, b. Epistemology, and c. Truth (p. 160)	Positivism, interpretivism
E. Monod (2003)	a. Epistemology I: Object of knowledge, b. Epistemology II: Origin of knowledge	Diverse IS research paradigms and philosophical trends, e. g. functionalism, constructivism, critical realism
R. Weber (2004)	Diverse. Including e. g. ontology, epistemology, research object, method, theory of truth etc.	Positivism, interpretivism
B. Niehaves et al. (2004)	a. Ontology, b. Epistemology: Relationship of knowledge and object of knowledge	Positivism, interpretivism, radical constructivism

**Figure 4.** Assumptions of distinct research paradigms

Nevertheless, paradigms are in many cases unconscious and not explicated in every research approach or by everyone conducting research. Furthermore, paradigms themselves also base on certain assumptions.

- C. Thus, on the third level, the level of basic assumptions, we find entities that underlie those discussed above. Epistemological assumptions (which shape research paradigms as well as research methods) can be found here. They are mostly invisible and in most cases unconscious to the researcher. Consequently, simulation models are as artefacts (level A) only "the top of the iceberg". Thus, several questions will arise, for instance: When building simulation models, how do we gain the knowledge that the model comprises? On what paradigm do we base our research? On what epistemological assumptions? Here, for instance: Is the knowledge based on a real world assumption? Is it a reproduction or is it more a construction? There are several more epistemological assumptions that are implicit to the concept of the term "simulation model" which underlies the research. Answering those questions is of high importance, especially within a multi-disciplinary context of research – and this is the case with regard to the widespread use of simulation as a research method – where the assumptions made by different researchers may vary fundamentally. Therefore, the extensive publication of epistemological assumptions is thus, in effect, almost mandatory. In the following, we thus want to structure and to systematize epistemological issues relevant to this context with the help of certain central questions.

## Epistemological Reference Framework

### 4.1

The discussion of epistemological questions must, at least presently, be considered as an open issue. For this reason, no theory based on a philosophy of science can be considered as binding for researchers. The individual selection, however, necessitates the extensive publication of the epistemological assumptions made by individual researchers. Here, basic epistemological questions can be differentiated from one another. In this section, we thus will present an epistemological framework that consists of five questions each addressing one core epistemological aspect (cp. Figure 5).



<p>[I] What is the object of cognition? (Ontological aspect)</p>	<p><i>(Ontological) realism.</i> A world exists independently of human cognition, i. e. independent of thought and speech processes [cp. e.g. Bunge (1977)].</p>	<p><i>(Ontological) idealism.</i> The „world“ is a construct depending on human consciousness [cp. e.g. von Foerster (1996)].</p>	
<p>[II] What is the relationship between cognition and the object of cognition?</p>	<p><i>Epistemological realism.</i> objective cognition of an independent reality is possible. It claims the possibility of eliminating subject-dependent distortions of the cognition of reality, as soon as suitable measures for the removal of appropriate intervening variables are found [cp. e.g. Loose (1972)].</p>		<p><i>Constructivism.</i> Cognition is subjective, i. e. „private“. The relationship of cognition and the object of cognition is thus determined clearly by the identifiable subject [cp. e.g. Glasersfeld (1986, 1987), Lorenzen (1987), Wyssusek and Schwartz (2003)].</p>
<p>[III] What is true cognition? (Concept of truth)</p>	<p><i>Correspondence theory of truth.</i> True statements are those which correspond with „real world facts“ [see below].</p>	<p><i>Consensus theory of truth.</i> A statement is true (for a group), if and only if, it is acceptable for the group [see below].</p>	<p><i>Semantic theory of truth.</i> A requirement for true statements is the differentiation of an object and a meta language [see below].</p>
<p>[IV] What is the origin of cognition/knowledge?</p>	<p><i>Empiricism.</i> Experience-based knowledge is called a <i>posteriori</i> or <i>empirical knowledge</i> [Alavi et al., 1989, Berkley, 1975, Hume, 1978, Locke, 1982, Carnap, 2003, Quine, 1961, Carnap et al., 1929].</p>	<p><i>Rationalism.</i> Non-experience-based knowledge is referred to as a <i>priori knowledge</i>. [Leibniz, 1962, Chomsky, 1965, Spinoza, 1992, Hanson and Hunter, 1992, Descartes, 1996, Bonjour, 1998].</p>	<p><i>Kantianism.</i> Conciliating positions recognize both experience and intellect as sources of cognition. Thoughts are meaningless without content, cognitions are blind without being linked to terms [Kant, 1999].</p>
<p>[V] By what means can cognition be achieved? (Methodological aspect)</p>	<p><i>Inductivism.</i> Induction is understood as the extension from individual cases to universal phrases, the generalization. An inductive conclusion means the transfer from statements via (observed, empirical) individual cases to a universal law a statement on the basis of an assumption of homogeneity on nature [cp. e.g. Rott (1995), Seiffert (1996)].</p>		<p><i>Deductivism.</i> Deduction is seen as the derivation of a statement (thesis A) from other statements (hypothesis A<sub>1</sub>, ..., A<sub>n</sub>) with the help of logical conclusions. It is the derivation of the individual from the universal and is applied, for example, in mathematical axiom systems [cp. e.g. Gethmann (1995)].</p>

Figure 5. Epistemological Reference Framework (cf [Becker and Niehaves 2005](#))

### 1. What is the object of cognition? (Ontological aspect)

Ontology is the science, the theory or the analysis or investigation of 'what is' and 'how it is' ([von Foerster 1996](#)). In the context of this epistemological analysis, ontology reveals its relevance in that objects are analyzed, to which the process of cognition refers. The process deals with the question of the way reality exists beyond the realms of pure imagination of the subject ([Bunge 1977](#); [Decker, Erdmann et al. 1999](#); [Shanks, Tansley et al. 2003](#); [Weber 2003](#)).

- a. If the researcher assumes a real world in his investigation, a world that exists independently of cognition, i. e. independent of thought and speech processes, he thus assumes the position of *(ontological) realism*.
- b. If the researcher negates the existence of a real world independent of human thinking and speech, that is, if he perceives reality as a construct dependent on human consciousness, he thus assumes the position of *(ontological) idealism*.

Thus, for building a simulation model and applying simulation it has to be discussed

whether it has an objective point of reference outside the realms of human cognition (reality) or not.

## 2. What is the relationship between cognition and the object of cognition?

This epistemological question, which is often regarded as central, is about the relationship of cognition obtained by the subject to the object of cognition. The point is whether things beyond human thoughts and speech can at least in principle be recognized as objective. Two possible answers to this question can be differentiated according to their basic notions:

- a. In *epistemological realism*, the objective cognition of an independent reality is possible. It claims the possibility of eliminating subject-dependent distortions of the cognition of reality, as soon as suitable measures for the removal of appropriate intervening variables are found ([Loose 1972](#)).
- b. The understanding of cognition in *constructivism* is subjective, i. e. "private" ([Glaserfeld 1986](#); [Glaserfeld 1987](#)). The relationship of cognition and the object of cognition is thus determined clearly by the identifiable subject ([Lorenzen 1987](#); [Wyssusek, Schwartz 2003](#)).

This question becomes relevant to building simulation models discussing the influence of the individual subject on the perception of the problem domain. In case of a constructivist position (b), for instances, simulation addresses a problem "perceived" due to the assumption that it cannot be assessed objectively. In case the research setting is problem solving oriented, it will solve the problem perceived.

## 3. What is true cognition? (Concept of truth)

A central topic of epistemology is the question as to how humans can achieve "true" knowledge. Expressed more intuitively, that means how far "correct" knowledge can be obtained and how the "correctness" of knowledge has to be verified<sup>[1]</sup>.

- a. *Correspondence theory of truth*. According to the theory of correspondence, truth causes a *correspondence* in terms of an *analogy* or *equivalence* between two relata. The first relatum of a two-digit relation are *statements*. The capacity for truth determines the characteristic of statements. By correlating statements and facts, the former can be classified as true or false. Facts thus represent the second relatum in the context of the correspondence view and act as *truth inducers* for statements, because of their assumed status as objective ([Baumann 2002](#)). In the context of this construct, mainly the terms correspondence and fact, pose problems ([Kirkham 1992](#); [Schmitt 1994](#)). If the term correspondence is understood as *analogy* or *equivalence* in terms of a *correct reproduction*, this is ultimately nothing other than rephrasing of truth, the explanation of which should have been object of the investigation. The solution to this problem can be found in the operationalization of the term correspondence from Wittgenstein, designated as *image theory* (cp. [Wittgenstein 2001](#); a reconstruction in Stenius [1960](#); a related theory in Russell [1956](#)). Image theory links the correspondence to two conditions:
  - i. The elements of a statement represent appropriate, corresponding, elements of a fact (*semantic condition*).
  - ii. The elements of a statement are arranged between each other as the elements of a fact (*condition of structural consistency*).

This deconstruction of the correspondence term, presents another problem: the likewise unclear term *structural identity*, cannot be perfectly and accurately defined. Thus, image theory creates the dilemma, that it either requires the term *truth* to be clarified or that it is substituted with the less clear term *structural identity* ([Baumann 2002](#)).

- b. *Consensus theory of truth*. The consensus theory of truth is a social variant of the epistemic truth concept. In its elemental form, truth results from the consensus of everyone ([Habermas 1973](#); [Apel 1979](#); [Baumann 2002](#)):
  - i. *A statement is true if, and only if, it is rationally acceptable for everyone under ideal and optimal conditions.*



A variant of this thought can be, for example, that the range of truth is reduced. No longer is everyone then required for the consensus on the truth or falseness of a statement, only a group of a certain size. With this understanding, statements about truth are thus always to be understood relative to a group. The reference to rationality could also be dropped. To what extent the group now accepts the statements and what the sources of cognition are (from which the acceptance of the statement arises) remains intentionally open. A concept of the consensus theory of truth, altered to this effect, might be:

- ii. *A statement is true (for a group), if and only if, it is acceptable under ideal and optimal conditions for the group.*

This concept of truth implies that nothing exists or proves to be relevant in the context of a test of truth, which would not be apparent to the community/group doing the perceiving. Within the search for consensus and truth, the existence of facts and things which are independent from thought and speech of the subject striving for cognition, are not necessary conditions.

- c. *Semantic theory of truth.* Tarski's *semantic theory of truth* suggests greatly discussed in the literature. This theory achieves clarity and precision of argumentation by using the compact instrument of modern semantics. Regarding the following remarks on the semantic theory of truth, see ([Tarski 1944](#); [Tarski 1956](#); [Tarski 1993](#)) as well as ([Haak 1978](#); [Kirkham 1992](#); [Schmitt 1995](#); [Baumann 2002](#)). The attempt to enlarge Tarski's concept of truth beyond formalized languages can be found in Davidson ([1984](#)).

Tarski's vision of truth is based to a large degree on linguistics. Thus, truth (T) is determined in terms of Tarski's semantic concept as follows. It applies to s, L and p:  
 (T) "s" is a true sentence of the object language L, if it applies: p  
 s: the statement of the object language, whose validity has to be proven  
 L: object language, which expresses the statement, whose validity has to be proven  
 p: translation of the object language based statement "s" into the meta language M  
 M: meta language, which contains predicates of truth regarding object language based statements

Thus, the differentiation between object language and meta language is significant. The object language and meta language must be different from one another. In fact, a language can contain predicates of truth, their application area, though, has to be limited to other languages. Furthermore, it becomes clear that truth always refers to a language, the object language, and thus can be understood as relative linguistic truth.

- d. **Where does cognition derive from? (Source of the cognition capability)**  
 The question as to the origins of cognition, relates to positions regarding the fundamental capability to perceive. The relevance of this question becomes clear if formulated as: where does our knowledge derive from?
  - a. Experience is regarded as one source of knowledge (impressions of senses). Experience-based knowledge is called *a posteriori* or *empirical knowledge* ([Alavi, Carlson et al. 1989](#)). The assumption of this source of cognition is often oriented towards natural science theory and practical experience and is represented by the school of *empirism* ([Carnap, Hahn et al. 1929](#); [Quine 1961](#); [Berkley 1975](#); [Hume 1978](#); [Locke 1982](#); [Carnap 2003](#)).
  - b. Intellect can also be assumed as a source of cognition. An object can become a matter of cognition through the conceptual efforts of the subject, in turn through the use of a differentiation system. Non-experience-based

knowledge is referred to as *a priori knowledge*. The assumption of intellect as source of cognition is represented by supporters of *rationalism*, often also known as *apriorism* ([Leibniz 1962](#); [Chomsky 1965](#); [Hanson, Hunter 1992](#); [Spinoza 1992](#); [Descartes 1996](#); [Bonjour 1998](#)).

- c. Conciliating positions recognise both experience and intellect as sources of cognition. According to Kant, none of these features has to be preferred to another. Without a sensory element, no object would be given, and without intellect, no one perceived. Thoughts are meaningless without content, cognitions are blind without being linked to terms. Thus it is also necessary as well, to make ones terms sensory ([Kant 1999](#)).
- e. **By what means can cognition be achieved? (Methodological aspect)**  
The methodological aspect of epistemology deals with the question as to how humans perceive. This question addresses the modes which are considered to be valid for acquiring knowledge within a research process.
  - a. Cognition can be obtained *inductively* on the one hand. Induction is understood as the extension from individual cases to universal phrases ([Seiffert 1996](#)), the generalisation. An inductive conclusion means the transfer from statements via (observed, empirical) individual cases to a universal law a statement on the basis of an assumption of homogeneity on nature ([Rott 1995](#)). It is an a posteriori method which is often applied in the natural sciences.
  - b. On the other hand, cognition can be acquired through a *deductive* method. Deduction is seen as the derivation of a statement (thesis A) from other statements (hypothesis  $A_1, \dots, A_n$ ) with the help of logical conclusions ([Gethmann 1995](#)). It is the derivation of the individual from the universal and is applied, for example, in mathematical axiom systems.

The presented set of questions suggests a basis for the epistemological discussion of research approaches and offers the chance to support a comprehensive comparison of particular assumptions made. Where appropriate, this list of questions should be extended to further issues (e. g. linguistic aspects).

## Epistemological Implications — Example of a Consensus-oriented Approach

### 5.1

Simulation as a research method has several epistemological issues underlying (cp. Section 4). Consequences are, for instance, the validity claims which can be made. Therefore, the following section seeks to furthermore specify these consequences by giving a demonstrating example, the consensus-oriented approach which is deeply based on the *critical linguistic approach* ([Kamlah, Lorenzen 1973](#); [Wedekind 1979](#); [Ortner 1991](#)). The consensus-oriented approach addresses the basic epistemological assumptions (Section 4) as follows:

1. *What is the object of cognition? (Ontological aspect)*. The existence of a (real) world is assumed, which is independent of human thoughts and speech and for this reason exists even beyond human consciousness. Simulation models therefore are supposed to refer to a real world issue describing elements that are part of this real world.
2. *What is the relationship between cognition and the object of cognition?* In the context of consensus-oriented approach, specific importance is attached to the influence of subjects in the process of cognition: each cognition is seen as subject related. In this sense, the consensus-oriented approach follows the tradition of interpretivism, which becomes particularly obvious in relation to the studies of Kamlah and Lorenzen ([1973](#)). Against this background, a simulation model can be understood mainly as a linguistic (re)construction of a real world issue. For this reason, the simulation results also have to be seen as relative to an individual's subjective standpoint. For instance, in case the simulation is problem oriented, it becomes obvious that it can only address the problem perceived.
3. *What is true cognition? (Concept of Truth)*. In the context of *consensus-oriented approach* it is assumed that truth emerges through the consensus of a linguistic community. Truth is,

thus, regarded as relative to a language (semantic theory of truth) and relative towards a group (consensus theory of truth), in this case to a linguistic community. According to the consensus theory of truth ([Habermas 1973](#); [Apel 1979](#); [Baumann 2002](#)), a statement is true if, and only if, it is acceptable for everyone. Focusing certain problem domain suggests, that the reduction of "everyone" to a group of smaller size is permitted. In this context, the concept of the consensus theory of truth, altered to this effect, might be: A statement is true (for a group), if and only if, it is acceptable for the group. This implies that truth is relative to the group in which consensus was obtained about the truth or non-truth of a certain statement. In order to express the statements in form of a model several modeling languages can be used. By this means, simulation models are a formalized way of stating the consensus. Here, the formalized modeling language functions as an object-language (L). Natural language, e. g. English, can be used to discuss whether the statements within a conceptual information model are "correct". Hereby, it contains the predicates of truth regarding the object-language based statements and poses as a meta-language (M). Both languages are thus owned by the linguistic community. Consequently, the truth of certain statements made in or by a simulation model depends on the fact that a group of domain experts has agreed to them. Furthermore, agreeing to or discussing those statements, a (formal) modelling language has to be applied which is different from the (natural) language that the group of experts uses within the discussion.

4. *Where does cognition derive from? (Source of the cognition capability).* Both empirical statements ([Kamlah, Lorenzen 1996](#)) and a priori statements can be made, which form the basis statements included in a simulation model. Therefore, statements are derived via theoretical reflection as well as through observation.
5. *How does cognition emerge? (Methodological aspect).* Simulation models are artifacts that can contain both empirical and a priori knowledge. Both inductive and deductive conclusions can be accessed in the context of the model creation. Here, single statements are generalized based on a set of individual tests (induction). Creating a simulation model can, however, can be achieved deductively as well, for example by attaching object-class-specific attributes to model elements on the basis of their linkage to certain object classes.

## 5.2

Thus, consensus-oriented approach is strongly influenced by the critical linguistic approach by Kamlah and Lorenzen ([1984](#)). The simulation models developed contain formalized linguistic statements. If these models are valid, depends on the expertise of the members of the group that made up the simulation model. Their expertise is supposed to be derived from the application of additional (empirical) research methods. This is done through members of a linguistic community in order to obtain consensus. Therefore, elements of the semantic theory of truth and the consensus theory of truth are considered and used. With the help of this instance, we demonstrated how the epistemological framework developed can be applied for discussing the epistemological assumptions and their implications for simulation.

## 5.3

As a consequence, communication of simulation research results varies. Those researchers assuming that objective cognition would be possible in general (2a) have to clarify what steps they have undertaken to gain "objective" knowledge and how they devolved the researching subject from the research process. Their maxim thus is: Explain how objectivity is achieved. On the other hand, those researchers denying the possibility of objective cognition (2b) have the following maxim: Explain which influence the subject has on the research process. In the case of the consensus-oriented approach to simulation model building, one has to first clarify the terms used within the language community. Furthermore, the researcher's individual proposition regarding the research aims have to be pointed out.



## Conclusions and Further Research

## 6.1

Simulation is a research method which bases very much on formal models. But considering the model, a variety of epistemological statements is (implicitly) made. The publication of these epistemological statements is mandatory due to the fact that they profoundly influence the validity and the reliability of research results. An epistemological framework was used to analyze and to systemize epistemological assumptions. Five epistemological questions appearing most relevant in this context were made obvious and discussed. The consensus-oriented approach was used as an example of how the epistemological framework can be applied.

## 6.2

As future research, the framework presented here has to be applied for explicating the assumptions of other research methods. By doing so, it will be possible to analyze the interdependencies of epistemological assumptions of simulation and those other research methods which are used to collect information used to make up the simulation model.



## Notes

<sup>1</sup> This question cannot be answered dichotomously. In philosophy, miscellaneous approaches towards clarifying the term *truth* are discussed. In this article, we will thus present a selection.



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