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Abstract

This study seeks to situate the philosophical discussion on models and scientific representation within the larger context of questioning representation that is taking place in other fields, especially in science and technology studies. It addresses four related questions: (i) What kinds of different reactions there have been to the puzzle of representation? (ii) From where do the seeming epistemological difficulties concerning representation stem? (iii) How can representation be approached in a non-representationalist way? (iv) What kinds of things are models, and how do they give us knowledge?

A new artefactual approach to models is advanced that loosens the epistemic value of models from representation and ascribes it instead to their materially embodied constraints and interactive enablings. The thesis draws four additional major conclusions: (1) Our understanding of modelling should not be reduced to models representing some external target systems. Apart from being representative things models are typically also productive things whose workability and experimentability is crucial for their epistemic value. (2) Representation should be approached both from the use and production points of view. (3) From the use point of view representation appears as a two-fold phenomenon that is based both on the medium-specific affordances of the material sign-vehicle and on the intentional process of relating the sign-vehicle to the represented. (4) From the production point of view a major portion of the work of representation that is taking place in sciences concentrates on what is already represented and modelled somehow. Looking at representation from this angle stresses the methods, ingredients and various representative devices that are needed in producing models.

The study consists of a contextualising introductory essay and six original research papers. The first two articles deal with more general issues concerning representation. The next four articles study representation in the context of modelling. Common to all of them is the idea that models can be seen as epistemic artefacts. The articles refer to this idea in discussing the interrelated questions of representation, modelling, and cognition.

Contents

Preface

My fascination with the question of representation has been the red thread running through my travels in different disciplines, and it has finally led me to the completion of this doctoral dissertation in philosophy. While taking my first Master's degree in economics, I started to wonder how seemingly very austere and unrealistic economic theories and models are able give us knowledge about our complex economic life, what kind of knowledge that is, and, ultimately, what science is all about. In the philosophy courses given in the Helsinki School of Economics I came to understand that these problems were philosophical in nature. I wish to express my gratitude to Professor Uskali Mäki for this insight, for his teaching and for the scholarly example he has set over the years.

I probably would never have started to work on this doctoral thesis had I not studied semiotics at the end of 1990's. The circle of semioticians that surrounded Professor Eero Tarasti at the University of Helsinki was international, liberal and yet academically ambitious, and this spirit can, I think, be attributed directly to Eero Tarasti himself. Over the years I have participated in various projects and events under his leadership, and I am grateful for his considerate guidance and assistance.

In the Center for Activity Theory and Developmental Work Research I found the same kind of multidisciplinary and active milieu that I had experienced in semiotics. I was fortunate to be a doctoral student in the Center during the years when it was among those units at the University of Helsinki that had been nominated by the Academy of Finland as Centers of Excellence. Many foreign guest lecturers and research fellows visited the centre and Professor Yrjö Engeström led all of this activity in a very convincing and expansive manner. I wish to thank all the personnel of the Center for Activity Theory and Developmental Work Research, especially Ritva Engeström, Jaakko Virkkunen, Leena Harjula-Jalonen and Heli Kaatrakoski.

I have been blessed with three supervisors, who all have contributed to this dissertation in different ways. The long and

enthusiastic discussions I have had with Professor Reijo Miettinen about the importance of artefacts have obviously had a great effect on how I conceive of models. Moreover, my participation in the remarkable research group led by Professor Miettinen has taught me that science is above all a collaborative and collective effort. Professor Ilkka Niiniluoto supervised my thesis before becoming Rector of the University of Helsinki. I am grateful for his help and encouragement, above all for his open-minded attitude to philosophy. Professor Matti Sintonen has guided me through the difficult (and admittedly nervewracking) phase of finishing this thesis. He has been supportive and always on hand to answer my questions. Moreover, I owe him a lot for his insights into the history of philosophy.

Professor Fred Karlsson, Professor Timo Honkela and Docent Atro Voutilainen have helped me substantially with the case studies on language technology and neural network modelling. In addition, both Honkela and Voutilainen co-authored one of the articles I am submitting as a part of this thesis. Erika Mattila has been my helpful partner in our common endeavour to understand modelling better, loyal both in good and bad days—and always ready to work even harder.

My special thanks go to the following colleagues and friends with whom I have collaborated in recent years and from whose advice and generosity I have benefited: Kristian Bankov, Marcel Boumans, Sampsa Hyysalo, Hanna Johansson, Timo Kaitaro, Marja-Liisa Kakkuri-Knuuttila, Jonna Kangasoja, Sakari Katajamäki, Hannele Kerosuo, Janne Lehenkari, Aki Petteri Lehtinen, Juha Leminen, Johannes Lenhard, Andrea Loettgers, Endla Lõhkivi, Martina Merz, Sami Pihlström, Veikko Rantala, Kristina Rolin, Max Ryynänen, Jussi Silvonen, Juha Tuunainen, Marja Väätäinen and Petri Ylikoski. I also want to thank Henry Fullenwider and Marjatta Zenkowicz warmly for English-language revision of some of the manuscripts, and Tinde Päivärinta for the layout of this book.

I am grateful to Professor Mary S. Morgan and Professor Mauricio Suárez, whose work I greatly appreciate, for agreeing to pre-examine my thesis and comment on it.

Scholarships from the Finnish Cultural Foundation and the Research Funds of the University of Helsinki made it possible for me to finish this thesis. I have received travel grants from the Chancellor of the University of Helsinki, the Finnish Konkordia Fund and the

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Finally, it is ultimately people who make academic life a worthwhile endeavour. More often than not, colleagues become friends and sometimes they become more than friends. I am so happy that I have been able to share so many things with Susanna Välimäki and Harri Veivo. What funny, witty and caring companions you have been.

As for family and friends, I wish to thank one and all (some of whom have already been mentioned above). And I am ever grateful to my parents Raili and Petteri Knuuttila, my husband Panu Savolainen, my nephew Jan, my daughter Laura and son Sauli for all their love and care!

I dedicate this book to my beloved sister Petra Anneli (1962-1999), who would have loved to see me making it.

Helsinki, October 2005
Tarja Knuuttila

List of original publications

1) Knuuttila, Tarja (2003), "Is Representation Really in Crisis?", *Semiotica* 143: 95-111.

2) Knuuttila, Tarja (2002), "Signing for Reflexivity: Constructionist Rhetorics and Its Reflexive Critique in Science and Technology Studies", *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, [On-line Journal], *3*(3). Available at: http://www.qualitative-research.net/fqs-texte/3-02/3-02knuuttila-e.htm (52 paragraphs).

3) Knuuttila, Tarja and Atro Voutilainen (2003), "A Parser as an Epistemic Artifact: A Material View on Models", *Philosophy of Science* 70 (Proceedings): 1484–1495.

4) Knuuttila, Tarja (in press), "Models, Representation, and Mediation", *Philosophy of Science* 72 (Proceedings), 2005.

5) Knuuttila, Tarja (in press), "From Representation to Production: Parsers and Parsing in Language Technology", in Johannes Lenhard, Günther Küppers and Terry Shinn (eds.), Simulation: Pragmatic Constructions of Reality. *Sociology of the Sciences Yearbook*. New York: Springer, 2006.

6) Knuuttila, Tarja and Timo Honkela (in press), "Questioning External and Internal Representation: The Case of Scientific Models", in Lorenzo Magnani (ed.), *Computing, Philosophy, and Cognition*. London: King's College Publishing, 2005.

Part 1. Summary

1. Introduction

1.1 Background

If there is any theme that unites the heterogeneous postmodern discussions in the fields of philosophy, humanities and cultural theory, then representation is certainly a good candidate. Different "postist" movements such as poststructuralism, postcolonial theory and certain currents of feminism have questioned representation in several ways. The main thrust of these critiques has been that our cultural representations are not to be trusted since there is no way for us to ascertain whether they (re)present their objects—or reality—truthfully. Moreover, this scepticism has concerned even scientific representations which especially in the field of science and technology studies have been "unmasked" as more or less contingent, and thus questionable, products of their times. The outcome of the recent discussion has been that there is something wrong with our received notion of representation, which conceives of knowledge as accurate representation of the independently existing world. In this sense the crisis of representation is not a new phenomenon, but can be dated back at least to the beginning of the 20th century, where it can be found for instance in abstract art in general, dadaism and cubism. When it comes to science, already both John Dewey and Martin Heidegger criticised the idea of knowledge as that of spectating the world as a picture,[1] a theme that was picked up by Richard Rorty in his seminal and controversial *Philosophy and the Mirror of Nature* (1980). This book can be regarded as a successful manoeuvre in bringing the notion of representation to the centre of the debate in analytical philosophy as well.

Neither was representation of central interest in the philosophy of science before the 1980's.[2] The term representation was not often used, and when it was, it was neither thematised nor questioned. In the 1980's the situation started to change largely due to the semantic approach to models. As the semantic approach loosened itself from the linguistic paradigm of the received view and began to conceive of theories as extra-linguistic entities, as families of (theoretical) models,

[1] Cf. Dewey's critique of the "spectator theory of knowledge" in Dewey (1929), and Heidegger's famous essay "The Age of the World Picture" in Heidegger (1977).

the question then became how these entities were linked to the world. Unlike with propositions and sentences, such terms as "true" and "false" did not seem to be apt in dealing with the relationship between models and their target systems. "Representation" was more appropriate.

This turn away from truth to representation also implied for many a definite change in how science was perceived. As Woodward has noted: "The notion of [adequate] representation is a more general idea than the notion of a statement's being 'true', with representation having to do with a qualitative notion of 'fit' between a model and world—a notion that admits of degrees" (2002, 380).[3] For some, the notion of representation has even served as a way to circumvent the question of realism altogether (see e.g. Frigg 2003, 12).

Now, twenty years later, a lively discussion concerning scientific representation is in full sway but it is largely still conducted in relation to scientific models and more recently, simulations (e.g. Winsberg 1999). This is actually quite remarkable. It suggests, among other things, how internalistic[4] this discussion has been. Indeed, Callender and Cohen have recently claimed that the specific problem

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[2] Of course there were notable exceptions among the analytical philosophers, such as Sellars (1968) and Rosenberg (1974). However, it was typical for the so-called linguistic turn of the analytical philosophy to use such terms as meaning, sentence and proposition, rather than representation (see Rorty [ed.] 1992). Nevertheless, it can be claimed, as Rorty (1980) in fact does, that in the background of this linguistically oriented philosophy there still loomed the old problem of representation, which motivated both the empiricists and idealists in their battle against scepticism. See Popkin (1980) on the constitutive role of the problem of scepticism in Western philosophical thought.

[3] Pace Woodward, the notion of truth can also be made to admit of degrees: sentences or statements can be classified according to their closeness to truth, that is according to their degree of *truthlikeness* or *verisimilitude* (see e.g. Niiniluoto 1999).

[4] By "internalistic" I do not refer to the internalism/externalism debate in epistemology (or in the philosophy of mind) but to the discussion in the sociology of scientific knowledge on whether or not science should be approached as a conceptual and rational activity only. To the extent that philosophers have tended to take this view on science, it has led them to be internalistic also in the sense of rather staying inside their own discipline. The relatively recent "return" to naturalism has changed this attitude quite a bit (see the section 1.3).

of scientific representation is a non-problem and that the discussion of *scientific* representation has neglected "the philosophical work on representation in general" (2005, 2). I think that there is a grain of truth in their accusation even though it misconstrues much of the work done in the burgeoning field of scientific representation. For one thing, the philosophical writers on scientific representation have (pace Callender and Cohen) considered the question of scientific representation in a larger framework: for instance several authors have related their discussion of representation in science to representation in art (e.g. Suárez 1999, French 2003, Frigg 2003). Ronald Giere's work on scientific representation has drawn resources from cognitive science throughout the years.

Having admitted this, it nevertheless seems to me that the present discourse on scientific representation has remained a rather solitary enterprise. It has been first and foremost interested in how (and by virtue of what) models represent reality. That science is a hugely complex and historically layered artefactual and representative enterprise has been largely ignored in this discussion, which has mainly been focused on ready-made models isolated from the practices of their production.

Another peculiar character of the philosophical discussion of scientific representation, also due to its internalistic character, is the way it has succeeded in remaining nearly totally untouched by the critical discussions concerning the notion of representation in the other fields of inquiry. The discussants have agreed that models are representative entities—otherwise, it has been supposed, they cannot give us knowledge—even though no common understanding of what representation involves has emerged. To be sure, already in 1983 Ian Hacking in his *Representing and Intervening* proposed shifting the focus of the philosophy of science from representing to intervening. This was an interesting move indeed—and far ahead of its time—taking into account that philosophers of science did not generally understand scientific endeavour in terms of representation in those days.

By the time Hacking was writing the turn to intervening was something that had already taken place in science and technology studies (STS), where the so-called laboratory studies aiming at accounting for how scientific facts were produced in scientific work were accumulating (Latour and Woolgar [1979]1986, Knorr Cetina 1981, Lynch 1985a). But the question of representation kept on coming

back. It refused to be repressed—if only because the constructivists presented their laboratory stories as descriptions of what "actually" took place in scientific "practice". This led not only to discussions of the problem of reflexivity (Woolgar [ed.] 1988) but also to some insightful studies on how representations are constructed with the help of diverse means and procedures (Lynch and Woolgar 1990), how they function as "working places" (Amann and Knorr Cetina 1990) and as "immutable mobiles" that "draw together" things and diverse activities (Latour 1990).

Another source from which the philosophical work on scientific representation could have taken nourishment, but in fact has not done so (with such notable exceptions as Ronald Giere and Paul Thagard) is cognitive science and the philosophy of mind. Especially in cognitive science some fundamental representationalist assumptions concerning the interrelationship between cognition and representation have been called into question by researchers studying the importance of environment and artefacts for what can be called "embodied, situated and distributed cognition" (Clark 1999; see also Varela et al. 1991, Hutchins 1995, Clark 1997). These studies have in part contributed to the recent discussion of the notion of mental representation, where different standpoints vis-à-vis representation have been taken, ranging from adopting less metaphysically impregnated words and expressions such as "tools for thinking" instead of "representation " (Dennett 2000) to arguing for a need to "rehabilitate representation" (Smith in Clapin [ed.] 2002).

An interesting feature of the above-mentioned discussions in the field of STS and cognitive science is that, irrespective of their scepticism concerning our representationalist heritage, they have actually resulted in fresh approaches to representation—leading also to radical reconstructions of what should count as knowledge and cognition. Nothing like that, I claim, has yet happened in the philosophy of science. Even so, I think that at least two features of the discussion of scientific representation should make this discussion rewarding also from a more general point of view. Firstly, the recent work on scientific representation has focused on specifying and evaluating the relative merits of different dyadic and triadic accounts of representation (e.g. Giere 2004, Suárez 2003 and 2004, Frigg 2002 and 2003, Bailer-Jones 2003). The relevance of this kind of theoretical work is not limited to scientific representation only. Secondly, philosophers are now seriously interested in studying the functioning

of specific models in scientific practice. The volume *Models as Mediators*, edited by Mary S. Morgan and Margaret Morrison (1999), can be seen as an epitome of this kind of work. In the introductory articles of that book they lay the basis for a research programme for studying models from the point of view of scientific practice (Morrison and Morgan 1999a, 1999b). Morrison and Morgan's approach to models as mediating instruments provides a potential bridge between philosophical theorising and the more practice-oriented approach of STS.

The almost non-existent dialogue between the aforementioned different discussions of representation in general and scientific representation in particular set the double agenda of this thesis: On the one hand I situate the philosophical discussion of scientific representation in the larger context of questioning representation that has taken place in other fields, especially in STS. On the other hand I take part in the discussion of models and representation in the philosophy of science. The red thread that ties these interests together is the material and artefactual approach to representation that I am both developing and arguing for in this dissertation. What is special about this approach is that it gives a non-representationalist account of scientific representation.

1.2 Aims and plan

As already hinted by the double agenda adopted, the aims of this study range from the more general to the more specific. At the most general level, the goal of this study is to investigate the philosophical or, more exactly, the epistemological problem of representation that seems to underlie the recent critiques of representation. Thus, I *first* study the various different reactions to the puzzle of representation. *Secondly*, on this basis I attempt to diagnose the causes of the seeming epistemological difficulties concerning representation. The hypothesis guiding this study is that the so-called problem of representation: i.e. "how is it possible for one thing to represent something else?" (Crane 1995, 9), is due to our representationalist heritage and that representation need not be understood in a representationalist way. This leads me, *thirdly*, to set as my next goal the developing of a non-representationalist approach to scientific representation. Since the discussion of scientific representation has so far taken place in the context of modelling, my aim of developing an alternative approach to

scientific representation entails, *fourthly,* answering the question of what kinds of things scientific models are and how they give us knowledge.

The underlying assumption of this study is that scientific representation is a very good place to study the puzzles of representation and representationalism. This is due to science being perhaps the one human activity that is most critically dependent on the representationalist notion of representation. We are accustomed to thinking that our scientific theories and models refer to an independently existing reality outside of them and that they can at best be considered as truthful, or accurate, descriptions of it. On the other hand, however, sciences typically study unobservable entities with the most sophisticated investigative machinery created by humans so far, which makes the question of scientific representation especially challenging. Last but not least, to inquire into representation is to inquire into the nature of knowledge as well. The epistemic value of models has traditionally been attributed to their representative dimension. Thus studying how scientific models give us knowledge—and what this knowledge is like—helps us to understand more generally in which ways representation, knowledge and, ultimately, cognition are intertwined.

That this dissertation consists of individual articles has some consequences for how its aims are tackled. Since articles typically focus on relatively narrow questions, part of the background of these more specific topics is provided by the present summary (Part 1). Hence to contextualise the individual articles and to give them a common raison d'être, I discuss first what is meant by the notions of representation and representationalism and how these concepts are related to one another. Then I take up the phenomenon of the crisis of representation from the point of view of scientific representation.[5] I study the diverse ways in which certain recent authors have sought to settle the problem of representation and ask whether or not we should renounce the concept of representation altogether or rather strive to interpret it in a different way. As I do not think that it is possible—or

[5] Despite the institutional differences and different goals of art and science, the question of representation provides a common point of view from which the specific features of art and science can be fruitfully compared and examined (see e.g. Baigrie, ed. 1996 and Jones and Galison, eds. 1998).

even desirable—to renounce or deconstruct the notion of representation entirely, my discussion of models is an attempt to show how the problem of representation could be dealt with in a positive way—yet taking into account the recent critique of representationalism.

I suggest that in trying to approach representation in a fresh way one should resist the traditional temptation to ground the representative power of actual representative artefacts in primary immaterial and ideal representations (e.g. abstract structures, "mental models" or concepts). Instead, the actual processes of scientific representing should be analysed from the epistemic point of view. This means focusing on the production and use of materially embodied representations. Along these lines I approach models, which have generally been regarded as representations, and advance an alternative conception of models as epistemic artefacts.

The main points of this thesis can be summarised as follows: i) models are human-made artefacts which are used to interact with the world rather than merely to represent it; ii) thus instead of being abstract theoretical constructions they are better conceived of as entities that are materialised in some media; iii) the epistemic value of models accrues importantly from their material dimension, which explains why models have many other epistemic functions besides that of representing the world; iv) the representational function of models should not be approached in "representationalist" terms; v) representation is best understood as activity that relies both on the medium-specific affordances of the material sign-vehicle and the intentional process of relating the sign-vehicle to its object.[6]

1.3 A note on the method

Being careful examiners of other scientists' methods and presuppositions, philosophers of science were remarkably silent on their own method until recently when the discussions of naturalism (see e.g. Giere 1988 and 1999; Kitcher 1992, Downes 1993) and the disunity of science (Dupré 1993, Galison and Stump 1996) swept over the field. As to the discussion of naturalism Philip Kitcher (1992) argues that philosophy of science is slowly (re)turning to the

[6] I am grateful to Mauricio Suárez in helping me to explicate the main points of my thesis.

naturalist epistemology. It is based on rejecting either one or both "Post-Fregean" assumptions of how to pursue epistemology. According to them, epistemology should be both an *apsychological* and an *a priori* investigation—"knowledge is to be given a 'logical analysis'" (57). These assumptions were constitutive for analytical philosophy for decades. Accordingly, "for at least a period, philosophers could be confident of their professional standing, priding themselves of a method—the method of conceptual analysis—which they, and they alone, were trained to use" (54).

On the level of doing philosophical research, the naturalist epistemology means that we should take seriously the results of scientific research. According to Giere "any conclusions one reaches about the nature of science are subject to criticism based on theoretical, historical, psychological, or social investigations into particular scientific practices" (1999, 5; see also Giere 1988, 8-10). Thus as a result of adopting the naturalist epistemology my work is also multidisciplinary. In tackling the problem of representation I have drawn resources from semiotics, STS, activity theory (see Engeström and Escalante 1995, Engeström et al. 1999, Miettinen 2001) and distributed cognition. What is common to these approaches is that they, in one way or another, concentrate on mediation provided by signs or tools in explaining human activity and cognition. Furthermore, several of the articles of this study participate also in the philosophically inclined discussions in the aforementioned fields. Last but not least, my approach to the problem of representation is uncompromisingly naturalist in the sense that I do not want to posit any fundamental representations behind those things that we actually use in scientific practices in order to represent.

Provided that we accept the results of empirical science as part of philosophical reasoning, should we then stop at that? Is there a place for empirical study in philosophical argumentation? I think that there is, if only because a lot of research done in the philosophy of science proceeds by presenting cases from specific disciplines, taking historical data into account as well. Since I approach representation and modelling from the point of view of scientific practice, I have felt a need to get some grasp of the practices themselves. Thus in one of the studies concerning modelling ("From Representation to Production: Parsers and Parsing in Language Technology") I present a case of modelling in language technology in which I use interviews of the researchers working in the field. This is partly because research

on the procedures and phases of modelling is largely non-existent, and knowledge of it remains largely at the tacit participant-level.

My empirical data consists of 24 transcribed semi-structured interviews that I conducted in two phases between the years 2000 and 2002 and in spring 2004 with researchers and developers of language technology who have either been doing language technological research in the Research Unit for Multilingual Language Technology in the Department of General Linguistics in University of Helsinki, or have been otherwise affiliated to the group. The key researchers and developers were interviewed more than once for a relatively long period (from 1 ½ hours to 3 hours). The written material on which the case study is based consists of publications of the researchers interviewed, other literature on computational linguistics and language technology, and some reports and documents concerning the Research Unit for Multilingual Language Technology and language technology in Finland in general. I have also benefited from casual discussions with the language technologists, attended some courses on language technology and taken part in language technological events and activities. Moreover, I have been observing a language-technological project funded by National Technological Agency of Finland (TEKES), in which researchers from the Department of General Linguistics have participated. Some of the researchers interviewed also commented on the earlier drafts of my papers on language technology, and Study 3 "A Parser as an Epistemic Artefact: A Material View on Models" was co-authored by Atro Voutilainen, a member of that team.[7]

As for the claims of the disunity of science, it is already widely acknowledged that physics may not provide an appropriate model for approaching other sciences. Yet, in discussions of modelling the theoretical models of physics are typically taken as representatives of models in general. In this study I have instead used models from the fields of computational linguistics and artificial intelligence as examples. One of the purposes for choosing them has been to show the limitations of the traditional notion of models as representations of their target systems. As the traditional notion fits inadequately these models, I wish to articulate an approach to models that would suit them better. I do not claim that the computational models I have chosen can serve as representatives of models in general—if only because no model can. Nevertheless, the importance of computational models and simulations in science is constantly increasing and in fact

creating new fields of inquiry. On the other hand, I would like to suggest that the notion of models as epistemic artefacts is useful as a general approach to models, as a way of viewing them from another angle than has been customary.

2. Representation and its discontents

2.1 The concept of representation

The word representation comes from Latin *raepresentare* "to make present or manifest or to present again" (Pitkin 1967, 241). It was almost exclusively applied to inanimate objects, the political idea of human beings representing each other appeared only after the fourteenth century (ibid.). In her etymological study of the concept of representation Pitkin describes the meaning of *raepresentare* in the following way:

> It can mean to make them [inanimate objects] literally present, bring them into someone's presence, accordingly it also comes to mean appearing in court in answer to summons, literally making oneself present. It can also mean the making present of an abstraction through or in an object, as when a virtue seems embodied in the image of a certain face. And it can mean the substitution of one object for another, instead of the other (Pitkin 1967, 240).

The modern usage of representation developed from the latter meaning of the aforementioned quotation (Volli 2003).[8] Thus, for instance, Prendergast (2000) discriminates between two basic meanings of the term: between the older "re-presentation" and the

[7] It appears to me that since scientific inquiry is nowadays so specialised and heterogeneous, the philosophers and other researchers who are studying science should work collaboratively, or at least in constant dialogue, with the scientists whose work and discipline they are examining (unless they themselves have some experience of the field of inquiry in question). The ethnographical approach to scientific work, once so popular among STS researchers, was successful in making scientific work and its material dimension visible. However, I do not think that "anthropological observation" per se could help us get any more than a superficial understanding of the content and methods of different disciplines.

more recent "standing for". Instead of striving to produce the illusion of presence, to re-present, the representative relation of standing for is that of substitution, of substituting something absent with something present. The substitution can take the form of simulacrum, but it is a form of representation as making present (in the older sense of representation) only if it produces an illusion of presence by virtue of being an accurate replica of the real thing.

As distinguished from "re-presentation", representation as "standing for" is not to be confused with the thing itself. Pitkin notes how representation as "standing for" seems to require a certain distance or difference as well as resemblance and correspondence (1967, 68). Representation as "standing for" is typically approached through the metaphors of portrait, map or mirror: what they have in common is that they are all renderings of an "original" in a medium different from it. Thus the function of representation as "standing for" is to bring knowledge: it "consists of the presence of something from which we can draw accurate conclusions about the represented, gather information about the represented because it is in relevant ways like the represented" (Pitkin 1967, 81). When applied to political sphere this idea of representation provided a justification for representative democracy. The substituting representatives for the whole people were like a copy, a second-best approximation of direct democracy, which would have been the ideal system according to the Anglo-American democratic ideology (ibid., 84).

As for my focus on the epistemic value of models, I find Pitkin's evaluation of representation as "standing for" in the political realm insightful: "…[this] view of representation … does not allow for an activity of representing. … It has no room for any kind of representing as acting for, or on behalf of, others; which means that in the political realm it has no room for the creative activities of the representative legislature, the forging of consensus, the formulating a policy" (90). In fact, I am going to claim in this thesis that treating models as

[8] There have been, of course, many other conceptions of representation, but representation as "standing for" seems to be the most common and prevailing one (see e.g. Peirce CP 2.273; Palmer 1978, 262; Crimmins 1991, 791). Even though typical for the modern period, it originates from the scholastic *aliquid stat pro aliquo*. However, Nöth (1995) claims that medieval philosophers used more often another formulation, namely *supponit aliquid pro aliquo*, which means "something serves in place of something else" (84).

predominantly representative entities—as surrogates that stand for—ignores their material and interactive side, from which their heuristic, mediating and many other epistemic capabilities arise.

2.2 Representationalism

Representation as "standing for" seems to be embedded in *representationalism*. According to representationalism, the sensing and knowing mind cannot have direct acquaintance with its objects. It can approach them only through ideas, which are assumed to represent them. Thus knowledge is conceived of as an assemblage of representations that reproduce accurately, i.e. stand truthfully for, what is outside the mind (or, after the "linguistic turn", outside linguistic description—or other external representations) (see e.g. Rorty 1980, 3-6; Gutting 2001, 336). The crucial difficulty of representationalist theory is that the mind "supposes" that its ideas represent something else but it has no access to this something else except via another idea.

The conception of a mind as container of ideas is most commonly associated with Locke. He was criticised already by other empiricists, but he nonetheless succeeded in articulating the way the early modern age thought about perception and knowledge. In his *Les mots et les choses* (1966) Michel Foucault claims that this age, the "Classical Age" as he calls it, was that of representation par excellence. It strove for a universal method of analysis that would perfectly order representations and signs to mirror the real orderings. Language coincided with thought, it was the transparent system of signs that represented the representation, that is, the ideas. Moreover, it was assumed that language by its very nature made successful representation possible, which led Foucault to characterise "classical language" as "the common discourse of representation and things" (1970, 311). Thus the Classical age relied on the ability of language to represent the world as it is, but as a consequence man as representer was left out of the "picture". This is what Foucault aims to show with his lengthy analysis of Velásquez's painting *Las Meninas*, to which the first chapter of *Les mots et les choses* (1966) is dedicated. Foucault takes *Las Meninas* to be a perfect image of Classical representation, which makes the different aspects of representation visible, yet leaving them dispersed because there is no "unifying" subject. The mirror behind the painter shows what he sees and what he is in the process of

depicting on his canvas, the ruling couple Philip IV of Spain and his wife Mariana. Yet neither the painting itself nor the act of painting are shown in *Las Meninas*: the painter is standing back from his work; if he had been in the process of painting, he would have disappeared behind the canvas. Moreover, as spectators, we realize that the royal couple is in fact standing in our place—everything else is depicted except the subject of representation and the act of representing.

As the Modern age no longer treated discourse as a perfectible and transparent medium, the representational capacity of man became available as a distinct object of knowledge. Foucault remarks how Kant and the age that followed him did not complain about man's limited capacity to know how things are. They rather turned it into an advantage, a condition of all factual, empirical knowledge. Epistemology, as an attempt to explain and *justify* how things in general can be given to representation, was born. Foucault writes:

> The Kantian critique…questions representation, not in accordance with the endless movement that proceeds from the simple element to its possible combinations, but on the basis of its rightful limits. Thus it sanctions for the first time that event in the European culture which coincides with the end of eighteenth century: the withdrawal of knowledge and thought outside the sphere of representation. That space is brought into question in its foundation, its origin, and its limits: and by this very fact, the unlimited field of representation, which Classical thought had established…now appears as a metaphysics (Foucault 1970, 242).

Interestingly, whereas for Foucault Kant broke away from the representationalist paradigm, in the alternative philosophical story of representationalism provided by Richard Rorty, Kant more or less perfected it and thus laid down the lines for the representationalist tradition of (analytical) philosophy to come.[9] In his *Philosophy and the Mirror of Nature* (1980) Rorty claims that two assumptions have dominated the representationalist tradition of Western philosophy. One is the Kantian, according to which human knowledge should be understood as a special relation between the objective knowledge substrate offered by the world and the active cognitive abilities of the subject. The other assumption is the platonic belief that there is a way to portray things that can reach them as they are. However, also for Rorty the representationalist tradition has roots in the beginning of the modern age. Rorty sees representationalism as a reaction to the

emergence of the new natural sciences, which led to the relocation of the intentional and phenomenological in the realm of the mental. Thus philosophy turned to inspect the ideas in the mind. The rationalists and the empiricists alike tried to establish a secure foundation for knowledge, and that foundation was to be found from inside of the mind. The earlier distinction between appearance and reality was replaced by that between inner and outer and the question became "How can I escape the veil of ideas?" (1980, 160). Kant provided this an elegant answer, according to Rorty, by changing the empiricist question of psychophysiological mechanisms into a discussion of the legitimacy of science itself (1982, 145). He took up an unresolved scientific problem—the relation of sensations to their objects—and turned it into a question about the possibility of knowledge, which question was to be resolved in the sphere of representation. Thus Rorty holds Kant responsible for the foundational pretensions of philosophy: "the Kantian picture of concepts and intuitions getting together to produce knowledge is needed to give sense to the idea of 'theory of knowledge' as a special philosophical discipline" (1980, 168).

It is important to bear in mind that Rorty's anti-representationalism is not only an attack against the notion of representation as "mirroring", corresponding or resembling but even more importantly against what he calls "privileged representations"

[9] Rorty seems not to pay enough attention to the fact that for Kant the activity of thinking is not mimetic but constructive (Rusterholz 2003, 53). Kant can be considered one of the founding fathers of constructivism. As Matti Sintonen (1995, 1996) has argued, the gist of Kant's transcendental method and of the entire "Copernican Revolution" was in acknowledging the active contribution of the mind. The transcendental method in epistemology requires not just that one examines the objects of putative knowledge but also that one focuses on the conceptual tools used in knowledge acquisition as well as on what one must do to obtain knowledge. Nor does this constructivism confine to the representation of the external world. Jaakko Hintikka (1973, 1974) has maintained that there is a close relationship between Kant's transcendentalism and his theories of space, time, and mathematics. On these themes, see Sintonen (2005, forthcoming). Also Sismondo (1996) and Hacking (1999) consider Kant to be the forefather of constructivism, Sismondo even dubs the whole STS constructivism the "Neo-Kantian science".

and their privileging of philosophy.[10] This clearly emerges from the following short resume of his antirepresentationalist story:

> To describe this development as a linear sequence is of course simplistic, but perhaps it helps to think of the original dominating metaphor as being that of having our beliefs determined by being brought face to face with the object of belief (the geometrical figure which proves the theorem, for example). The next stage is to think that to understand how to know better is to understand how to improve the quasi-visual faculty, the Mirror of Nature, and thus to think of knowledge as an assemblage of accurate representations. Then comes the idea that the way to have accurate representations is to find, within the Mirror, a special privileged class of representations so compelling that their accuracy cannot be doubted. The privileged representations will be the foundations of knowledge… Philosophy as epistemology will be the search for the immutable structures within which knowledge, life and culture must be contained—structures set by the privileged representations, which it studies. (Rorty 1980, 163).

Rorty's reconstruction of the history of Western philosophy is not only provocative but also revealing. It is indeed not difficult to find privileged representations in which philosophers have sought to ground their endeavour: ideas, concepts, logical forms, Husserlian "essences"… and structures, which have featured importantly in the discussions of models and representation.[11]

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[10] According to Rorty, the turn to language did not entail any notable change for the representationalist tradition of philosophy, since analytical philosophy attempted to formulate many traditional epistemological problems by linguistic means. In *Why Does Language Matter to Philosophy?* (1975) Hacking expressed a similar view. He calls the early modern age the "heyday of ideas", whereas he considers himself to be writing in the "heyday of sentences". Hacking notes how language was not an interesting problem during the heyday of ideas, which was instead interested in "mental discourse". Hacking nevertheless claims that "the structure of the recent philosophical problem situation... is formally identical to the seventeenth century one, but the content of that structure is different" (1975, 167). The problem of the "interface between the knower and the known" has remained much the same, but public discourse has replaced mental discourse and sentences have replaced ideas.

2.3 Against representation?

The remarkable thing about the "postmodern" discussions of representation and representationalism is that they have been conducted nearly exclusively in negative terms. The concept of representation has been found lacking both in theory and practice. Theoretically, it seems that our Kantian heritage has left us captives of the sphere of representation. Either representation cannot reach the things in themselves, providing only a deficient substitute for them, or then it creates an effect of reality that it strives to capture, but in vain (because there is nothing to capture—according to the most adamant poststructuralists). Hence it is hardly astonishing that the question of representation has been a subject of constant *epistemological* concern and even *horror* (an expression by Steve Woolgar). Moreover, at a practical level, given the diversity of the representations we use and the complexity of our practices of representation, it seems clear that the general concept of representation as "standing for" does not help us much in explaining what kinds of things representations are and how they are supposed to represent.

In this situation many have felt that something needs to be done—but what? At least three different positions vis-à-vis the problematics of representation have been taken. Some wish to renounce representation and simply evade the problem as unproductive and unfruitful. Then, instead of putting the question of representation aside, one can attempt to deconstruct the notion—to show that in talking about representation we are actually talking about different ways of rendering, referring to, denoting, indicating, etc. that do not share any common core that entitles us to call them representations. Finally, one can seek to reconstruct our notion of representation in such a way that it pays due attention to the criticism.

Renouncing representation

In *Philosophy and the Mirror of Nature* Rorty (1980) concludes that it is time to break with the received epistemological framework and to stop

[11] On the other hand this predilection for privileged representations has been typical of the cognitive sciences as well, where such hypothetical entities such as concepts, symbolic structures, mental models, prototypes, schemes, etc. have been ascribed to our minds to explain our cognitive capabilities.

thinking of knowledge in terms of representing accurately that what is outside the mind and, subsequently, language. Actually, we should stop thinking about language in terms of representation entirely:

> We must get the visual, and in particular the mirroring, metaphors out of our speech altogether. To do that we have to understand speech not only as not the externalizing of inner representations, *but as not a representation at all*. We have to drop the notion of correspondence for sentences as well as for thoughts and see sentences as connected with other sentences rather than with the world. We have to see the term "corresponds to how the things are" as an automatic compliment paid to successful normal discourse rather than as a relation to be studied and aspired throughout the rest of the discourse. (371-72, italics mine)

As noted above, Rorty is predominantly interested in targeting philosophy as a discipline that takes upon itself the task of legitimising the knowledge claims of the other areas of culture. Without the notion of knowledge as accuracy of representation and the consequent privileged representations, the claims that "philosophy should consist of 'conceptual analysis' or 'phenomenological analysis' or 'explication of meanings' or examination of 'the logic of our language'…would not have made sense" (1980, 12).

Rorty has actually been rather uninterested in science.[12] However, claims similar to his have been presented also in the context of science. Ian Hacking and Andrew Pickering, among others, have contested the centrality of representation for our notion of what science is about. Hacking (1983) aims to turn from truth and representation to experimentation and manipulation:

> Realism and anti-realism scurry about, trying to latch on to something in the nature of representation that will vanquish the other. There is nothing there. That is why I turn from representing to intervening. (145)

Pickering (1995), for his part, contrasts "representational and performative idioms of thinking about science":

[12] Hacking notes, rightly I think, that "Rorty's version of pragmatism is yet another language-based philosophy, which regards all our life as a matter of conversation" (1983, 63).

> The representational idiom casts science as, above all, an activity that seeks to represent nature, to produce knowledge that maps, mirrors, or corresponds to how the world really is. In so doing, it precipitates a characteristic set of fears about the adequacy of scientific representation that constitute the familiar philosophical problematics of realism and objectivity… (5)
> …My suggestion is that we should see science (and of course, technology) as a continuation and extension of this business of coping with material agency. And, further, we should see *machines* as central to how scientists do this. (7)

In the face of these claims I wonder whether it is desirable, or even possible, to do without the notion of representation? Is renouncing representation just a question of talking differently, and consequently even thinking differently—using perhaps the proposed notions of *conversation* (Rorty), *intervention* (Hacking) or *machines* (Pickering) instead? But are not scientific intervening, testing and producing effects, or "coping with the material agency" activities involving complex representative artefacts and skills? If so, then what could be meant by the need to get rid of representation or to contrast it with an intervening or a performative idiom? I think that this former question is especially justified in the context of models, which occupy an interesting middle ground between representation and experimentation. What seems to motivate the aforementioned attempts to get rid of the notion of representation for good is that continuing to use the concept would eventually evoke the representationalist conception of science. I do not see that this needs to be the case, as the various attempts to reconstruct or rehabilitate representation show.

Deconstructing representation

Instead of evading the question of representation, scholars in the field of science and technology studies have attempted to tackle it head-on. Inspired by ethnomethodology they have gone into "the field" to observe how scientists "actually" go about representing. Their studies deconstruct scientific representation into complex processes making use of various "documents" or "inscriptions". Representations become things that are worked upon, being ultimately "rich depositories of 'social' actions" (Lynch and Woolgar 1990, 5). In examining these "representative documents", the studies in question begin by inquiring: "What do the participants, *in this case*, treat as

representation?" (ibid., 11), rather than asking what is meant by representation.

What follow from this approach are studies that meticulously follow the "assembly line", the processes of constructing scientific representations. From this point of view scientific representation appears as a subtle "dialectic of gain and loss" (Latour 1995). It is not just a question of reduction or simplifying. Some methods of representation further fragment, upgrade and define the specimen in order to reveal its details, whereas others add visual features for the purposes of clarifying, extending, identifying, etc. Often the aim of scientific representation is to mould the scientific object so that it can assume a mathematically analysable form or to be more easily described and displayed using different textual devices (see e.g. Latour 1990, Lynch 1985b and 1990). Scientific representation widens in these studies into an expanded process of circulating and arranging diverse extracts, "tissue cultures", photographic traces, diagrams, chart recordings, verbal accounts and so on into a serial order. The epistemological problem concerning the relation of scientific representations to the reality surrounding us is due, according to this view, to our forgetfulness of these expanded material and social processes behind the finished representations. "Through successive stages [sciences] link us to an aligned, transformed, constructed world" (Latour 1999; 79, see also Latour and Woolgar [1979]1986, 69).

I find this approach insightful and corrective of the received view on representation in its stress on the complicated process of producing scientific representations. Yet something seems to be missing from these studies. This has been expressed nicely by Ronald Giere, who entitles his review of them tellingly: "No representation without representation" (Giere 1994). Despite all the careful studies on how scientists go about representing, nothing is actually said about what possibly makes the inscriptions examined representative—except of course for the overall claim that the representation and represented both emerge and merge in the same material process of scientific work.

It seems that these studies are playing a double game. On the one hand they proceed as if they had excluded any consideration of the epistemological question of representation and were instead interested in the representative practices as social phenomena only. As Michael Lynch puts it: "For the sociological purposes, the 'real object' is the

representation in hand, e.g. the visual display, and not the invisible phenomenon or abstract relationship out there" (1990, 154). On the other hand these studies nevertheless have a distinct epistemological aim to "explode" the supposed homogeneous conception of representation in order to make room for the "deeds performed, when those [representational] items are embedded in action" (Lynch 1994, 146). This is in line with ethnomethodology, which has inspired much research in STS particularly with its disdain of theoretical discourse (In Study 2 I examine this double agenda of STS in some detail).

Now there is something contradictory about this way of proceeding. Firstly, in an effort to deconstruct the notion of representation the protagonists rely on what is commonly taken as representation already in their choice of case studies. Rather than exploding the notion of representation these cases reveal what a complicated phenomenon scientific representation is. Secondly, in order to challenge what they take to be the philosophical view on representation, these studies claim that they show us what *really* goes on in scientific representation. But then the question is whether ethnomethodologists and other STS scholars themselves are relying on a rather traditional notion of representation—the very same notion they set out to demolish.

Reconstructing representation

Why is representation such a bad word for so many? It appears that this reaction results from our inherited representationalist conception of knowledge, which ties knowledge firmly to representation and for which representation is a static relation between that which represents (statements of language, ideas in the mind, abstract structures, etc.) and that which is represented ("reality", the "world", some physical system, and so on). Whether the representation is true of its intended object is a question of observing a *correspondence* (analysed most often as isomorphism or similarity) between the representation and that which is represented. Moreover, according to this view, that which is represented, i.e. reality, consists of a fixed totality of mind- and representation-independent objects. I do agree with the critics of representation that *this* view of representation deserves to be set aside. However, I do not think that this conclusion should lead us to banish the notion of representation (or the representative idiom) altogether—if only because the question of

representation seems to stay with us however uncomfortable we are with it. The aforementioned struggles of STS scholars with representation provide good examples of this.

On the other hand the notion of experimental manipulability, which Hacking (and to a certain extent Pickering) professes, does not really succeed in its task of replacing representational realism. In the first place, it fits well only those sciences that allow for experimentation, and thus it is not particularly suitable for the social sciences. To illustrate, let us take the case of economics. Mäki (1996) argues that whereas the existence of the entities to which the theoretical terms refer is problematical for the natural sciences, the problems of economics are different. The argument from experimental manipulability cannot easily be applied to economics. Apart from the difficulty of conducting experiments in economics, experimental manipulability is not needed for ontological realism in economics because we are not uncertain to which entities many theoretical terms of economics (such as "consumer" or "firm") refer. Furthermore, as I have already noted, efforts to avoid or renounce representation do not work even in the experimental sciences except on the level of general declarations. This is because as soon as we start to inquire how scientist intervene, we find ourselves engaged in complex representative processes involving specialised artefacts that record, chart, trace, etc.

Since representation cannot so easily be dismissed, one possibility of tackling the problem of representation is to loosen it from its representationalist grip by reconstructing it. This effort is actually being made on several fronts, both in philosophy and in other fields of study. In regard to my line of argumentation I find three approaches especially relevant: the work on embodied and distributed cognition in cognitive science, the recent pragmatic approaches on models and scientific representation in the philosophy of science, and the theorizing and historical studies of scientific objects in STS. One way to see how these very different approaches contribute to a non-representationalist conception of representation is to see how each of them attacks one of the following three basic assumptions of representationalism:

1) Knowledge consists of a collection of (internal) representations
2) These representations correspond accurately to the bits and pieces of reality
3) Reality is already made up: it consists of a fixed totality of representation-independent objects

Recent work in the field of embodied and distributed cognition has questioned the first assumption by concentrating on what has been called "cognition in the wild" (Hutchins 1995). This economical and embodied cognition uses external scaffolding, environmental clues and cheap tricks in its cognitive tasks instead of creating complete, internal representations of the world. The argument is that the human brain evolved originally to coordinate the body, which made cognition action-oriented rather than reflective. Instead of one single central processor controlling all the cognitive activities, evolution preferred a solution with many, more specialized processors (see e.g. Varela et al. 1991, Clark 1997 and 2003). On this basis it is possible to claim that our cognition is distributed between individuals and artefacts (Hutchins 1995) and that it is also largely skill-based and tool-using. Thus for instance Dennett stresses the importance of "florid representing", which depends on the "objectification" of certain skill-based contents into tools suitable for exercising other skills (Dennett 2000). Latour takes up this theme of the cognitive value of creating objects about objects when he argues that the possibility of superimposing, reshuffling and recombining signs and inscriptions can engender totally new phenomena (Latour 1990). Giere (2002a) has approached scientific cognition as distributed, claiming that "most models in science, even in classical mechanics, are too complex to be fully realised as mental models" (10).[13] The recent, active discussion of expertise and the tacit dimension of knowledge (see e.g. Dreyfus and Dreyfus 1986, Collins and Evans 2002, and Study 5 of this dissertation) is partly related to these developments.

[13] An important precursor of this line of thinking was Lev Vygotsky, who already in the 1920's suggested that the development of a child's *higher psychological functions* is a result of the *internalisation* of social forms of action mediated by signs and tools (Vygotsky 1978). Cognition is thus not only embodied but also cultural. Interestingly, we do seem to use internalised public tools, such as language, when thinking and trying to solve cognitive problems "in our heads".

Whereas the first approach concentrates predominantly on the nature of knowledge and cognition, the second line of attacking representationalism focuses directly on the relation of representation to what is represented. These studies criticise the assumption that representation is a dyadic relation of correspondence between the representative vehicle and its target. In the field of the philosophy of science a host of pragmatic approaches to representation have recently been proposed (Suárez 2004, Giere 2004, Bailer-Jones 2003, Frigg 2003). They all stress the importance of the use and users for representation. Consequently, what is common to these approaches is that they focus on the intentional activity of representation users and deny that the relation of representation to what is represented can be based only on the respective properties of the representative vehicle and its target object (see Suárez 2004). Instead of asking "how do models represent the world?" one should rather ask "how models are *used* to represent the world" (Giere 2004). In arguing for three- or even four-place relation between representation and the represented, these pragmatic approaches in fact follow the tradition set up by C. S. Peirce, for whom the sign relation was irreducibly a triadic relationship including the sign (or "representamen"), the object and the interpretant. Furthermore, Peirce understood sign activity, semiosis, in terms of inferentiality and mediation, both of which have been discussed in recent literature on models and representation.[14]

Finally, representationalism can be challenged by denying that it makes sense to think about the world as consisting of representation-independent objects. This is because "objects" are not available to us except through representation. From a thoroughly constructivist point of view, talking about representation should not pose any problem, since representations are freed from representing the world as it is. Quite the contrary, we construct scientific, artistic and other objects by way of representing them. This theme has been insightfully explored by the work on "epistemic things" or, alternatively, "epistemic objects" by Hans-Jörg Rheinberger (1997) and Karin Knorr Cetina (1999, 2001). In their work, conventional scientific entities appear as open-ended epistemic things that are actually effects of manifold and interwoven representative practices. For neither Rheinberger nor Knorr Cetina does this open-endness mean relativism, since scientists are not free to construct objects as they wish—representative practices constitute part of "experimental systems" (Rheinberger) and are constantly "in the process of being materially defined" (Knorr Cetina

2001, 181). The implication is that the material world somehow resists scientists' attempts to mould it, the "the things strike back", as Latour (2000) has put it. [15] In scientific practice, this constraint is actively sought, which is most evident in the case of experimentation.[16] However, I will argue later in the individual studies of this dissertation that this is also done in modelling, even though there also the constraint itself is constructed and not just the setting in which it is aspired after, as in experimentation. If scientific objects are treated as constructions, then their historical trajectories become possible topics of their own. Thus Lorraine Daston claims in her introduction to the collection of essays *Biographies of Scientific Objects* that scientific objects can be both real and historical; that is, their existence is relative: "new scientific objects pour forth, and old ones fade away" (2000, 5). That this way of thinking seems strange to most philosophers is due exactly to the fact that they tend to think that the scientific objects were always there waiting to be found.[17] But then the history of science does not offer much support for this thought.

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[14] On Peirce's later stress on mediation, see Bergman (2004, ch. 4). Eco (1984, ch. 1) and Merrell (1995, ch. 1) have in turn stressed the inferential character of Peirce's conception of the sign.

[15] The "objectualists" appear to claim that reality is both a construction and a constraint, which is of course confusing. It appears to me that behind their way of seeing things there is actually a distinction between reality and the real. This distinction, which can be traced to the work of French psychoanalyst Jacques Lacan, somehow captures the flavour of the poststructuralist theorising of the ineffable. (French poststructuralist theory has had an important influence on both Knorr Cetina's and Rheinberger's views on epistemic things). *Reality* is an effect of the coherence of our representative practices: it is, as Hacking has aptly put it, a second-order concept that follows from our practice of representation. "The world has an excellent place, even if not the first one… It was found by conceptualising the real as an attribute of representations" (1983, 136). Thus reality is, from the very outset, a fictive construction which is continuously questioned by the *real*. The real is the unrepresentable ground of the subject's own being and that of the world beyond it (see Boothby 2001, 12). Thus the real constrains the way reality can be constructed and maintained (see also Ragland-Sullivan 1996, 192).

[16] For instance Ludwik Fleck claims that the "general aim of the intellectual work" is to create a "maximum thought constraint": "The work of the research scientist means that in the complex confusion and chaos he faces, he must distinguish that which obeys his will from that which arises spontaneously and resists it" (1979, 95).

I find all these different strategies of shattering the assumptions underpinning representationalism important and have tried to accommodate them in my work on scientific models. Through the notion of models as *epistemic artefacts* I have tried, firstly, to detach the epistemic (and cognitive) value of models from their representational status. Secondly, as artefacts, models are used in scientific practice many ways, one of which is representation. I am not contesting representation itself but rather the way it is conventionally understood—thus I side with forces of the pragmatists of representation. Thirdly, my view on models as first and foremost artefacts rather than representations implies that I do not think that there is any pre-packaged collection of objects available for us to represent. Rather, it seems to me that models help us to imagine what there could be, as Morgan (2004) and Frigg (2003, ch. 5) have pointed out. With the notion of the epistemic artefact I have nevertheless wanted to show how importantly tied our imagination is to materiality and to the established ways of using various representative media. Moreover, the artefactual account of models easily lends itself to the consideration of the processes by which models and their subsequent productive properties are built—an aspect that has been stressed by the STS studies on representation (see above).

Next I will turn into a discussion of scientific models. To ground the idea of models as epistemic artefacts I will provide a short overview on how models have been treated in the philosophy of science and how the question of representation has arisen in that discussion.

[17] The idea that our objects of knowledge are not independent of our knowing dates back at least to Kant, see the footnote 10. Several philosophers have also attacked the notion of the "ready-made world" (see e.g. Putnam 1982, Tuomela 1985). What distinguishes these views from the recent interest in scientific objects is that, unlike the philosophical discussion, the study of scientific objects does not understand construction predominantly in conceptual and linguistic terms but rather as social and material activity.

3. Scientific models in the philosophy of science

The discussion of models in the philosophy of science has heterogeneous beginnings, testifying to a variety of theoretical, formal, and practical aspirations that appear to have different and even conflicting goals (Bailer-Jones 1999, 32). Thus in addition to approaches that have predominantly been interested in the pragmatic and cognitive role of models in scientific enterprise, attempts have been made to establish, within a formal framework, what scientific models are. The syntactic view of models, once the "received view", and the semantic approach to models, the prevailing model-theoretic approach, are both attempts of this kind.

3.1 Syntactic and semantic views on models

According to the syntactic view, a model is designed to give an interpretation of an uninterpreted formalism or calculus. Thus, according to Ernest Nagel, for example, a model is an interpretation of "the abstract calculus which supplies some flesh for the skeletal structure in terms of more or less familiar conceptual or visualizable materials" (1961, 90). For the proponents of the syntactic view a scientific theory was such an uninterpreted or partially interpreted formalism, a purely syntactic structure consisting of a set of axioms. To interpret a theory was to specify a model for it, which makes all the axioms of the theory true (or false). Consequently, a model for a theory T could be defined as a set of true propositions with the same formal structure or calculus as T (96).

The semantic conception of models contested this "linguistic" view of models by replacing the syntactic formulation of the theory with the theory's models, which are non-linguistic entities. In this view, theories are not assemblages of propositions or statements, but "extralinguistic entities, which may be described or characterized by a number of different linguistic formulations" (Suppe 1977, 221). These extralinguistic entities—models—are taken to be structures that are defined either by the use of set-theoretical predicates (e.g. Suppes 1961, da Costa and French 1990) or by the use of suitable mathematical language (e.g. van Fraassen 1980). The emergence of the semantic conception dates back to the 1960's with impulses both from mathematics and computer science (see Suppe 1989, Prologue).

Of the semantic approaches to models (and theories) perhaps the best-known are those of van Fraassen (1980) and Giere (1988). Their approaches differ from each other in the degree of their abstractness and in the ways they utilise aspects of the semantic approach to accommodate their divergent standpoints to the empiricism-realism debate (French and Ladyman 1999, 104).

Van Fraassen, the (constructive) empiricist, advances a "new picture of theories":

> To present a theory is to specify a family of structures, its *models*; and secondly, to specify a certain part of those models (the *empirical substructures)* as candidates for the direct representation of observable phenomena. The structures which can be described in experimental and measurement reports we call *appearances*: the theory is empirically adequate if it has some model such that all appearances are isomorphic to empirical substructures of that model (1980, 64).

Ronald Giere, a (constructive) realist, denies that the relation between a model and a real system should be isomorphic. Giere (1988) develops his account of models on the basis of classical mechanics as presented in advanced textbooks. He proposes that, to take an example, the "linear oscillator" referred to in mechanics texts is not a single model with different specific versions but a cluster of models of varying degrees of specificity (80). Thus Giere finds in the standard textbooks "a population of models consisting of related families of models" (82). The models as such are not true or false with respect to the world; the role of the theory is rather to claim a "good fit" between the models and some important types of real systems. Consequently, Giere suggests that a theory is comprised of two elements: (1) a population of models, and (2) various hypotheses linking those models with systems in the real world (85).

Giere argues that the relationship between models and the world is not primarily that of truth, correspondence or isomorphism, but *similarity*. He is not very worried about the vagueness of the notion of similarity, since in his opinion the cognitive sciences are accumulating evidence that "human cognition and perception operate on the basis of some sort of similarity metric" (81). Moreover, Giere claims that even the links between the models are rather relations of similarity than logical connections. As a consequence a scientific theory turns out not to be a well-defined entity. Nothing in the

structure of any model itself could determine whether it belongs to a given family of models or not. It is up to the scientific community to judge whether the resemblance is sufficient.[18]

The semantic conception replaced the "received view", becoming itself a received view.[19] Frederic Suppe (1989) states confidently that "the Semantic Conception of Theories today probably is the philosophical analysis of the nature of theories most widely held among the philosophers of science; it frequently is used to analyse and treat other philosophical problems" (3). That a conception of theories should provide us a prevailing approach to models seems already at the outset somewhat paradoxical. It tends to downplay models in respect to theories, as has been pointed out by Morrison and Morgan:

> The semantic view claims that models, rather than theory, occupy a centre stage, yet most, if not all of the models discussed within the framework fall under the category 'models of theory' or 'theoretical models'… Viewing models strictly in terms of their relationships to theory draws our attention away from the process of constructing models and manipulating them, both of which are crucial in gaining information about the world, theories and the model itself. (1999a, 7-8).

Consequently, Morrison and Morgan propose that we should investigate the models actually used in science to understand what kind of entities scientific models are and how they function. In this

[18] Giere's views of models have remained generally similar over the years, but they show signs of changing. In Giere (1999) he claims that models are "humanly constructed abstract entities" (168). It seems to me that this idea does not fit very well with the notion of distributed cognition, a topic that he has shown a good deal of interest recently (2002a, 2002b). The idea that models are abstract entities is better suited to the idea of "mental models" that was still popular in cognitive science some years ago (see Giere [ed.] 1992). But in order for cognition to be distributed, models must be materially existing things of some kind—if they are to function as central tools of science and mediate between people and other artefacts.

[19] German structuralism (see e.g. Balzer, Moulines and Sneed 1987) also has a model-based approach to scientific theories. They are however more concerned with the architectonic of sciences than with individual models. Recently, several researchers have developed the so-called "partial structures" view, which limits the isomorphic relations between the model and its target system (see e.g. Bueno 1997, and French and Ladyman 1999).

they are following a long tradition of approaching the epistemic value of models from the point of view of scientific practice.

3.2 A practice-oriented approach to models

It can in fact be claimed that the very discussion of models was originally motivated by practice-oriented considerations—even the proponents of the semantic view understood themselves as providing a more realistic picture of theories (see van Fraassen 1980, 64). Yet the practice-oriented approach has usually involved taking into account different aspects of the actual *making* of science. In the 1960's issues of theory reconstruction and theory change as well as of scientific discovery prompted many philosophers to start to study models (Bailer-Jones 1999, 31). Various writers including Achinstein (1968), Black (1962), Hesse (1966) and Hutten (1954) likened models to analogies and metaphors in their attempt to understand how models function in scientific reasoning. Moreover, both Max Black and Peter Achinstein created typologies of models in an effort to give a more complete account of the variety of models used in science.

It is of interest that both Black and Achinstein started their discussion of models by considering three-dimensional physical objects, which Black thought were the "standard cases" of models in a literal sense of the word. He called them *scale models*, covering "all the likenesses of material objects, or systems, or processes, whether real or imaginary, that preserve relative proportions" (1962, 220). When we make scale models, Black points out, our purpose is to reproduce in a relatively manipulable or accessible embodiment, selected features of the "original". "We try to bring the remote and the unknown to our own level of middle-sized existence. There is, however something self-defeating in this aim, since … we are forced to replace a living tissue by some inadequate substitute, and a sheer change of size may upset the balance of factors in the original" (221). Thus, "inferences from a scale model to an original are intrinsically precarious and in need of supplementary validation and correction" (ibid.). Achinstein, too, paid attention to the manipulability or "workability" of physical models (which he called representational models). According to him "representational models, although used in all the sciences, are particularly central in engineering. Instead of investigating an object directly, the engineer may construct a representation of it, which can be studied more readily" (1968, 209).

Morrison and Morgan's conception of models as mediators that function as investigative instruments amounts to a return to this tradition, in that they also stress the epistemic importance of building and manipulating models.

The notion of models as mediators builds importantly on the work of Nancy Cartwright (1983). In arguing that the fundamental laws of physics do not describe the regularities that exist in nature, Cartwright reverts to models. There is a gap between the general theoretical principles of physics and the messiness and complexity of data which phenomenological laws in turn strive to capture. It is the task of models to bridge that gap: "The route from the theory to reality is from theory to model, and then from model to the phenomenological law. The phenomenological laws are indeed true of the objects of reality—or might be; but the fundamental laws are true only of objects in the model" (4). For a model to function as a bridge between theory and data, a model has to include some genuine properties of the objects modelled. But in addition to that, models contain properties of convenience and fiction (15). These features are needed to bring the objects modelled into the confines of the theory. Building models is pragmatic activity, "adjustments are made where literal correctness does not matter very much in order to get correct effects where we want to get them; and very often…one distortion is put right by another" (140).

The similarities between Cartwright's account of models as bridges and that of Morrison and Morgan's as mediators are clear. In both accounts models occupy the middle space between the theory and the world (or data), thus linking them. What is more, both accounts stress how "additional elements" are brought into models. This is exactly what makes models able to connect the different realms but it is also what makes them "at least" partly autonomous, a point that Morrison and Morgan especially stress. What I find particularly fresh and rewarding in Morrison and Morgan's approach is precisely their emphasis on the epistemic importance of the independence of models and their mediating capabilities. I think that their approach can actually be used as a starting point for developing a non-representationalist account of models (granting that anything like this need not have been their original intention). However, before turning to that, I wish to examine the idea that models are, first and foremost, representations.

3.3 Models as representations

As already noted, a certain understanding of representation is part and parcel of the semantic approach, since the structures specified by models are posited as possible representations of either the observable phenomena or, even more ambitiously, the underlying structures of the real target systems. This relation of representation between a model and its target is understood in terms of isomorphism or partial isomorphism. Thus, according to the semantic view, the structure specified by a model represents its target system if they are structurally isomorphic. By isomorphism I refer to a kind of mapping that can be established between the two that preserves the relations among their elements. Isomorphism can be defined formally, which is one of the charms and motivating forces behind the semantic theory. Not all protagonists of the semantic theory agree with the formulation presented above. For instance Giere (1999) thinks that it represents a "carryover from an older picture of science":

> The clearest expression of the old picture is to be found in the philosophy of mathematics and logic, and in formal semantics. The idea is that the structure of reality mirrors the structure of set-theory. Reality is conceived of as consisting of discrete objects, sets of discrete objects, sets of sets of objects, sets of ordered pairs of objects, and so on. True statements are those that describe objects as belonging to the sets to which they in fact belong. A complete science would be the conjunction of all and only the true statements of this set-theoretically structured reality. (78)

In terms of the argument of this thesis it is evident that the above-mentioned picture of science painted by Giere is thoroughly representationalist: it depicts representation in terms of a correspondence created by isomorphism, supposes that reality consists of a fixed set of discrete objects and posits that there is a privileged set of representations, structures that are, to use an expression of Rorty "automatically and intrinsically accurate" (1980, 170).

Overall, the critics of the semantic approach have not worried very much about its representationalist view of science. Instead they have limited their critique to the tendency of the semantic approach to reduce representation to isomorphism (or similarity). The critics have argued, among other things, that denoting a symmetrical, reflexive

and transitive relation, isomorphism does not satisfy the formal and other criteria we might want to affirm concerning representation (see e.g. Suárez 2003, Frigg 2003). I find these critiques both thorough and conclusive, which is the reason this issue does not concern me here. I rather turn to the alternative accounts of models that have been presented by the critics of the semantic approach.

Interestingly, the critics of the semantic approach nevertheless share with them the same presupposition that the main task of models is to represent the world. In arguing against the semantic view of models, some of them have explicitly made representation *the* crucial property of models (see e.g. Frigg 2003, 33; Hughes 1997, and Suárez 1999), which is presumably something that most philosophers generally agree in. A characteristic statement of this linkage is that given recently by Paul Teller (2001):

> I take the stand that, in principle, anything can be a model, and that what makes a thing into a model is the fact that it is regarded or used as a representation of something by the model users. Thus in saying what a model is the weight is shifted to the problem of understanding the nature of representation. I do not begin to have a workable account of representation, so what is accomplished by this move? The point is that when people demand a general account of models, an account, which will tell us when something is a model, their demand can be heard as a demand for those intrinsic features of an object which make it a model. But there are no such features. *We* make something into a model by determining to use it to represent.

While I do agree with Teller that it is *our* achievement that models represent, I would rather not propose that we make a thing into a model by deciding to use it as a representation of some aspect of the world. In my opinion there are several reasons why we should resist binding models too firmly together with representation:

1) *Needless stumbling over the "puzzle of representation"*. It is perhaps no wonder that the proponents of the semantic view have not presented any explicit analyses dealing with scientific representation, since the semantic approach takes the question of "in virtue of what do models represent" to be solved by reverting to isomorphism.[20] The problem of representation arises when, on the one hand, models are regarded as being primarily representational entities and, on the other hand, it is granted that constructing models involves idealisations,

approximations, conventions, fictions, and the like. Thus the question becomes, as Callender and Cohen have aptly put it: "How can [models] represent, if they, well, misrepresent?" (2005, 5). The urgency of this question is, of course, directly linked to the representationalist conception of knowledge. It dissipates once we stop linking the epistemic value of models to their being more or less accurate representations of the independently existing, real target systems. What is more, then we are not in such a pressing need of giving an all-around explanation for the possibility of representation. Rather, whether or not a model represents something will be judged case by case in view of its specific goals and with the help of other information at hand—and general philosophical intuitions concerning what makes a model a representation are largely redundant in this task. Perhaps the best a purely philosophical analysis can do is to offer a deflationary account of representation, as Suárez (2004) has suggested.

2) *Many scientific models cannot be considered as clear-cut representations of any specific external systems*. In the case of many scientific models we do not know what exactly they are supposed to represent. This is especially striking for instance in artificial intelligence, where new kind of reality is being created. For instance, in his study of early synthetic brain models Asaro (2005) claims that "it is hard to conceive of just what entities these models were supposed to be modelling" (55), granting that these models were models of mental functions, whose ontological status is questionable as opposed for instance to those of behaviour or neurons. It seems to be more true of scientific practice that rather than functioning as straightforward representations of some "real" systems, models often present us some tentative mechanisms, processes or solutions that can then function as a basis for various inferences. On many occasions models are used primarily as demonstrations, exemplifications, proofs of existence, test-beds, etc. Interestingly, even bad models and errors give us knowledge, which runs counter to the idea that knowledge is based on

[20] This is of course a somewhat simplified claim. Both van Fraassen and Giere have been stressing the pragmatic nature of representation in their recent writings (Giere 2004, van Fraassen 2004). But then I do not know whether Giere can still be classified among the adherents of the semantic conception.

representing things rightly (in relevant respects and aspects). That this should be so is occasionally reflected in the way authors interested in scientific practice write about representation. For instance, when discussing representation, Morrison and Morgan (1999b) use such expressions as "rendering" and "translation". Their choice of these words seems to result from their uneasiness with the traditional notion of representation as that of "standing for" (though they refer to "mirroring"). "Rendering" and "translation" are commonly-used words in STS.[21] Both terms refer to the accomplishments that are brought about by the participants' actions. From this perspective, representation becomes a complicated productive and interpretative process, which is one of the points I make in Study 5.

3) *Conceiving of models as representations accepts the cognitive challenge of modelling in the wrong way.* It is as if we already knew enough of the world to be able to represent the *real* objects waiting there to be represented. The representational approach also seems to assume that we already know *how* to represent the objects to be represented and have the appropriate means at hand. But if this were the case we would not need to represent the object in the first place for other than perhaps didactic and practical purposes (for those who do not know what we know and for the purposes of communicating and remembering). Thus representationalism approaches science from the point of view of finished science. I suggest that we model the phenomena because we usually do not know enough about those "systems". Thus one has to conjecture what the different features of the phenomena are like, how they are organised and how they function. This conjecturing has to happen through and with the help of certain already familiar representative means (formal languages, diagrams, three-dimensional objects, modelling methods, etc.), the use

[21] "Rendering" is used by ethnomethodologists, who thereby dissociate themselves from the representationalist paradigm (see Garfinkel 2002, ch. 3). "Translation", in turn, has been made popular by the actor-network theory. Latour (1999) defines it in the following way: "Instead of opposing words and the world, science studies, by its insistence on practice has multiplied the intermediary terms that focus on the transformations so typical of the sciences… In its linguistic and material connotations, [translation] refers to all the displacements through other actors whose mediation is indispensable for any action to occur" (311).

of which is by no means a minor part of the problem. As I argue in Study 5, the problem of representation does not concern only what is being represented, but also the ways to do it. Moreover, the means of representation are themselves conducive to certain kinds of solutions and problems—which is due to the affordances of the medium used.[22]

4) *Models have many other distinctive uses apart from representation.* Because of this, it is misleading to reduce modelling to representation. Firstly, models typically occupy an intermediate space between representing and experimenting. They share with representation the property that their medium of expression is different from that of their object of reference. On the other hand they share with experimentation the fact that one can try out different possibilities with them. For instance, it is possible to study how the "structures [of the model] behave when the parts of the model are put together and when we vary certain things in the model" (Morgan 2002, 220). Another typical feature of modelling is the way we "model" entities and processes of new domains with the help of already existing theoretical tools, computational templates and methods borrowed from another more established domains. One might call this procedure "representing as", but typically in this context the expression used is to "model on"; e.g. "many sciences are modelled on mechanics". This is related to the cognitive value of modelling: since the phenomena we are interested in seem often quite impenetrable to us, we can probe them by applying to them modelling methods and templates that have proven to be successful elsewhere. This is linked to the third point I want to make. Regarding models as representations have led many to argue that models are intended for specific phenomena (see Frigg 2003, 33; Suárez 1999). This seems to follow from the idea that models are, inherently, "models of" something. But models are as importantly "models for" something, as Fox Keller (2000) has pointed out. They are not just representative entities, but often also productive ones. I do agree that when a model represents, the model is intended for a

[22] A nice example of this is provided by Morgan (2004), where she discusses the mathematisation of economics, how in the beginning of the mathematisation of economics both "the process of making representations" and "the representing relation" remained partly opaque for the early developers. Moreover, Morgan notes how the mathematisation of economics changed the way economists understand and depict the economy.

certain phenomenon. But it seems to me to be more true of scientific practice that models are characteristically entities that can be used to represent many different kinds of things. The defenders of the "models of" view can certainly try to account for this by converting the material object representing different target phenomena into different models. This seems to me a legitimate philosophical move, yet it loses sight of one important characteristic of modelling: the detachability and the consequent re-applicability of certain already rather stabilised representative apparatuses to diverse kinds of problems and data.

I think that the basic problem of the representational approach in general is that it treats science as if it were already finished, or at least quite ready.[23] That this has not worried philosophers very much over the years is for the most part due to their preoccupation with what can be called as "the rational reconstruction of science".[24] However, if philosophers are, as I think they should be, interested in the very practices through which knowledge is being created, then the representational approach to models proves to be limiting. This is somewhat paradoxically acknowledged by the recent pragmatist accounts of scientific representation by Giere (2004) and Suárez (2002a, 2004) which both make it clear that nothing very substantive can be said about the relationship of representation in general. In these accounts representation is contextualised to the users', or agents', activity of *representing* (Giere) or inferring (Suárez) in view of their specific aims and goals.[25] Thus, on my interpretation, these accounts actually point out the need for an approach that, instead of

[23] Here I speak rather of "representational" instead of "representionalist", since those authors, like Teller, who consider models as representations do not underwrite all the tenets of representationalism (as semantic conception does, in my opinion).

[24] This attitude started to change, of course, already in the early 1960's due to the so-called "historicist turn" with philosophers such as Stephen Toulmin, Thomas Kuhn and Norwood Russell Hanson.

[25] Giere's four-place definition of scientific representation and Suárez's inferential conception of scientific representation are presented in Study 4 of this dissertation. This discussion is, however, based on the papers they presented at the 2002 Biennial Meeting of the Philosophy of Science Association (Giere 2002c, Suárez 2002b) and not on their final published symposia papers (Giere 2004, Suárez 2004).

focusing only on representation provided by ready-made models, takes a wider perspective on the epistemic value of models—an approach that takes seriously the epistemic importance of building and interacting with models.

3.4 Models as epistemic artefacts

It seems to me that Morrison and Morgan's framework of models as mediators provides an alternative to considering models as representations. They explicitly recognise the many tasks of models, of which representation is just one. As I will treat their approach in the individual articles of this dissertation, I will not go into its details here, but rather rehearse what I take as the most important characteristics of their programme, viz. the independence and mediating characteristics that they ascribe to models. Nevertheless, it appears to me that Morrison and Morgan do not quite cash out the radical potential of their programme. In order to turn the models-as-mediators approach into a true alternative to the prevailing models-as-representations approach, one needs to free models from the theory-data framework still present in Morrison and Morgan (1999b) and to interpret models materially, thus granting them an individual status as epistemic artefacts.

Provided that the word mediation can be understood in a very wide sense covering complex semiotic processes, including the activities of various actors, the mediation between theory and data (or world) that Morrison and Morgan concentrate on is a rather limited version of mediation. Morrison and Morgan point out that it is the (relative) independence of models that makes them able to mediate. I agree, but would like to add that it is in turn the material dimension, and not just "additional elements", that makes models able to mediate. It is the material dimension of objects that gives them the robustness necessary to maintain their identity across different sites.[26] But making this move means also leaving the conceptual and ideal world of philosophy and entering into the social and material world of human actors, where material objects, usually human-made artefacts, draw together numerous activities and different actors. From the scientific practice point of view, it is easy to see that scientific models are such things. This is especially evident in computer modelling, where models more often than not act as *boundary objects*

(Star and Griesemer 1989) between different groups of scientists from different disciplines.[27]

Now, apart from enabling the mediation between different actors, materiality is also important for the epistemic functioning of models. Morrison and Morgan attribute a large part of the epistemic significance of models to the processes of their construction and manipulation instead of focusing unilaterally on representation. As they stress that we *learn* from models by building and manipulating them, their approach in fact implies that there needs to be something more concrete than just conceptual ideas to work on. For us to learn from a model, it has to be a self-contained thing with which we can interact and work. The epistemic enablings of models are due to the way in which their materially embodied constraints intersect with their intentional uses. Consequently, I suggest that models are intentionally constructed and materially embodied things, *epistemic artefacts*, the constraints of which are characteristically turned into affordances for epistemic purposes. A fuller formulation of this idea is presented in Study 3.

I suggest that conceiving of models as epistemic artefacts provides a fresh outlook on models and their epistemic value. It attributes the epistemic value of models to their epistemic productivity rather than reducing it to the representation of some pre-existing natural or social systems. It also provides a new angle from which to approach the characteristics of models and representation. Namely, approaching models as artefacts makes it natural to ask how and of what elements they are made. This directs our attention to the processes of representation that underlie "ready-made" models. From this point of view representation appears as a complicated process that makes use of various representative means to convey something that has already been theoretically rendered or otherwise prepared into another medium or form. With this in mind we can turn to the original articles, on which the main burden of proof of this dissertation rests.

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[26] By "material" I mean something that is concrete and corporeal, occupying space and time and able to interact with other things and human beings. For a discussion of the ontology of material objects in the social world, see Harré (2002).

[27] See Mattila (2005) for an analysis of the interdisciplinary work of modelling the transmission of infectious disease.

4. An overview of the original articles

The articles are ordered according to the time of their writing. This seemed to be the most natural way to organise them in view of both their content and the emergence of the ideas presented in them: from them one can trace the development of the artefactual approach to scientific representation that I am arguing for in this thesis. As already mentioned in the Introduction, these articles participate in the specific discussions of scientific representation in various fields: philosophy of science, science and technology studies, semiotics and cognitive science. Consequently, in the abstracts of the articles below I shall, in addition to presenting their main arguments and results, also contextualise them and show how they relate to each other. The first two articles deal with more general issues concerning representation. The first focuses on the so-called crisis of representation in the humanities, and the second deals with the problem of reflexivity in the field of science and technology studies. The next four articles study representation in the context of modelling. Common to all of them is the idea of models as epistemic artefacts. They use this concept in discussing the interrelated questions of representation, modelling, and cognition.

Study 1:
Knuuttila, Tarja
"Is Representation Really in Crisis?"

Semiotica 143 (2003), 95-111.

"Is Representation Really in Crisis?" is written mainly for semioticians and literary critics. Accordingly it assumes some background knowledge of semiotics. It claims that there is nothing very "postmodern" or recent about the crisis of representation. The "crisis" has mainly dressed a traditional epistemological problem in more up-to-date garb. The most important point of the article is to show, however, how the work done on scientific representation in STS is relevant for the discussions of the crisis of representation. I argue that the excesses of postmodernist discourse depend on a too idealistic and traditional understanding of representation, an understanding for which the work being done in STS offers a good antidote. The theme of representation as artefact-using activity, which is central to this thesis, appears already in this article.

The article opens by distinguishing between two types of claims concerning the crisis of representation: an ontological and an epistemological version of it. The ontological version takes for granted that the crisis has been brought about by the expansion of mass communication, which has made our modern life world increasingly packed with representations and virtual artefacts of all sorts. It is supposed that rather than being in contact with reality, we are thus increasingly dealing with representations of it. On this basis it has then been claimed that reality proper is in fact receding—without us even noticing.

The epistemological version, in turn, questions the relationship between our representations and reality. The problem is how our ideas, words or other signs are able to "correspond" to real objects when they seem to be very different kinds of things. The linguistic turn of the last century externalised the sphere of representation, yet the problem of representation stayed much the same. A recent externalist version of the problem of the empiricists can be found for instance in Umberto Eco's semiotics (e.g. 1984). According to his notion of

encyclopedia, a sign cannot refer to an object but is simply interpreted by another sign. Thus the sphere of representation starts to look like a prison from which there is no access to reality proper.

It appears to me, however, that the proponents of the crisis of representation have not paid enough attention to the technological efficiency of our mediated lifestyle, which critically depends on our reliance on man-made representations of diverse sorts. I argue in "Is Representation Really in Crisis?" that postmodern discussions of representation have more often than not, forgotten that representations are themselves concrete, material things that have real effects. To make the point I present some exemplary work on representation done in the field of STS. Bruno Latour and Steve Woolgar's *Laboratory life* (1986[1979]) has shown how any scientific representation is a result of many laborious translations accomplished using diverse and often complicated inscription devices. The paradox of the process of representation is that once the final representation is reached, the process of making it is excluded in the discussions about what it means. Representations are treated as if they were direct "signatures of the phenomena under study", but as a by-product of this procedure the problem of representation emerges. I also discuss the work of Michael Lynch, who has attempted to show how in scientific representation the artificial properties introduced by the representational devices merge with the natural object and thus make it understandable in the first place.

Now, the problem is how to interpret these constructivist insights. I claim that they indicate a way out of the crisis of representation; however totally different conclusions from constructivism have also been drawn. For many, constructivism has meant relativism[28] (witness for instance the unhappy phenomenon of the so-called "science wars"). Reading Richard Rorty and Hilary Putnam I try to diagnose why being both a constructivist and a realist has been such an uneasy position for many philosophers. This seems to be at least partly due to the common predisposition of philosophers to treat construction as if it were a matter of conceptual and linguistic activity only. The situation becomes different once it is realised that our representative practices and their products take part in complicated

[28] This is of course one important reason why the constructivist standpoints presented in STS have created so much heated discussion (see e.g. Hacking 1999; Gross and Levitt 1994).

social and material activities with their own specific ends. These worldly activities, in which the representations themselves are produced and used, establish the link between them and those things, the processes and phenomena they are about. Moreover, this is actually a process of co-construction: through the interrelated activities of theoretical reflection, representation and experimentation scientific objects come into being. This kind of constructivist outlook leads to relativism only if we accept the tenets of representationalism, according to which the world consists of some fixed totality of representation-independent objects *and* expect that in order to give us knowledge our representations have to depict these objects truthfully or accurately.

Study 2:
Knuuttila, Tarja
"Signing for Reflexivity: Constructionist Rhetorics and Its Reflexive Critique in Science and Technology Studies"

Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, (2002), [On-line Journal], *3*(3). Available at: http://www.qualitative-research.net/fqs-texte/3-02/3-02knuuttila-e.htm (52 paragraphs).

As, paradoxically, many constructivists[29] themselves also understood realism in representationalist terms, the accusations of relativism that have been levelled at constructivists are at least partly justified. The second article inspects what happens when one takes into account the constructedness of our representations, but is still attached to the ideas of metaphysical realism and the accompanying correspondence theory of truth. I claim that it was exactly this combination that led "reflexivists" to claim that scientific discourse is fundamentally flawed in its attempt to create an illusion of objectivity. Since the 1970's these kinds of reflexive pronouncements were launched especially in the fields of anthropology, sociology and social studies of science. The declarations were followed by attemps to write scientific articles so that they would more obviously display their own undeniable artificiality.

The second article studies the discussion of reflexivity in STS. The STS discussion offers an especially good place to study reflexivity since reflexive critique was ambitiously practised there on at least in three interrelated levels. Firstly, the STS reflexivists pointed out the inherent reflexivity of STS itself: its aim of studying scientific study scientifically.[30] Secondly, though being in principle favourable to the emerging constructivist programme, the reflexivists nevertheless

[29] In this study I have used "constructionism" instead of "constructivism" in line with Hacking (1999). In the rest of this thesis I have used the STS participants' term "constructivism" instead.

[30] This critique applies especially to the "strong programme" of the so-called Edinburgh school, which still opted for causal explanation.

criticised the constructivists for forgetting the constructedness of their own accounts. From the reflexivists' point of view the constructivists' effort to describe what *really* goes on in science was dubious taking into account their own constructivist doctrines. Thus, thirdly, the reflexivists proposed that one should renew scientific writing by adopting literary devices that would make explicit the constructedness of any scientific account.

In regard to the aforementioned claims, "Signing for Reflexivity: Constructionist Rhetorics and Its Reflexive Critique in Science and Technology Studies" examines what kind of a problem reflexivity in STS is, and whether the new ways of writing proposed by the reflexivists constitute an appropriate reaction to the problems of scientific representation. The article attempts to show that the artificiality and conventionality of our representations lead to epistemological problems only if we assume that in order to give us knowledge of the world, our representations have to be more or less accurate or truthful reflections of it. If this is not the case, the rationale for writing reflexively vanishes. In fact, if we admit that any scientific representation is also a purposeful construction, then the question becomes in what ways representations satisfy their intended scientific uses best. Literary devices borrowed from artistic discourses may entirely miss the mark when it is a matter of conveying some features or results as clearly and convincingly as possible. In fact, the reflexivists' own discourse testifies to this. Their critiques of constructivism were written in the form of conventional critiques. Only after the point was thus successfully brought home did they start to experiment with reflexive writing.

Nothwithstanding their fruitless struggle with (literary) representation, the reflexivists made a genuine contribution in pointing out the self-refuting tendencies of constructivist rhetorics. Namely, the assertion that *all* knowledge is local, situated and socially accomplished contingent achievement seems to be either trivially true or leads to reflexive paradoxes. The question is why these kinds of claims were then repeated over and over again in STS—despite the reflexivist critique presented. I suggest that STS authors were, more or less consciously, practising deconstruction: they were attempting to contest the hierarchies invested in traditional distinctions such as global/local, theory/praxis, or general/specific. This work need not challenge the epistemic value of science per se, but if it gives the

appearance of doing so, it leads to a position that easily turns against the STS scholars themselves. A good example of this has recently been presented by Lynch and Cole (2002). They analyse the difficulties encountered by one of the authors, who, being known for his STS connections, had to account for his conception of science before being accepted to give expert testimony in a legal case.[31]

[31] "Signing for Reflexivity: Constructionist Rhetorics and Its Reflexive Critique in Science and Technology Studies" was already in press when this interesting paper was presented in the EASST 2002 Conference in York, which is the reason I do not refer to it in the Study 2.

Study 3:
Knuuttila, Tarja and Atro Voutilainen
"A Parser as an Epistemic Artefact: A Material View on Models"

Philosophy of Science 70 (Proceedings), (2003), 1484–1495.

In opposition to the widespread belief (also exemplified by the reflexivist struggles) that the artificial features of scientific representations somehow question their objectivity and epistemic status, this article claims that artefact building does bring us knowledge in various ways. The article takes part in the philosophical discussion of scientific models by proposing a new approach to models. I suggest that models can be conceived of as *epistemic artefacts*, the epistemic value of which derives from their being intentionally constructed and purposefully constrained material things. In addition to stressing the cognitive importance of artefactuality, this approach also departs from tradition by relating the epistemic value of models to their material dimension. The reigning semantic approach to models treats them as abstract theoretical entities for which only structural "two- or three-dimensional" representation matters. This view on models has as its goal to present a unifying, formal account of models, which, despite its proponents claims to the contrary, actually has problems in accommodating the very diversity of models in scientific practice. One may suppose, however, that the very plurality of models in scientific practice is not inconsequential, thus leading one to ask how these diverse things function in science.

The article takes as its starting point Morrison and Morgan's (1999b) practice-oriented conception of models as investigative instruments and develops it in the direction suggested by Marcel Boumans (1999) in the very same collection of articles. Whereas for Morrison and Morgan models are (partly) independent mediators between theory and data, Boumans loosens models from their subservience to the theory-data-framework by treating them as constructed entities made up of various ingredients. Inspired by this line of work I however take one step further and argue that models used in science are actually *epistemic artefacts*, whose *epistemicity*

importantly accrues from their *intentionality*[32] and *materiality*. The intentionality and materiality of epistemic artefacts are coupled through the notion of *affordance* due to James J. Gibson's ecological theory of perception (1979). What is remarkable about this notion is that it cuts across the dichotomy between the subjective and objective stressing the complementarity between the environment and the organism. Thus affordances are on the one hand based on the objective material properties of the environment and on the other hand on its consequences for the specific organism. [33] Applied to humans and artefacts this means that the materiality of an artefact constrains the uses to which it can be put. I argue that this element of constraint is in fact conducive to scientific reasoning, if devised in a skilled and purposeful way, which is where intentionality comes into the picture.

The notion of an epistemic artefact is applied to a language-technological artefact, a parser. The description of the parser is written by my co-author Atro Voutilainen, a language technologist. A parser is interesting model, in that its very status as a model is questionable from the traditional semantic point of view. As a working program, it cannot easily be rendered as an abstract structure, given that it seems to be more like a thing, or an instrument, that is primarily appreciated for what it produces: a morpho-syntactic analysis of written text. However, approaching a parser as an *epistemic artefact* discloses its affinity to various other things that scientists call models. In the case of a parser the constraints built into the language description are made operative by implementing it as a computer program. Consequently, the notion of models as epistemic artefacts makes room also for considering computer programs as models.

Finally, I discuss the implications of the artefactual approach developed for the question of representation. The article ends by taking up many themes concerning models and representation that will be more fully developed in the next two articles. Thus I argue that models as epistemic artefacts give knowledge in many other ways than just via direct representative links, being typically used as both objects and tools of inquiry. Moreover, I point out how the different roles of a model can be closely linked. Consequently, the instrumental success of a parser, i.e. its producing reliably what we expect from it, makes it also an interesting object to study in our effort to understand language and cognition.

Study 4:
Knuuttila, Tarja
"Models, Representation, and Mediation"

(in press) *Philosophy of Science* 72 (Proceedings), (2005).

This article continues and expands the discussion of models and representation started by the previous article. It relates the notion of models as epistemic artefacts to the discussion on models and representation in the philosophy of science. The article opens by observing that even though philosophers of science typically ground the knowledge-bringing aspects of models in representation, they have widely different opinions of what constitutes representation. This of course is bound to awaken suspicions of whether philosophers actually do agree as to what the *epistemic value* of models depends on. Consequently, I examine the recent discussion of models and representation, where a definite change from more traditional dyadic structuralist approaches to triadic pragmatist ones can be discerned. From a brief discussion on the shortcomings of the structuralist approach I move on to the pragmatic approaches advanced by Daniela Bailer-Jones (2003), Ronald Giere (2002c) and Mauricio Suárez (2002b).

Of the pragmatic accounts presented, I find Bailer-Jones's idea of approaching the question of representation through the propositions entailed by models somewhat misguided. It loses sight of the diverse media that models make use of, a consideration that seems to be important for understanding the specific scientific value of models as representations. Moreover, the talk about propositions in the context of models and representation appears to be somewhat paradoxical, given that the interest in models in the philosophy of science has been motivated by a desire to break away from the language-orientedness of

[32] Artefacts can be claimed to be intentional in the very general sense of being directed towards some goal or thing, which intentionality is bestowed upon them by human activity.

[33] For an interpretation of affordances in terms of material dispositions, see Harré (2002) and Scarantino (2003).

the so-called "received view" (see e.g. van Fraassen 1980, 44; Woodward 2002, 279-380; Frigg 2003, 10-11). In contrast, both the similarity account of representation by Ronald Giere and the inferential account by Mauricio Suárez seem to give interesting and partly complementary approaches to representation. Thus, whereas Giere stresses the properties of the representative vehicles (i.e. they should be similar to their targets in specified ways), Suárez focuses on the inferential activities of "competent and informed" users of representation.

What is interesting about these pragmatic approaches is that they agree that no more than a minimalist account of representation can be given, since representation is essentially an accomplishment of the users of the representation. Users make the model to represent that which it is modelling, relying, of course, on the properties of the model. Thus it may seem that the model becomes a model first when it is used as such, i.e. representing something with its help (see the discussion above). However, it appears to me that taking the pragmatic approach seriously actually implies that the link between the models and representation is looser than is usually supposed. I suggest that, rather than being representations, models should be approached as epistemic artefacts, as self-contained artificial objects that can be used in scientific endeavour in a multitude of ways. This makes room for the observation that from the point of view of scientific practice the representative links to reality provided by models are often more indirect, hypothetical and preliminary than we have thought. Moreover, the very same models can be used to represent different kinds of things. Consequently, in "Models, Representation, and Mediation" I end up articulating a *two-fold* approach to representation. My main idea is to approach representation as a dual phenomenon, comprised of both a material *sign-vehicle* and an intentional, three-place *relation* of representation that connects the sign-vehicle to whatever is being represented.

This two-fold approach makes it possible to study scientific representation from two different angles. On the one hand one should study the artefacts, the models, themselves: their specific constraints and affordances, as well as the media, methods and previous knowledge they rely on. On the other hand one should study how the representative relation between the sign-vehicle and its object is achieved. Besides, I find the distinction between representation as a sign-vehicle and as a relation illuminating because the word

"representation" is frequently used in both of these senses, causing them easily to coalesce into another. This is in fact what happens in dyadic accounts of representation, for example in the structuralist approach, which assumes that representative vehicles are able to create the relation of representation by themselves, due to their inherent properties.

Study 5:
Knuuttila, Tarja
"From Representation to Production: Parsers and Parsing in Language Technology"

(in press) in Johannes Lenhard, Günther Küppers
and Terry Shinn (eds.)
Simulation: Pragmatic Constructions of Reality.
Sociology of the Sciences Yearbook. New York: Springer, (2006).

In Study 4 I claimed that one of the reasons to treat models as epistemic artefacts is to loosen their *epistemic value* from their representative function. Consequently, the task of this article is to show what other epistemic roles besides representation a scientific model can have. I proceed by presenting a case study of the Constraint Grammar Parser, a computational model of a syntax whose primary goal is to give a morpho-syntactic analysis of a running text. In Study 3 the principles of building a slightly different kind of parser, the Finite-State Constraint Grammar, were presented. The parser was introduced by a linguist, who has himself been fabricating it. Here my goal is somewhat different: as I attempt to paint a down-to-earth picture of the place of a parser in language technological research, the study is based on the publications of a group of scientists making parsers, as well as on interviews conducted with them.

As a language technological artefact the parser can be claimed to imitate human performance in the sense that its task is to give same kind of analyses to a text that a human linguist can. Thus it is a simulation both in the sense of being a stand-in for a human linguist and being a computer program that executes the grammatical constraints of a specially devised language description. Yet, even though the task of a parser is to simulate the "output" of a human linguist, it cannot be taken as a realistic representation of the linguistic competence of a linguist. The parser thus presents us a clear case of being a *model for* something instead of being a *model of* something (Fox Keller 2000). It is, rather, a new kind of thing in itself than a representation of something that exists already. If the epistemic value

of models were tied to representation, the parser would not appear to be a very interesting epistemic thing in the first place. One might even question its status as a model, as already suggested in "A Parser as an Epistemic Artefact: A Material View on Models". In my opinion, this does not show that there is something wrong with the parser as an example of a model but rather with the philosophical outlook on models. As I have already argued, it is unclear in the case of many scientific models what exactly they are models of. Thus I would not make being a representation a criterion for what being a model amounts to, which has also the additional problem of how then to distinguish models from the other scientific representations which we would not prefer to characterise as models. The answer to this question is, as I have already claimed and will claim in this article especially, that we usually take as models such purposefully fabricated things that we can work, interact and experiment with — and it seems that computer simulations even radicalise this aspect of modelling.

The uneasy status of models as representations has of course been noticed by some philosophers of science and thus there has been some discussion of models as tools in addition to that of models and representation (see e.g. Cartwright, Shomar and Suárez 1995, Klein 2001). Indeed, it is a typical move in the general discussions concerning representation and representationalism that the things we take to be representations are claimed to be tools rather than representations. Thus, for instance, Rorty's critique of representationalism asserts that linguistic expressions, and consequently language itself, should be considered as tools. Considering representative artefacts as tools offers a convenient way for him to circumvent the variously intertwined notions of representation, realism and truth. The Constraint Grammar Parser I consider in this article is obviously a *tool*, but I argue that it is other things, too. It can be also considered as a worthy research object in its own right and as an inferential device. The fact that parsers are also *research objects* of computational linguistics and language technology serves to underline the fact that models need not be treated just as surrogates for reality proper. In its role as an *inferential device*, the parser comes closest to functioning like a representation of some kind. However, since it cannot be taken to offer any realistic representation of human linguistic competence, it gives indirect evidence of it instead.

Last but not least, I have tried to make the *work of representation* characteristic of modelling visible in my treatment of the parser construction. This is because the discussions of models and representation have been by and large neglectful of the way models are themselves products of various representative procedures. As they are results of the work of representation, they *present* us something, although it is uncertain how that something is supposed to represent something else in the external world. Looking at the way models are built offers also new insights into representation. Here representation appears as a mediative activity that conveys something that is already known or assumed, transforming it with the help of diverse representative means. Consequently, the cognitive problem of modelling concerns not only *what* is being represented but also *how* that can be done. Thus in addition to depicting the multifacetedness of parsers as epistemic artefacts, the article "From Representation to Production: Parsers and Parsing in Language Technology" tries to convey the flavour of the laborious work of representation that is inherent in modelling and of the expertise that is born in the very process.

Study 6:
Knuuttila, Tarja and Timo Honkela
"Questioning External and Internal Representation: The Case of Scientific Models"

(in press) in Lorenzo Magnani (ed.),
Computing, Philosophy, and Cognition.
London: King's College Publishing, (2005).

One way to put that what I have attempted to say in the previous articles on models and representation is that the things we treat as representations do not always act representationally and their epistemic value need not derive from their ability to represent. Models are a case in point. I have argued that they give us knowledge in many ways and that they can be made to bear on our knowledge of the world even if they cannot be taken as straightforward representations of external phenomena. The rationale for treating models as epistemic artefacts lies exactly in the potential of this approach to explain the epistemic value of models without recurring to their representative function. The target of my criticism is not representation itself, but representationalism, which in the case of models has such a firm grip on us that it has seemed nearly beyond doubt that models give us knowledge *because* they succeed in representing something external to themselves. This has led, as we have seen, to claims that to be a model is to represent. In my opinion this eventually leads us to ask why we believe that to know is to be in command of a representation that depicts something that already exists rightly, in relevant respects or aspects.

Why is representation so important? An answer already hinted at is provided by the representationalist theory of knowledge, which seems to be deeply ingrained in our epistemological thinking. Thus, for instance, the author of a recent monograph on models and representation does not hesitate to claim that: "Science aims at giving us empirical knowledge. If models are to serve this purpose, they must be representational. … They can instruct us about the nature of reality only if we assume that (at least some of) the model's aspects have counterparts in the world. Hence in order to be a source of knowledge

models must be representational." (Frigg 2003, 19). As already noted earlier, the roots of representationalism lie in the idea that the external world is not directly presented to the consciousness, but only through mental content that can be regarded as a collection of internal representations of some kind. Thus knowledge is identified with internal representation, which poses the question of the relationship between internal and external representation.

In order to know how internal and external representation are linked to each other, one would need to know what internal representations are like and how they are connected to the external world (including external representations). Unfortunately, there is even less agreement concerning internal representation than external representation. Whereas we are empirically acquainted with the external representations we produce and use, the same is not true of internal representation. There is no agreement as to what kind of representations our minds house. Such being the case, the article "Questioning External and Internal Representation: The Case of Scientific Models" approaches the question of internal representation by examining what can be inferred about our cognition from our external practices of representation. Study 6 examines in particular a special kind of model, the self-organising map (SOM), which is approached as a multifunctional epistemic artefact. Timo Honkela, a computer scientist experienced in building and studying SOMs, has characterised them in this article. What gives a special twist to the case of the SOM in the context of internal and external representation is that it can also be used, among other things, as a model of the mind. Thus it can be conceived of as an external representation, which conveys us knowledge of our supposed internal representations. However, even in this capacity the SOM, rather than being a representation of our brains, functions as a device with which some interesting results concerning the adaptive cognitive processes can be shown. Consequently, it rather demonstrates and exemplifies than really represents.

As for the question of internal and external representation, we argue that the idea of models as epistemic artefacts finds support in recent trends in cognitive science according to which cognition is distributed between embodied humans and their environment. This human environment is largely artefactual, and thus the distinctively human kind of knowledge can be regarded as a product of our artefactual practices (including language). Thus both external and

internal representations should be understood rather performatively than representationally, as oriented towards action, and as parts of complicated causal, cultural and inferential webs. This of course sets limits on how well the notion of representation itself can be expected to explain cognitive and epistemic processes. Our conclusion is that the explanatory power of the representationalist paradigm is diminishing as a consequence of such developments as distributed cognition, which ultimately relativises the strict division between the internal and external representation.

5. Conclusions

It seems that the crisis of representation emerges from the uneasy encounter of our representationalist epistemological heritage with the observation that our representations are artificial and conventional constructs. The conception of knowledge of the modern era has been representationalist in the sense that correspondence with the world "as it is" has provided the criterion for whether a representation is true or not. From this point of view any traces of artifice must make the representation seem less truthful and more contrived. Yet, as the representations we produce and use cannot be but artificial, suspicions concerning their "objectivity" start to abound. How can our obviously constructed and media-specific representations really stand for reality in the sense of depicting some aspects of it accurately?

The answer, I suggest, is not to doubt the artificiality of representation but rather our representationalist convictions. As I have argued in this dissertation, our representationalist heritage ties together several different ideas in assuming that knowledge consists of a collection of representations that correspond accurately to reality, which is comprised of a fixed totality of representation-independent objects. What I have attempted to do here is to join others in untying the knots that are characteristic of representationalism: the conflation of knowledge and representation, representation and correspondence, and finally representation and (metaphysical) realism. Even though I have been inspired and motivated by these big questions my work has remained largely in the sphere of modelling and scientific representation.

In this dissertation I have developed a practice-oriented artefactual approach to models that loosens the epistemic value of models from representation (understood in the representationalist sense). Treating models as epistemic artefacts attributes their epistemic value to the interplay of their material and intentional dimensions, which is due to their being both purposefully constrained and materially defined, yet interpretatively open things. What is new about my approach is its stress on the materiality and artefactuality of models—properties that have been of secondary importance for the philosophical tradition, which values the abstract, theoretical and conceptual. From my naturalist point of view, we do not however represent with the help of structures or conceptual ideas alone. These ideas they have to be built

into, and with the help of, specific media, which partly determines that what can be conveyed through models and representations.

As to the question of modelling and scientific representation, this dissertation draws the following conclusions:

Our understanding of modelling should not be restricted to the view that models represent some external target systems accurately. Apart from being representative things, models are typically also productive things whose workability and experimentability are crucial for their epistemic value. Models can function not only as tools and inference generators, but also as research objects in their own right. In the capacity of inference generators models can be used as representations. In scientific practice, however, they also function as exemplifications, proofs of existence, demonstrations and test-beds. Thus conceiving of models as representations loses the sight of many of their distinctive properties. What is more, it gets the cognitive challenge of modelling the wrong way, as it assumes that we already knew what our relevant target systems were and had the appropriate means at hand to represent them.

Representation can be approached both from the use and the production points of view. Philosophical analyses of scientific representation have so far concentrated rather one-sidedly on the use of ready-made models. From this starting point, I have argued that representation should be approached as a *two-fold* phenomenon that is based both on the medium-specific affordances of the material sign-vehicle and on the intentional process of relating the sign-vehicle to whatever it is that is being represented. The fact that a sign-vehicle is a materially constructed historical artefact leads us to consider the complex culturally constructed artefactual chains through which our knowledge of the world is actually mediated. As no sign-vehicle is representative of anything in and of itself, the intentional process of relating it to its object is needed for the representation to become accomplished.

Treating models as artefacts makes their production processes visible. Seen from this angle a large part of the work of representation that is taking place in sciences is conveying into another form that what is already represented and modelled somehow. Looking at representation from this point of view stresses the methods, ingredients and various representative devices that are needed in producing models. The production point of view on representation

seems to me an important complement to the use point of view. It shows how any ready-made model is already a complex representative achievement in itself and not an isolated theoretical entity. I think that this has a certain sobering effect: one needs not be puzzled about what connects the model and its supposed target system since the model is from the very outset a result of various procedures of connecting. Thus representing lies indeed at the heart of the modelling enterprise, but not where it has been conventionally taken to be.

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