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DISCUSSION

Matters of Interest: The Objects of Research in Science and Technoscience

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Abstract This discussion paper proposes that a meaningful distinction between science and technoscience can be found at the level of the objects of research. Both notions intermingle in the attitudes, intentions, programs and projects of researchers and research institutions—that is, on the side of the subjects of research. But the difference between science and technoscience becomes more explicit when research results are presented in particular settings and when the objects of research are exhibited for the specific interest they hold. When an experiment is presented as scientific evidence which confirms or disconfirms a hypothesis, this agrees with traditional conceptions of science. When organic molecules are presented for their capacity to serve individually as electric wires that carry surprisingly large currents, this would be a hallmark of technoscience. Accordingly, we propose research on the ontology of research objects. The focus on the character and significance of research objects makes this a specifically philosophical project.

Keywords Ontology · Research objects · Technoscience · Dispositions · Affordances · Philosophy of scientific experimentation

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> Das Wesen des Erkennens fordert schlechthin, daß derjenige, der es ausüben will, sich in eine Ferne und eine Höhe über die Dinge begebe, von der aus er ihre Beziehung zu allen anderen Dingen überblicken kann. Wer sich ihnen nähert, teilnimmt an ihrem Weben und Wirken, der steht im Leben, nicht im Erkennen; ihm zeigen die Dinge das Antlitz ihres Wertes, nicht ihres Wesens.
> By its very nature knowledge demands that the one who seeks knowledge assumes a distance and elevation above the things from which one can survey their relations to all other things. Whoever gets closer to them and participates in their agency and efficacy, partakes in life and not in knowledge; face to face with the things one beholds their value and not their nature. (Schlick 2009, 288)

The founder of the *Vienna Circle* articulates a conception of knowledge and science that not only expresses a particular self-understanding of the sciences but that left a lasting imprint on the philosophy of science. His *General Theory of Knowledge* provides a requirement of how things must appear in order to be objects of knowledge and objects of scientific experience. Some scientific research is purely observational, other kinds of research involve close experimental engagement with the things, but in both cases, knowledge can be obtained only if the scientists step back far enough from the experiment to discern relevant factual relations that disclose the nature of things, for example, their regular exhibition of dispositional behaviors.

This conception of science did not originate with Schlick and the *Vienna Circle*. It is part of a tradition that began long before them and that is still with us today. The rhetoric of discarding as non-scientific the "practical arts" like pharmacy, medicine and engineering, today's materials research, nano- or biotechnologies can be found, for example, in William Whewell's *Novum Organum Renovatum*: "Whatever place in human knowledge the Practical Arts may hold, they are not Sciences. And it is only by this rigorous separation of the Practical from the Theoretical, that we can arrive at any solid conclusions respecting the nature of Truth" (Whewell 1858, 134). Following Whewell's or Schlick's lead, philosophers of science have a lot to say about truth and representation, hypothesis and reality, hypothesis-testing and theory-choice—and little to say so far about scientific research that seeks to control phenomena and master complexity and that does not issue in propositions that can be true or false and that describe the facts from some distance or elevation.

There is increasing recognition of late that there has always been and continues to be a great deal of research, including the most highly prized research of today, that engages the things, participates in their agency and establishes their value (e.g. Carrier and Nordmann 2010; Chang 2004). It establishes novel properties that might be functionalized in certain ways, it exhibits valuable behaviors or performances, and it seeks to master complexity and to control processes and phenomena. Research of this kind can be called "technoscientific" research. Accordingly, one major difference between science and technoscience might be how things appear as objects of research. This is an ontological difference. The following programmatic reflections invite philosophers of science and technoscience to engage with this question of ontology—not only in order to appreciate the difference between science and technoscience but also to draw their attention toward neglected epistemological, methodological or ontological dimensions of research.[1] This is an invitation, quite literally, since it marks the beginnings of a long-term research-project. At the beginning and in this paper, guiding questions can be posed and philosophical claims motivated. If these

[1] Funded by the French and German Research Councils, ANR and DFG, the project "Genesis and Ontology of Technoscientific Research Objects" is set to develop a number of case studies in a larger collaborative setting. For more information see http://www.goto-objects.eu.

provoke dissent or do not yet appear sufficiently clear or seem to require more extended case studies, we welcome a critical exchange about this.

1 Towards a Philosophy of Technoscience

Whether the distinction between science and technoscience needs to be taken seriously is an open question for philosophers. For many it coincides with the familiar difference between pure and applied science. Others object to the notion of "technoscience" because there has always been a close interaction between science and technology, between representing and intervening (Hacking 1983). If technical intervention amounts to a necessary condition of all knowledge production in modern science, so they maintain, it cannot serve to distinguish scientific and technoscientific knowledge production (e.g. Boon and Knuuttila 2011). This objection misses the point, however, if experimental practice and technological tinkering are considered only so as to add the necessary detail to a standard picture of science according to which science aims for truth or empirical adequacy. If instruments and experimental practice are considered solely for the purpose of understanding how theoretical knowledge is produced and validated, science is still distinct from technology, let alone engineering. Here, then, the interplay of representing and intervening underwrites a familiar conception of science and does not capture "technoscience." The latter notion suggests that science is not distinct from engineering, that the knowledge produced is at the same time theoretical and technical.

We begin by reviewing some of the more principled arguments for a distinction between science and technoscience, allowing that the proof of the pudding will lie in the eating, that is, in the philosophical work that can be done with the help of this distinction—for example, regarding the ontology of research objects. "Technoscience" is not the missing ingredient to a more rounded image of science, it is not a disciplinary label that picks out a subset of the sciences, nor is it science contaminated by extraneous intentions, interests, or application pressures. But what is it then?

If "technoscience" is not descriptive of a particular subset of the sciences, there can be scientific and technoscientific accounts of the very same research practices, and these accounts can inform each other in productive ways. Instead of being classificatory, then, the terms "science" and "technoscience" designate guiding ideals or research orientations that shape practice in different ways even within the same fields of research (Bensaude-Vincent 2009; Nordmann 2011). Explicitly and implicitly, philosophers of science have been articulating what "science" is and how it orients research to a variety of epistemic ideals. We might therefore begin by briefly reconstructing the much shorter history of "technoscience" and how it orients research to technical ideals.

Gilbert Hottois coined the term in 1984 and used it to refer to science that is done in a technological setting or *milieu* and that is technology-driven (Hottois 1984). Accordingly, the term technoscience has some affinity to techno-music where the sounds cannot be separated from the technological context in which they are produced—as opposed to the musical score of a classical piece. Along these lines, Bruno Latour employed the term "technoscience" initially as shorthand for and fusion of "science-and-technology," that is, as a technology/science hybrid where the two cannot be separated out from one another in terms of basic and applied research (Latour 1987). According to these definitions, "technoscience" is an alternative to "science and technology" with its assumption that science and technology are distinct but interacting spheres. Instead of discussing in detail how the term has been used by Gilbert Hottois, Bruno Latour, Donna Haraway, Katherine

Hayles, Don Ihde, Isabelle Stengers, Raphael Sassower, and many others,[2] we need to develop further just what is implied by the "scientific" idea that science and technology are separate but interacting spheres—and what is implied by the "technoscientific" surrender of this claim.

The very term "technoscience" exposes that the distinction between science and technology is not at all self-evident. Indeed, when one looks through a telescope, prepares a sample, controls for artifacts, produces an effect, or sets up a field experiment, it requires considerable care to distinguish science and technology. Accordingly, when philosophers and scientists separate out these spheres, this involves further divisions such as those between nature and artifice, between the representation of a given world and intervention into the lifeworld, between nature and culture, between pure theoretical knowledge and the practical control of complex situations. The conceptual work of separating out these interrelated domains has been called a work of purification because it yields the ideas of pure science and pure theory and also yields a notion of nature as something prior to and independent of culture. The view of "science" as a primarily intellectual enterprise of gaining understanding of an already given world has resulted from this remarkably successful work of purification. Inversely, we might define that we encounter technoscience when this work of purification is abandoned because it proves impossible or unnecessary. While this is not the only way of defining science and technoscience, and perhaps not even the best way of doing so, these are the definitions we adopt for the purpose of this programmatic paper: Both science and technoscience involve an interplay of representing and intervening. Science is defined by its orientation to the epistemic ideal of purification, that is, of separating out as clearly as possible what the scientists contribute and what belongs to a given world or mind-independent reality: scientists contribute concepts and theories and measurement-techniques and experimental interventions but presumably all these serve to register something that exists or a "natural" response to an experimental stimulus.[3] Technoscience is defined by its neglect or abandonment of this work of purification. It does not pursue it either because it appears to be impossible and a futile exercise from the get-go, or because it is taken to be unnecessary if not nonsensical. Since this definition of technoscience is only negative, in order to mark the contrast to science, it requires further elaboration.

According to the first half of this definition of technocience the work of purification can appear to be impossible—in light of certain conditions, even the attempt of doing so is doomed from the start. Technoscience is therefore a kind of research where theoretical representation and technical intervention cannot be held apart even in thought. In the case of laboratory experiments this means that it may not only always be possible to distinguish for an observed effect the contribution by the researchers with their instrumental apparatus from the contribution of nature. Even though experimental design often serves to ensure that this distinction can be made, it becomes extremely difficult, if not impossible, when the observed phenomena and effects appear to be engineered—for example, when one studies the "natural" behavior of genetically engineered organisms. This difficulty might

[2] Hottois (1984) and (2002); Latour (1987); Haraway (1997); Hayles (2004); Ihde and Selinger (2003); Sassower (1995); Stengers (2010).

[3] This definition does not make any assumptions as to whether this work of purification ever succeeds, nor does it commit science or philosophy of science to a realist metaphysics. Indeed, the differences and debates between various brands of realism, conventionalism, instrumentalism, constructivism arise within the scientific enterprise—they result from the question what the work of purification can achieve, and how the "signs of the real" should be interpreted.

serve as a criterion to distinguish technoscience from science and, significantly, it arises on the side of the research objects.

According to the second half of the definition, we encounter technoscience when the work of purification is considered irrelevant and unnecessary. Along these lines Peter Galison proposed the notion of "ontological indifference" (Galison 2006, see also Daston and Galison 2007, 393, 414): For technoscientific research it makes no sense to artificially separate out theory and reality, mind and world and only then to relate them to one another. For instance, when biomedical research produces a pharmaceutical therapy, there is no interest or there is no reason to separate the respective contributions by technology and by nature to the efficacy of the therapy. In contexts like these, one wouldn't expect the phenomenon of interest to be anything but the confluence of natural processes and human art.

Thus, only as long as the purpose of research is to determine scientifically what is and or isn't really the case, it is crucial to know what is the case independently of what humans think and do—caught up in this question, realists, positivists, conventionalists, or constructivists interpret the work of science as aiming to represent a relatively mind-independent reality. But when the purpose of research is to technoscientifically acquire and demonstrate a capability of control, to make and build something, or to show what can be done, it is clear from the start that all of this depends not only on what the world is really like but also on what humans think and do. Here it is therefore quite unnecessary to juxtapose natural agency and human intervention.[4] (For those who are looking for the Higgs Boson, the claims of realism or constructivism make a big difference; for those who make carbon nanotubes grow or who get molecules to function like machines and motors, there is no question here.) While this holds for the engineering sciences, it is characteristic more generally for "an engineering way of being in science" or for "research in a design mode" (Galison 2006, Ann Johnson in conversation, Nordmann 2010b). These designations might therefore serve as equivalents to "technoscience."

Associated with this definition of the technosciences as essentially impure is another general feature that has caught the attention of sociologists and policy-makers in particular. The technosciences cannot retreat into a protected disciplinary sphere of facts as distinct from social values. This is often put in terms of a "new social contract between science and society" or the general statement that the boundaries between science and society have become porous. Indeed, one might say that the shortage of philosophical characterizations of technoscience is more than compensated by an abundance of sociological accounts that contrast mode-1 and mode-2 research, normal and post-normal science, public and commercialized or entrepreneurial science, academic and post-academic science.[5] While these various sociological accounts often operate with rather superficial distinctions between different modes of research, they complement the juxtaposition of science and technoscience in one respect. All these accounts show how research practices and their objects are determined by scientific, technical, as well as societal factors. The work of purification therefore fails not only in respect to the distinction of representation and intervention but

[4] An anonymous reviewer suggested a way of refining the question here that might be especially fruitful for a project dedicated to the ontology of research objects: The question of realism versus positivism or constructivism arises in respect to the problem of reality (*Realität*) as an object of representation. In contrast, research that engages the agency or efficacy of things that function outside the laboratory is interested in actuality (*Wirklichkeit*). However, some theories of reality assume that what is actually and efficaciously the case affords the only "signs of the real" that serve as the evidentiary basis for representations of reality.

[5] See Gibbons et al. (1994); Nowotny et al. (2001); (2000). For an overview and discussions see Nordmann et al. (2011).

also in respect to fact and value, in respect on the one hand to the description and control of the phenomena, on the other hand their significance or (promise of) utility.

In summary then, these are the ways in which "science" and "technoscience" serve as guiding ideals or research orientations that shape practice in different ways even within the same fields of research.

The ideal of "science" orients the many special sciences towards the acquisition of a kind of knowledge that takes the propositional form of theories or hypotheses, of models, explanations, or representations. From the point of view of philosophy of science, at least, the main problem for all the various sciences is the relation of theory and reality: How can one ascertain the agreement between scientific representations and the way things really are in mind-independent reality? Arguably, this problem and its many variants are a common denominator of the scientific enterprise and they involve an ontological presupposition. Since the scientific representations in question typically assume the form of propositions, the world is typically taken to be composed of facts and not of things—and a fact is "that something is the case," "that a thing is so and so," "that this has been observed or measured" etc.[6] Accordingly, the bridging between theory and reality consists in some arranging of propositions that state facts—be it syntactically and along the lines of deductivism or be it by establishing a local fit between model and phenomenon (e.g. de Jong and Betti 2010). The disciplinary organization of the sciences directs attention to problems, anomalies and knowledge gaps in the theoretical description of features of the world.

The technoscientific ideal orients the many special technosciences towards the acquisition of a kind of knowledge that consists in demonstrable capabilities to control phenomena. These include capabilities of visualization, measurement, (simulation)-modeling, intervention and manipulation, along with more specific capabilities such as the isolation of gene sequences, the controlled growth of carbon nanotubes, the synthesis of new compounds, or the in vivo observation of a cellular process. In this context, experimental interventions are not designed to strategically answer a disciplinary question but to elicit surprising, and potentially useful behaviors or properties. These experiments uncover the resourcefulness, plasticity and potential for surprise that reside in the objects of research. The plasticity of technoscientific objects suggests a different ontology. The objects of technoscience are things or processes and their power to surprise, to perform, or to be functionalized. They are defined by what they can do, and how they might prove valuable. This, to be sure, is only a first approximation to the ontological difference between scientific and technoscientific objects. If the proof of the pudding lies in the eating, one way of establishing the philosophical fruitfulness of the notion of "technoscience" consists in showing that it affords more precise and differentiated analyses also of the ontology of research objects.

2 Complementary Perspectives

This proposal is an invitation to philosophers of science to take seriously the notion of "technoscience" in order to bring to light a range of questions that have been neglected so

[6] Ludwig Wittgenstein, in particular, articulated this ontology: "The world is the totality of facts, not of things."—"It is essential to a thing that it can be a constituent part of an atomic fact."—"Objects I can only *name*. Signs represent them. I can only speak *of* them. I cannot *assert them*. A proposition can only say *how* a thing is, not *what* it is" (Wittgenstein 1958, 1.1, 2.011, 3.221).

far even in the context of the philosophy of experiment, of modeling, of scientific practice. We suggest that the perspective of "technoscience" can stimulate debate not only about the ontology of research objects, but also about the role of theory in different contexts of research, about different styles of scientific reasoning, about different understandings of technology, about modeling and explanation, or about the role of conservation laws in research practice (Bensaude-Vincent 2009; Loeve 2010; Nordmann 2010a, Schwarz and Nordmann 2010).

If one does not give priority to science or to technoscience but views them as complementary, one should expect that both notions intermingle in the attitudes, intentions, programs and projects of researchers and research institutions—that is, on the side of the subjects of research. And one should also expect that the difference becomes more explicit when research results are presented in particular settings and when the objects of research are exhibited for the specific interest they hold. The difference between science and technoscience becomes clear, for example, when an experiment is presented as scientific evidence which confirms or disconfirms a hypothesis ("science"), and when organic molecules are presented for their capacity to serve individually as electric wires that carry surprisingly large currents ("technoscience"). It is with this focus on specific material articulations rather than the intentions, institutions, economic settings, or goals of research that we set apart our philosophical project from sociological or deconstructivist approaches.

Whereas the ideal of "science" results from a more or less successful work of purification that can always be deconstructed by historians and social theorists of science, Bruno Latour, Donna Haraway, or Andrew Pickering consider "technoscience" as the true expression of the real, impure, mixed practices of science. By identifying technoscience with the original and authentic character of science which has been obscured by the commitment to purity and detached representation, they tell a story that inadvertently takes a Hegelian turn. According to this story, eighteenth to twentieth century theoretical "science" obscured its Baconian origins and impure practices; it finally came to know itself in the age of nuclear weapons and space exploration, of computer science and biotechnological research. Only now, science came to understand and fully realize itself as technoscience.[7]

While we agree that, for example, contemporary nano- and biotechnological research draws attention to the technoscientific character of scientific research practice in general, we do not maintain that all of science can be exposed as technoscience, or that the work of purification is a futile and meaningless pursuit. Instead, we view as complementary the scientific and technoscientific orientations of research and the corresponding perspectives on the research practices. To acknowledge this complementarity is to acknowledge the real efficacy and historical significance of both perspectives. One perspective places research in the context of progressive theory development with its concern for representational correctness, the other perspective foregrounds the extension of capabilities of control for human ends. "Science" foregrounds and brings to light a primarily intellectual activity that draws on technology for purposes of validation, whereas "technoscience" foregrounds and brings to light an artisan or design activity that draws on skills, materials, practical and theoretical knowledge to shape and reshape features of the world.[8] Accordingly, both

[7] For a critique of this story-line see Rabinow (1997).

[8] How do the ways of "foregrounding" different aspects of the same research relate to the distinct definitions of science and technoscience? Take the example of "control." We stated that the sciences aim for true representations, the technosciences for capabilities of control, but we did not use this to define the

perspectives one-sidedly idealize certain aspects of knowledge production, and in this sense, both are "mythical"—science dedicated to the Enlightenment project, technoscience to the transgressive power of innovation. Each of these perspectives on research is most compelling where it describes just those practices that are most explicitly dedicated to their respective mythical ideal. For this reason we aim to explore how idealized notions of science and technoscience can shape scientific practice all the way down to the research objects (Bensaude-Vincent 2009). As the ideals are worked out in the encounter with real objects, the distinction between science and technoscience will become ever more salient.[9]

3 Facts, Objects, and Things

The following, very schematic account begins to further articulate the ontology of scientific and technoscientific research objects. In the case of science, the ontology of objects turns out to be dependent on the ontology of facts.[10] In the case of technoscience, objects are of interest as things.

The mode of existence of scientific objects is circumscribed by their occurrence in states of affairs. Since the existence of a state of affairs is considered a fact, scientific objects are relevant to the extent that there are facts about them. And since it has become a philosophical commonplace that one cannot know things as they are in and of themselves, the way to know objects is to state those facts, that is, how the objects appear in specific contexts of experience by being observed, measured, probed or prompted in specific ways. To know objects by their behaviors, actions and reactions, or responses is tantamount to knowing facts about them, and these facts rather than the objects themselves ground the sciences.

Footnote 8 continued
difference. After all, according to certain pragmatist and empiricist accounts of science, one ascertains the correctness or adequacy of a representation by taking as evidence a resulting capability to control. According to our definition, then, this is the decisive difference: In the case of those pragmatist and empiricist accounts of science control validates propositions and is not knowledge in its own right. In the case of technoscience, however, control is knowledge in its own right and the task for the philosophy of technoscience is to reconstruct the underlying epistemology, notions of validation etc. Having done this for technoscience, we can turn back to look at the sciences and ask whether there, too, is operative "under the surface," so to speak, that other epistemology according to which the achievement of control is knowledge in its own right, indepedently of whether it validates a proposition. This is how "foregrounding" works and it leaves quite intact, of course, the notion that the sciences are oriented to the ideal of purification and thus to representations and propositions that are true or false.

[9] However, it could be argued that such a top-down approach, in which objects embody idealized ontological frameworks, should be complemented by a more bottom-up approach, where one would investigate how research objects may prove able to reconfigure the overall map of knowledge, including the guiding ideals of science and technoscience. This is not only a purely methodological "top-down versus bottom-up" problem but concerns the status of ontology in respect to epistemology. Is the ontology of objects framed by a prior epistemological standpoint, or do the objects constrain the epistemic strategies of science and technoscience? To what extent and how exactly are technoscientific objects plastic to human ends and modalities of access—as opposed to the much emphasized resistance or recalcitrance of scientific objects? Do technoscientific attempts at mastering complexity encounter something like a "plastic stubbornness" of technoscientific objects? Here, different approaches come to mind, such as "existential pluralism" (Souriau 1943), "agential realism" (Barad 1999), or "object oriented metaphysics" (Harman 2005). This problem could also be addressed by reconstructing "biographies of objects" (Daston 2000).

[10] Arguably, the ontology of facts is underpinned by an ontology of data where data are thought to be meaningless unless apprehended in the shape of propositions that organize them as facts.

The various particular sciences and philosophies of the special sciences can be distinguished by the answers they give to the general question of how objects appear in experience and how facts about their behaviors can add up to theoretical knowledge, e.g., knowledge of laws of nature or empirically adequate generalizations. For example, Galileo's or Locke's distinction between primary and secondary qualities served to exclude certain features of objects, namely those that did not yield to quantitative measurement. Similarly, the notion of a dispositional property served to distinguish the vast number of unrealized and unobserved behaviors from manifest behaviors that exhibit regularity and that a science of the real can take into account. What is known about the things are their regular behaviors so that particular things become representative samples of a class of objects. This theoretical knowledge of nature can then be used to design processes or devices that rely upon and exploit this regularity. In all of this, the encounter with the things is constrained by the ontology of facts as building blocks of scientific knowledge.

In many ways, technoscience is "face to face" with the things. It is less interested in what they are or what regular behaviors they are naturally disposed to exhibit, and more interested in what they can become or what they might offer. More immersive methods of modeling, for example, do not provide schematic representations but a substitute reality in which researchers encounter the agency of particular things in the context of particular systems, and in which arguments from the similarity between simulated and real system are admissible. By way of this substitute or duplicate reality—e.g., in silico rather than in vivo—researchers engage with their objects: They interact with them by physically experiencing the effect of parameter variations on their model, or by learning to see molecules in the manner in which molecules are said to "see" each other. If general statements can be inferred from this engagement they do not owe to natural lawfulness. They are established technically, on a case by case basis, by rendering operations more and more robust as the phenomena move from one laboratory to the next and through the attempts at scaling them up all the way to industrial production. Each of these developments can draw, of course, on given theories and algorithms. The further development of these theories and representational devices is not at issue as long as they can serve as a toolbox for modeling the potential performances of technoscientific objects.

While the representational demands of science constitute and constrain how objects can appear, the technoscientific approach assumes a plasticity of things that is not limited in an a priori fashion (Schwarz and Nordmann 2010). Just like embryonic stem cells are coveted for their "totipotent" capability to become any other cell, anything composed of molecules is sometimes imagined as capable of becoming any structure whatsoever, as in a game of lego (Bensaude-Vincent 2009).[11] These attributed capacities are unlimited as long as the things do yield novel and promising properties.[12]

In order to further explore this world of boundless possibility, various working hypotheses might be pursued. The following four provide a sampling:

- *Technoscientific objects are value-laden*: Technoscientific objects come into being, not by way of constitution within a categorical or conceptual scheme as apparently value-

[11] An extreme illustration of this point was provided by Nobel-laureate Gerd Binnig, one of the inventors of the scanning-tunneling microscope, suggesting that a rock is not a rock but could be anything else (2004, 7).

[12] To be sure, we are not assuming that, in fact, the technosciences can overcome notions of a limited world and discover unlimited resources for endless novelty and surprise. Obviously, such ideas can be criticized as technoscientific hubris. We do claim, however, that the notion of limits (as in conservation laws) are not constitutive for technoscientific research practice, while they may well be necessary preconditions for the representation of the world.

free objects but through a process of valuation (Echeverria 2003). The case of arctic ice or that of blood from the umbilical cord makes this point: These have been objects and perhaps objects of scientific interest before an assignment of value turned them into technoscientific objects, and now they challenge the traditional contrasts of pure and impure, morally neutral and socially invested.

- *Technoscientific objects are performative*: By becoming an object of technoscientific interest, an already familiar object becomes something new or something else. Indeed, its very nature changes in that it is no longer defined by what it is, but by its expected technical performance. Its structure, properties, and structure–property dependencies fade into the background, while potential functionalities acquired through dynamic modeling and re-engineering take center stage. This anticipatory performativity confers a strange temporal status to technoscientific objects that are simultaneously "already there" and "not yet realized." As such they function as proofs of concept that signify that a process or phenomenon has been demonstrated and at the same time refer to something that does not exist as yet but might come into being.
- *Technoscientific objects are familiar*: When one asks about the nature of objects in the context of scientific research, the answer typically produces a divorce between everyday experience and scientific experience. Accordingly, the search for explanatory structures begins with a distrust of how things appear to the untutored mind. However, the epistemic rupture between science and lay knowledge, emphasized particularly by Gaston Bachelard (1938), does not seem to apply to technoscientific objects. Even where these objects originate in a strange world like the nanocosm, they are represented as mundane objects of human engineering that can be handled in effective ways and that yield a technical performance which can be related to imagined human purposes or alleged societal needs. Even though many technoscientific objects might be unobservable, in fact, they are not therefore "theoretical entities" that provoke debate among realists and instrumentalists, but come into being only to the extent that they are conceived (and visualized) as if they were straightforwardly observable and treated as material building blocks for new technologies.
- *Technoscientific objects have unrestricted materiality:* Only some features of scientific objects are relevant for the pursuit of certain questions. The most famous example of this is the distinction between primary and secondary qualities: If one investigates an object in order to understand its laws of motion, the color of the object will be neglected. For technoscientific objects there are no antecedent constraints regarding the material features that will be relevant for their exploration and understanding. It is up to explorative experimentation to discover which physical features of a thing might alter its behavior under certain conditions.

4 Carbon, OncoMouse, and the STM: Three Examples

General considerations of science and technoscience, and of the difference between their objects of research, call for a more sustained consideration of particular examples. Indeed, these programmatic remarks intend just that—to interest historically minded philosophers and philosophically minded historians or STS scholars to contribute to a collection of studies of technoscientific objects. Here, there is only space to offer a few reminders of objects that have received attention in recent years for the ontological questions they raise.

The first of these objects is especially significant for the fact that in the course of its long history it has appeared in different research contexts, allowing us to see that it is not the same object in these various contexts. To be sure, this is true of a great number of objects, most prominently perhaps the gene which began its scientific career as a hypothetical entity introduced for explanatory purposes and which is now a technoscientific design tool. What makes *carbon* an even more striking example is that it is such an ordinary and familiar object. In the nineteenth century, carbon was identified as a chemical element. In the periodic system set up by Mendeleev in 1869, it appears as a "typical element," the head of a column which exemplifies the properties of its "family." Although charcoal was the main pillar of the industrial revolution, Mendeleev was not concerned with the properties of charcoal. Rather he considered the element carbon, the basic substance that exists in all known allotropic forms of carbon, namely diamond, charcoal and graphite. Mendeleev drew a clear distinction between the abstract notion of elements and the concrete stuff of simple substances. Elements cannot be isolated while simple substances come into existence at the end of a process of analysis and purification. As an element carbon is a "separate homogeneous substance, the material but invisible part of compounds" (Mendeleev 1952, 439). It is a material entity notably with no essential physical features, as illustrated by its protean role in the chemistry of life. It is characterized by its atomic weight, a property derived from theoretical views about atoms and molecules and with experimental data on the various compounds formed by carbon. It was precisely this abstract distinction between elements and simple substance that provided a clue for Mendeleev's discovery of the periodicity of the chemical properties of elements. Without this abstract notion, Mendeleev could never have predicted the existence of new elements, before they could be isolated as simple substances—a phenomenological notion of simple substance would not allow predictions of unknown elements.

Mendeleev's emphasis on the centrality of elements was maintained and even reinforced in the early twentieth century with the discovery of isotopes. The periodic system served as the chart of chemistry, the inscription of the basic building blocks that are used by nature and simultaneously the revelation of a unique and general law governing the irreducible diversity of chemical phenomena. Elements such as carbon were significant objects of investigation when chemists were concerned with establishing order in the jungle of individual substances. And thus, although the development of quantum theory shifted the attention of chemists from the macroscopic properties of chemical substances to the inner structure of their atoms, the notion of elements remained fundamental for chemists. When the term 'isotope' was forged, this reaffirmed the pertinence of the concept of the element as a distinct chemical entity, albeit now defined in relation to the sub-atomic particles that are the constituents of matter.

From a technoscientific perspective the periodic system is seen as a kind of well-organized toolbox. And over the past decades of the twentieth century, carbon has been the focus of intensive research as a resource for the construction of potential tools for specific applications such as high-modulus reinforcing fibers or semi-conductors. The attention has shifted from the element carbon to the variety of its allotropes and novel manifestations: fullerenes, nanotubes, graphene. The various architectures of carbon molecules have been systematically explored as potential materials for performing specific tasks. What used to be one of the fundamental elements of the material universe became a mine of materials, a vehicle of functional properties that could be useful for technological applications. The old familiar chemical element carbon now exists at the intersection of specific natural dispositions and social, economic, military, environmental concerns.

New instrumental techniques such as electron microscopy and scanning tunneling microscopy reconfigured not only the identity of carbon, but its potential at the level of individual molecules. Significantly, the carbon-60 fullerene structures that were discovered in the 1980s were not scrutinized as exotic laboratory curiosities that would shed light on the structural properties of carbon. In a short time, these buckyballs favored the rediscovery of the long-forgotten nanotubes. These rapidly became the starting point of a race for designing single-wall and multiple-wall carbon nanotubes for electronic or medical technologies. Starting in 2004, graphene—a structural component of graphite—became a major focus of research. This isolated plane of carbon atoms is a thermodynamically unstable sheet of graphite. For this reason, it was not expected to exist in isolation from graphite and the individual plane of carbon atoms existed only as an 'academic material'. Nevertheless, once artificially isolated, it revealed to be perfectly stable. After the Nobel prize awarded in 2010 to Andrei Geim and Konstantin Novoselov "for groundbreaking experiments regarding the two-dimensional material grapheme," the three novel forms of carbon were brought together in a single narrative—the story of the carbon sheet "unfolding itself" to visibility at increasing dimensionalities: Fullerenes (zero dimension) where first studied with mass spectroscopy and calculations, nanotubes (one dimension) were discovered with electron microscopy, and finally, graphene (two dimensions) can be observed with visible light microscopy.

Graphene is neither an elementary building block nor a bulk material. It is but a pure surface, a surface without bulk, a surface in itself. As a surface, it combines plasticity, sensitivity and reactivity, as a single layer of carbon atoms it promises regularity of structure and control—every atom matters but the atoms are reasonably well behaved. As a pure surface again, it has a unique electronic structure: an anomalous quantum-Hall effect and a zero-gap band structure; its electrons are massless and behave like relativistic particles describable by the Dirac equation (and not by the Schrödinger equation). Graphene thus also furnishes a "pocket playground" to model relativistic quantum mechanics. Moreover, graphene is both a nanoscale and a macroscopic object: It is part of the nanoworld, and part of our world, and can be engineered at both scales. It is therefore considered a promising substitute for silicon in information technology—while there are speculations about silicon-based lifeforms.

All this suggests that carbon is an attractive object to scientists and technoscientists alike. What makes it attractive, however, is different at different times and in different contexts. As a pure element it holds a key to the constitution of matter and of life—it is an elusive building block behind the appearances. And as a carrier of functional properties it holds the promise of material proliferation and of technologies to be—its protean character epitomizes the plasticity of nature, that is, its malleability to human ends.

In contrast to inconspicuous carbon, *oncomouse™* is the posterchild of "hybridity." Along with other transgenic laboratory animals it has gotten considerable attention as a new kind of research object that transgresses the categories of the natural and the artificial, of living organism and constructed thing, of *physis* and *techne*. Indeed, any investigation of the ontology of technoscientific objects is likely to begin by pronouncing that these objects are hybrids. However, philosophical analysis has to move beyond this finding and should not mistake it for a profound insight. The transgression of received categorical distinctions can only be an effect that accompanies the ontological character of an object. To say that the oncomouse is simultaneously a living organism and a constructed thing is only to conjure an air of paradox and serves to show that it eludes familiar distinctions which do not therefore have to be surrendered (see Schiemann 2005; compare Dupuy 2010). For all its fame, therefore, the oncomouse still deserves close scrutiny. Only some of its features shall be mentioned here.

The oncomouse is usually considered a "model" but what kind of model is it, and if it is a model, what does this tell us about modeling? Several overlapping distinctions have been proposed—that between animal model and model animal, between being a model *of* and a model *for*, between serving as representation of a denoted reality and allowing immersion in a substitute reality (see, e.g., Keller 2000; Gzil 2007, Nordmann 2006). All these distinctions revolve around features of the oncomouse that become salient in different contexts of its design and use. If the mouse is to develop a kind of cancer that also occurs in humans, its design requires a physical correspondence between the human cancer and the mouse cancer, and its designers will therefore be able to account for that correspondence, e.g., by referring to the pertinent genes that are responsible for the expression of the tumor. For the biomedical researchers who study cellular processes and seek ways to suppress tumor development, these questions of correspondence drop out of the picture entirely. Instead, they may well spend their entire career studying the oncomouse, seeking a way to treat cancer in a creature that has been engineered to have that cancer. For these researchers, the oncomouse cancer is not a *model of* human cancer, just as little as the oncomouse is a model of a human being. For them, the oncomouse is a *model for* biochemical tinkering, that is, a substitute reality that exhibits certain behaviors which are subject to practical influence—a reality, therefore, to engage with in a sustained, intimate, immersive manner. And yet, this immersive engagement with the material reality of the oncomouse is thought to promote the discovery of therapies for human cancer. What is done for the treatment of the oncomouse is simultaneously for the treatment of the human cancer—not because the genetic structure of the mouse cancer somehow depicts the genetic structure of the human cancer, but on the assumption that the mouse cancer *is* the human cancer and vice versa: The oncomouse participates in the reality of the human cancer patient. And this may be an important ontological feature of the oncomouse: It is what it is in terms of its physiology and material reality, and beyond that it is also the bearer of a disease process by virtue of the participation, jointly, of mouse and human in a shared reality. The oncomouse as model animal is thus set off from representational models and at the same time moved into the vicinity of computer simulations, experimental systems, and even of the magical thinking that can also be found in voodoo practices.[13]

All this is further complicated or perhaps amplified by the fact that at least in the case of the oncomouse, this notion of participation cannot be reduced to instantiation: The cancer of the oncomouse is not an instance of human cancer. This becomes evident when one considers the following difference: A human being may have a natural disposition to develop cancer, but the cancer in the mouse is an engineered affordance. The notion of dispositional property to respond to a stimulus-condition supports the work of purification: The external, perhaps technical or environmental stimulus is distinct from the natural or automatic response to that stimulus. In a classical scientific experiment, for instance, the scientists or experimenters actively construct the instrumental set-up and provide a stimulus condition, and then they step back to become mere passive observers of the way in which the system naturally responds to the stimulus. Similarly, if a human being has a disposition to develop cancer, any number of processes or events might serve as stimuli,

[13] It might appear far-fetched to speak of "magical thinking" in respect to technoscientific research practice. But the far-fetched comparison makes a point about inferences from the similarity of two physical systems, e.g., from the similarity of cancer in the oncomouse and a human, or from the similarity of a dynamic behavior in silico and in vivo (of a simulation model in a computer and of a physical process in an experimental system). Precisely because these similarities are constructed with the help of research technologies, one can take them as indicative of a shared reality that makes these systems similar. (Compare to this the skeptical rejection of inferences from similarity in modern theories of knowledge: similarity judgments are thought to be reducible to statements of the form "identical in specific respects, different in other respects" and not to signify anything *sui generis*—see Goodman 1972 in contrast to Foucault 1973, esp. 17–25).

but once this likely or unlikely event has occurred, it is thought to be in the nature of that human being to develop the cancer. The oncomouse does not instantiate this dynamic. It does not require a stimulus to develop cancer but does so simply through its existence or by its very nature where that nature, however, is specifically designed to suit human research purposes. When a thing delivers an effect, performance, or service to its user, one speaks of an affordance.[14] Affordances resist the work of purification: It is in the "nature" of the oncomouse to afford a cancerous tumor just as it is in the "nature" of a bicycle to afford a kind of transport.[15]

Once the oncomouse is seen as a material system in its own right that participates in the reality of other things, and once this relation is understood as an engineered affordance rather than a mere instantiation of a natural process, one sees how the oncomouse is heavily invested with human values and purposes. This is, indeed, how the oncomouse was popularized by Donna Haraway (1997). Indeed, Haraway suggests that the oncomouse is perhaps not an object of research at all but a subject: The mouse performs a sacrifice for human beings; it was dispatched by us into the war against cancer, and now it acts on our behalf and dies for us in this war. If objectivity consists in gaining a proper distance, the subjectivity of the oncomouse and its investment with human value and purpose presents a challenge to the philosophy of technoscience. If it cannot be secured through intersubjective agreement on detached representations, it must originate in its material character and the technical robustness of its performance.

Our third example of a technoscientific object is most readily recognizable as such and may prove to be a source or warrant of objectivity. The *scanning tunneling microscope* (*STM*) is the research technology that is said to enable nanotechnology and is to this date probably the most effective and transformative nanotechnology, if only because it contributed to the transformation of research practice. The STM brings about a new instrumental concept in microscopy: near-field probing. It consists of approaching the object as closely as possible in order to pick-up the information at the surface of the sample. As one of the pioneers of probe microscopy relates, "traditional scientists shunned this method because its intimacy was seen as a violation of objectivity and distance, a gospel of nineteenth-century science and epistemology" (Gimzewski 2008, 260). The very functioning of the STM itself induces a 'collapse of distance' (Nordmann 2006).

Despite its name, the scanning tunneling microscope is an apparatus of manipulation as much as of observation—not only in the sense in which observation always requires some intervention, but more straightforwardly in the sense that it can be used to construct the structure that it then subjects to observation. The STM is both a tool and an instrument, or best: it is an interesting instrument *because* it is a tool (it individualizes some atomic features of the sample by establishing a short-circuit between them and the atoms of the tip). And conversely, it is an interesting tool *because* it is an instrument (it enables

[14] "In many cases the outcome of activating a disposition does not depend on any particular human situation, interest, or construction. However, in some cases the phenomenon has a specifically human aspect. Compare the generic outcome that ice of a certain thickness can bear a certain weight per unit area, expressed in a generic disposition, with the claim that ice of that thickness affords walking for a person. Generalizing the notion of an affordance we can say that an apparatus/world complex can afford *things*. For instance, wheat, yeast, and a stove can afford loaves of bread. A lathe can afford chair legs, and a discharge tube can afford gamma rays. […] The phenomena that are produced in an [apparatus/world complex] are the manifestations of affordances. These are dispositions that bring together two sets of causal powers that cannot be disentangled. There are the powers of the material stuff organized as an apparatus and the powers of the world realized in the phenomena." (Rom Harré 2003, 37f.).

[15] Here the concept of "nature" follows an Aristotelian conception whereby every thing has its own nature and no longer refers to a homogeneous space of lawful regularities.

collecting data of our intervention in the nanoworld under the form of "manipulation signals"). Finally, it brings together the sensory modalities of touch, hearing, and sight.[16]

Ian Hacking's question whether we see through (or with) a microscope served to determine the standing of the instrument as an object entrenched in observational practices, especially by being calibrated to other observational tools (Hacking 1981).[17] This entrenchment provides individual observers with a warrant regarding the trustworthiness of their more or less inferential visualizations.

But what if we ask whether we see through a scanning tunneling microscope? For answering this question, another interesting feature of scanning probe microscopy becomes significant, namely its twofold calibration or immediacy. First of all, experimenting with the STM is always seeking immediacy: Probing in the near-field means going *where the object is* and recording the very immediate and local interaction of the object with the instrument's tip. For the purpose of 'explanation' the ectoplasm-like images and the manipulation signals that constitute the rough data are then compared with those produced by a simulation of the whole experimental setup. These simulations use models that are calibrated to make theories fit with the experiment. They do not test theories. Rather, they simulate the interpretation of theories in a back-and-forth process with the experiment, until the two present a sufficiently satisfactory likeness.[18] And secondly, once this interpretation is done, it is rendered user-friendly by producing a visual kind of immediacy: The rough image is reprocessed numerically with the kind of topographic software that is used in geography, simulation modelling and video gaming—this software is best suited for the representation of what goes on at the surface of a body. Atoms, molecules and surfaces are thus depicted as familiar objects with colours, shadows, foreground and background. Aside from providing the pleasure of experiencing a very familiar-looking space that stands ready to be colonised by nanotechnology, it stacks the deck in favour of inferences from the likeness of STM-images and the visualisations of computer simulations.

Tellingly, this twofold immediacy makes the STM conceptually even more complicated but perceptually even simpler than electron microscopy. In a recent interview, one of the inventors of the STM notes as the most striking feature of nanotechnology that for a new generation of scientists 'playing with atoms' has become perfectly straightforward (Binnig 2009)—because perceptual ease and ease of manipulation makes one forget the conceptually complicated inferential structure.

If one reconsiders the history of 'seeing with microscopes' one might say that much of it was concerned with realism or truth: Straightforward seeing is associated with seeing how things are, whereas a highly theory-laden and inferential mode of perception suggests that what we see is a construct of sorts.[19] The reliability of a way of seeing—with the electron microscope, for example—was judged in comparison to apparently straightforward cases of immediate perception. Calibration, for example, provides a warrant to the effect that one can trust the microscope as much as one normally trusts one's naked eyes. In contrast, the

[16] See Mody and Lynch (2010); Hennig (2006) and (2011); Soentgen (2006); Baird and Shew (2004); Shinn (2008).

[17] This and the next paragraph have been adapted from Nordmann 2010a.

[18] This first production of immediacy can be said to be 'analogic' in two senses: it is based on the STM's operation as an analogue to sensing, and it takes recourse to analogies between the experiment and the model.

[19] To be sure, more sustained reflections of microscopy indicate that the question about realism and truth is based on a misleading dichotomy. For much instrument-aided observation one can say that it does not provide straightforward access to something given, but that it is not therefore an inferential construction of something invented.

reliability of observations with the STM does not depend on representational features but on the technical robustness and performance of the system. Seeing with the STM cannot be likened to a human observer who confronts an outside reality and wonders whether a mental image provides a truthful representation—owing to the fact that the STM is an instrument of intervention as well as observation, a tool and an instrument, and due to its twofold calibration. Instead, the STM is coordinated with a multitude of other instruments and procedures and is judged by the way it agrees with and improves upon a whole system of observational and experimental techniques. Firmly entrenched in a variety of contexts and practices, the STM is not a method of seeing atoms on surfaces but an apparatus/world complex that affords perceptual and manipulative access to atoms and molecules on surfaces.[20]

5 Outlook

More questions, hypotheses, and examples could be offered at this point. But the proof of the pudding is not in the quantity of suggestive considerations. It consists in sustained analyses of particular research practices and their objects. We began by referring to Moritz Schlick, William Whewell, or Ludwig Wittgenstein to articulate an ontology of scientific facts which views the things from a representational distance and considers objects only as they occur in states of affairs. In this context, we also included accounts of dispositional properties and did not thereby exhaust the scope of philosophical reflection on the ontology of scientific objects. As our research-project unfolds, Ludwik Fleck, Norwood Russell Hanson, and Thomas Kuhn would need to be considered, Quine's famous dictum that "to be is to be the value of a variable," (Quine 1980), Wilfried Sellars, Gilbert Ryle, Donald Davidson, and Nelson Goodman, but also Nancy Cartwright and Ian Hacking, and all who consider the ontological difficulties introduced by quantum physics or string theory (compare Balashov 2010). Our analysis of scientific objects should thus be informed by the rich tradition of what has come to be known as analytic philosophy, but it might also take its inspiration from Emile Meyerson, Gaston Bachelard, or Alfred North Whitehead.

The analysis of technoscientific objects need not begin empty-handed, either. For it, too, we hope to draw on a variety of philosophical traditions. In order to gain perspective on the many faultlines like the one between facts and things, it might be useful to go back to Aristotle, Leibniz, Locke or Husserl. Francis Bacon has been rediscovered as a major philosopher of science and technoscience, and we can consider his conception of the objects of research. The same can be said for philosophers of nature and of technology like Henri Bergson or Gilbert Simondon, Martin Heidegger or, perhaps, John Dewey. Also, some of the authors who elucidate the ontology of scientific research objects contribute to an investigation of technoscience—Ludwik Fleck and Alfred North Whitehead come to mind. Finally, the Science Studies literature of the last several decades offers many insights that can inform philosophical analysis (e.g., Mol 1999; Latour 1987, 1999, 2004; Stengers 2010; Verbeek 2000, 2005; Rabinow 1997).

We started with a quote from Moritz Schlick that expressed the scientific demand to recognize the nature and not the value of things and therefore to keep our distance from

[20] Compare Rom Harré's account of the difference between instruments that function like probes (the thermometer, the light microscope) and a complex of apparatus and world that makes a phenomenon available for research and development, for observation and intervention. As we saw above, he says of the latter complexes that they afford a thing or an activity (Harré 2003).

them. If only to underscore that one cannot engage in a philosophy of technoscience without bringing in philosophers who have been marginalized, if not excluded by the philosophy of science, we conclude with a quote from John Dewey's *Experience and Nature* (1971). In contrast to Schlick, it formulates the need to be engaged in order to realize the value of things through technoscientific research. Seeking to elucidate the "instrumental nature of the objects of scientific knowing" (xvii), Dewey mocks the tendency of philosophers first to oppose subject and object, mind and matter and then to ask "how the acts of mind can reach out and lay hold of objects defined in antithesis of them" (p. 12). Received conceptions of science highlight theoretical security and certainty, whereas a conception of things in the context of human practice will foreground the practical task of finding what is recurrent and stable (xv)—rather than juxtapose nature and culture, it accounts for the experience of things as shaped by custom, tradition, expectation, language, and as a matter of human interest:

> The office of physical science is to discover those properties and relations of things in virtue of which they are capable of being used as instrumentalities; physical science lays claim not to disclose the inner nature of things but only those connections of things with one another that determine outcomes and hence can be used as means. The intrinsic nature of events is revealed in experience as the immediately felt quality of things (xvi).

References

Bachelard, G. (1938). *La formation de l'esprit scientifique: contribution à une psychanalyse de la connaissance objective*. Paris: J. Vrin.

Baird, D., & Shew, A. (2004). Probing the history of scanning tunneling microscopy. In D. Baird, A. Nordmann, & J. Schummer (Eds.), *Discovering the nanoscale* (pp. 145–156). Amsterdam: IOS Press.

Balashov, J. (2010). *Persistence and spacetime*. New York: Oxford University Press.

Barad, K. (1999). Agential realism: Feminist interventions in understanding scientific practices. In M. Biagioli (Ed.), *The science studies reader*. New York, London: Routledge.

Bensaude-Vincent, B. (2009). *Les vertiges de la techoscience. Façonner le monde atome par atome*. Paris: La Découverte.

Binnig, G. (2004). Preface. In N. Boeing (Ed.), *Alles nano?! Die Technik des 21. Jahrhunderts*. Berlin: Rowohlt.

Binnig, G. (2009). Interview statesment. In: *Expedition Zukunft/Science Express (exhibition catalogue)* (p. 239 and 246). Darmstadt: Wissenschaftliche Buchgesellschaft.

Boon, M., & Knuuttila, T. (2011). Breaking up with the epochal break: The case of engineering sciences. In A. Nordmann, H. Radder, & G. Schiemann (Eds.), *Science transformed? Debating claims of an epochal break* (pp. 66–79). Pittsburgh: Pittsburgh University Press.

Carrier, M., & Nordmann, A. (Eds.). (2010). *Science in the context of application. Boston studies in the philosophy of science* (Vol. 274, p. 491). Dordrecht: Springer.

Chang, Hasok. (2004). *Inventing temperature. Measurement and scientific progress*. New York: Oxford University Press.

Daston, L. (Ed.). (2000). *Biographies of scientific objects*. Chicago, London: University of Chicago Press.

Daston, L., & Galison, P. (2007). *Objectivity*. New York: Zone Books.

de Jong, R., & Betti, A. (2010). The classical model of science: A millennia-old model of scientific rationality. *Synthese, 174*, 185–203.

Dewey, J. (1971). *Experience and nature*. LaSalle, IL: Open Court.

Dupuy, J.-P. (2010). The narratology of lay ethics. *Nanoethics, 4*(2), 153–170.

Echeverria, J. (2003). *La revolucion tecnocientifica*. Madrid: Fondo de Cultura Economica.

Foucault, M. (1973). *The order of things: An archeology of the human sciences*. New York: Vintage Books.

Galison, P. (2006). *The pyramid and the ring. Presentation at the conference of the Gesellschaft für Analytische Philosophie (GAP)*, Berlin.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge—The dynamics of science and research in contemporary societies*. London: Sage.

Gimzewski, J. K. (2008). Nanotechnology: The endgame of materialism. *Leonardo, 41*(3), 259–264.

Goodman, N. (1972). Seven strictures on similarity. In: *Problems and projects* (pp. 22–32). Indianapolis, Ind.: Bobs-Merrill.

Gzil, F. (2007). Animal models of Alzheimer's disease and cognitive ageing, *Presentation at the First Conference of the European Philosophy of Science Association*, *Madrid*, November 14–17.

Hacking, I. (1981). Do we see through a microscope? *Pacific Philosophical Quarterly, 62*, 305–322.

Hacking, I. (1983). *Representing and intervening. Introductory topics in the philosophy of natural science*. Cambridge: Cambridge University Press.

Haraway, D. (1997). *Modest_witness@Second_millenium. FemaleMan©_meets_Onco-mouse™: Feminism and technoscience*. New York: Routledge.

Harman, G. (2005). *Guerilla metaphysics. Phenomenology and the carpentry of Things*. Chicago: Open Court.

Harré, R. (2003). The Materiality of instruments in a metaphysics for experiments. In H. Radder (Ed.), *Philosophy of scientific experimentation* (pp. 19–38). Pittsburgh, PA: University of Pittsburgh Press.

Hayles, K. (Ed.). (2004). *Nanoculture: Implications of the new technoscience*. Chicago: University of Chicago Press.

Hennig, J. (2006). Changes in the design of scanning tunneling microscopic images from 1980 to 1990. In J. Schummer & D. Baird (Eds.), *Nanotechnology challenges: Implications for philosophy, ethics and society* (pp. 143–163). Singapore: World Scientific Publishing.

Hennig, J. (2011). *Bildpraxis: Visuelle Strategien in der frühen Nanotechnologie*. Bielefeld: Transcript.

Hottois, G. (1984). *Le signe et la technique. La philosophie à l'épreuve de la technique*. Paris: Aubier.

Hottois, G. (2002). *Technoscience et sagesse?*. Nantes: Pleins Feux.

Ihde, D., & Selinger, E. (Eds.). (2003). *Chasing technoscience*. Bloomington, IN: Indiana University Press.

Keller, E. F. (2000). Models of and models for: Theory and practice in contemporary biology. *Philosophy of Science, 67*(3), 72–86.

Latour, B. (1987). *Science in action: how to follow scientists and engineers through society*. Cambridge: Harvard University Press.

Latour, B. (1999). *Pandora's hope*. Cambridge: Harvard University Press.

Latour, B. (2004). *Politics of nature: How to bring the sciences into democracy*. Cambridge, MA: Harvard University Press.

Loeve, S. (2010). About a definition of nano: how to articulate nano and technology? *HYLE–International Journal for Philosophy of Chemistry, 16*(1), 3–18.

Mendeleev, D. (1952). The relation between the properties of the atomic weight of the elements. In H. M. Leicester & H. S. Klickstein (Eds.), *Sourcebook in Chemistry 1400–1900* (p. 439). New York: Dover.

Mody, Cyrus. C. M., & Lynch, M. (2010). Test objects and other epistemic things: A history of a nanoscale object. *British Society for the History of Science, 43*(3), 423–458.

Mol, A. (1999). Ontological politics: A word and some questions. In J. Law & J. Hassard (Eds.), *Actor-network theory and after* (pp. 74–89). Oxford: Blackwell.

Nordmann, A. (2006). Collapse of distance: Epistemic strategies of science and technoscience. *Danish Yearbook of Philosophy, 41*, 7–34.

Nordmann, A. (2010a). Philosophy of technoscience in the regime of vigilance. In G. Hodge, D. Bowman, & A. Maynard (Eds.), *International handbook of regulating nanotechnologies* (pp. 25–45). Cheltenham: Edward Elgar.

Nordmann, A. (2010b). Science in the context of technology. In M. Carrier & A. Nordmann (Eds.), *Science in the context of application. Boston studies in the philosophy of science* (Vol. 274, pp. 467–482). Dordrecht: Springer.

Nordmann, A. (2011). The age of technoscience. In A. Nordmann, H. Radder, & G. Schiemann (Eds.), *Science transformed? Debating claims of an epochal break* (pp. 19–30). Pittsburgh: Pittsburgh University Press.

Nordmann, A., Radder, H., & Schiemann, G. (Eds.). (2011). *Science transformed? Debating claims of an epochal break*. Pittsburgh: Pittsburgh University Press.

Nowotny, H., Scott, P., & Gibbons, M. (2001). *Re-thinking science: Knowledge and the public in an age of uncertainty*. USA: Blackwell.

Quine, W. V. O. (1980). *From a logical point of view: Nine logico-philosophical essays*. Cambridge, MA: Harvard University Press.

Rabinow, P. (1997). *Essays on the anthropology of reason*. Princeton, NJ: Princeton University Press.

Sassower, R. (1995). *Cultural collisions: Postmodern technoscience*. New York: Routledge.
Schiemann, G. (2005). *Natur, Technik, Geist. Kontexte der Natur nach Aristoteles und Descartes in lebensweltlicher und subjektiver Erfahrung*. Berlin, New York: de Gruyter.
Schlick, M. (2009). *Allgemeine erkenntnislehre*. Wien: Springer.
Schwarz, A., & Nordmann, A. (2010). The political economy of technoscience. In M. Carrier & A. Nordmann (Eds.), *Science in the context of application. Boston studies in the philosophy of science* (Vol. 274, pp. 317–336). Dordrecht: Springer.
Shinn, T. (2008). *Research-technology and cultural change. Instrumentation, genericity, transversality*. Oxford: The Bardwell Press.
Soentgen, J. (2006). Atome sehen, Atome hören. In A. Nordmann, J. Schummer, & A. Schwarz (Eds.), *Nanotechnologien im Kontext. Philosophische, ethische und gesellschaftliche Perspektiven* (pp. 97–113). Berlin: Akademische Verlagsgesellschaft.
Souriau, E. (1943). *Les différents modes d'existence*. Paris: Presses Universtaires de France 2010.
Stengers, I. (2010). *Cosmopolitics*. Minneapolis: University of Minnesota Press.
Verbeek, P. P. (2000). The thing about technology: Toward a phenomenology of technological artifacts. In C. Mitcham (Ed.), *Metaphysics, epistemology, and technology* (pp. 281–301). Chicago: The University of Chicago Press.
Verbeek, P.-P. (2005). *What things do: Philosophical reflections on technology, agency, and design*. University Park: Pennyslvania State University Press.
Whewell, W. (1858). *Novum organum renovatum* (3rd ed.). London: Parker.
Wittgenstein, L. (1958). *Tractatus logico-philosophicus*. London: Routledge & Paul.
Ziman, J. (2000). *Real science: What it is and what it means*. Cambridge: Cambridge University Press.