Understanding science-in-the-making by letting scientific instruments speak: From semiotics to postphenomenology

Bas de Boer¹, Hedwig te Molder² and Peter-Paul Verbeek¹

Abstract
Latour encourages us to use science-in-the-making as an entry point to understanding science, because it allows us to see how scientific knowledge is constituted and through which processes the ‘absolute certainties’ of ready-made science appear. He approaches science-in-the-making from the perspective of semiotics because it enables him (1) to attribute equal importance to humans and nonhumans, and (2) to let the actors in scientific practices speak for themselves. We argue that Latour’s semiotic approach to science-in-the-making and his understanding of scientific instruments as inscription devices do not fulfill these desiderata. This, in turn, prevents him from understanding the crucial role that scientific instruments play in science-in-the-making. As an alternative to Latour’s semiotic approach, we present a postphenomenological approach to studying science-in-the-making. Using the notion of technological mediation, we argue that scientific instruments actively mediate how reality becomes present to – and is treated by – scientists. Focusing on how intentional relations between scientists and the world are mediated by scientific instruments makes it possible to turn them into genuine actors that speak for themselves, thereby recognizing their constitutive role in the development of the interpretational frameworks of scientists. We then show how a postphenomenological approach can be understood as an ethnomethodology of human-technology relations that meets both of Latour’s requirements when studying science-in-the-making.

¹University of Twente, Enschede, The Netherlands
²Vrije Universiteit Amsterdam, The Netherlands

Corresponding author:
Peter-Paul Verbeek, Department of Philosophy, University of Twente, Ravelijn 4234, Enschede 7500AE, The Netherlands.
Email: p.p.c.c.verbeek@utwente.nl
Keywords
science-in-the-making, postphenomenology, Latour, technological mediation, semiotics, ethnomethodology

Introduction
In his *Science in Action* Latour shows that the Janus-faced nature of science turns it into an elusive object of investigation. When looking at the right side of its face, we see ready-made science: established and indubitable scientific facts that refer to natural objects that have always been there. When looking at its left side, we see science-in-the-making: facts that are under construction, an undetermined view of nature and no clear method prescribing how to do science. Latour (1987) encourages us to use science-in-the-making as an entry-point to understanding science, instead of trying to legitimize the stable reality of ready-made science (p. 4). Only in this way can we see how scientific knowledge is constituted and through which processes the ‘absolute certainties’ of ready-made science appear. Science no longer is the *explanans* of reality or rationality, but has become the *explanandum*, the phenomenon to be explained (De Vries, 2016: 56).

Latour borrows from semiotics to approach science-in-the-making because it enables him (1) to attribute equal importance to humans and nonhumans (e.g. Latour, 1988a: 194), and (2) to let the actors in scientific practices speak for themselves (Latour, 1988a: 10). In this article, we argue that Latour’s semiotic approach to science-in-the-making and his understanding of scientific instruments that follows from it, do not fulfill these desiderata. Our argument focuses on the specific understanding of scientific instruments that is presupposed in Latour’s notions ‘mediation’ and ‘inscription’ as developed in *Laboratory Life, The Pasteurization of France*, and *Science in Action*. We argue that Latour’s understanding of scientific instruments as inscription devices (e.g. Latour, 1987: 67–70; Latour and Woolgar, 1986: 51) threatens to black-box their role in the construction of scientific facts and objects. Because of this black-boxing, we argue, Latour’s approach falls short in attributing sufficient importance to scientific instruments, which undermines the possibility of recognizing them as genuine actors that can speak for themselves. This, in turn, prevents Latour from understanding the crucial role that scientific instruments play in science-in-the-making.

As an alternative to Latour’s semiotic approach, we present a *postphenomenological* one. Postphenomenologists are interested in understanding how technologies in scientific practices help to shape the reality that scientists investigate (e.g. Ihde, 1991, 1998; Rosenberger, 2012). To make clear how postphenomenology makes it possible to study science-in-the-making, we show how the postphenomenological notion of *technological mediation* differs from Latour’s notion of mediation. Latour’s notion is inspired by semiotics, and is used to describe the processes through which science-in-the-making is progressively turning into ready-made science. In contrast, the notion of *technological mediation* is rooted in a phenomenological vocabulary that focuses on how technologies help to constitute the reality scientists are studying by structuring intentional relations between scientists and the world. Using the notion of *technological mediation*, we argue that scientific instruments actively mediate how reality becomes present to — and is treated by — scientists (Ihde, 1990; Verbeek, 2005). Focusing on how intentional relations between scientists and
the world are mediated by scientific instruments makes it possible to turn them into genuine actors that speak for themselves, thereby recognizing their constitutive role in the development of the interpretational frameworks of scientists. We then show how a postphenomenological approach can be understood as an ethnomethodology of human-technology relations that satisfies both of Latour’s demands when studying science-in-the-making.

**Latour’s semiotic approach to scientific practice and the study of science-in-the-making**

One of the main goals of Latour and Woolgar’s early work on scientific practice is to counter the idea that we must (1) attribute an a priori rationality to the sciences, and (2) understand the objects of science as residing in an external world that exists independently of the human subject (Latour and Woolgar, 1986: 183). When accepting this set of ideas, we arrive at a philosophy of ready-made science (Latour, 1987: 4) that understands scientific facts as the product of a rational method that scientists employ, which allows them to move between the subject to the object sphere. This terminology – that prevails in the way scientists describe their own discoveries – does not give a convincing account of the construction of scientific facts: ‘The adoption of scientific versions of science would teach us little that is new about science in the making’ (Latour and Woolgar, 1986: 44). According to Latour, such a perspective mystifies the hard work happening in scientific laboratories.

Instead of relying on the retrospective analyses of scientists that describe scientific discoveries as the product of ‘eureka experiences’ (Latour and Woolgar, 1986: 19) or as ‘the sudden occurrence of a personal and abstract idea’ (Latour and Woolgar, 1986: 170), Latour’s account of scientific practice is ‘concerned with the social construction of scientific knowledge in so far as this draws attention to the process by which scientists make sense of their observations’ (Latour and Woolgar, 1986: 32). Unraveling these processes of sense-making can ‘demonstrate how a hard fact can be sociologically deconstructed’ (Latour and Woolgar, 1986: 107). Studying science-in-the-making thus challenges the two key assumptions which are taken for granted in the philosophy of ready-made science: (1) the rationality and uniqueness of the scientific method, and (2) the existence of the objects of science in an external natural realm.

According to Latour, the supposed ‘hardness’ of the facts and objects of science appears because the creation of a specific order constitutes a reality ‘in which not everything is equally probable’ (Latour and Woolgar, 1986: 246). In principle, so Latour argues, every reading of a particular event – ranging from the reading of a text to the reading of the output of a scientific experiment – can be challenged, because alternative readings are always in principle possible. However, science proceeds by undermining the likelihood and acceptability of alternative readings, thereby allowing the ‘hardness’ of science to appear. So, when we want to understand how scientific facts and objects come into being, we should focus on ‘how observers routinely ignore the philosophical problem of the constant availability of alternative descriptions and readings’ (Latour and Woolgar, 1986: 36). Adopting this view thus formulates the task of the analyst of scientific practice to lay bare the specific order generated within scientific practice through which possible alternatives are systematically made irrelevant.
To do so, the analyst of science-in-the-making has to pretend that they do not yet know what their world is made of. This provides an opportunity rather than a problem:

The fact that we do not know in advance what the world is made up of is not a reason for refusing to make a start, because other storytellers seem to know and are constantly defining the actors that surround them – what they want, what causes them, and the ways in which they can be weakened and linked together. (Latour, 1988a: 10)

According to Latour, semiotics is a vehicle to understand science-in-the-making from the perspective of the actors participating in it, instead of understanding scientific practices from an outside point of view that has already attributed a specific structure to reality: ‘Semiotics is the ethnomethodology of texts. Like ethnomethodology, it helps replace the analyst’s restricted and limited vocabulary by the actor’s activity at world-making’ (Latour, 1993: 131). In Latour’s view, semiotics reveals how actors within practices relate to one another without relying on the presuppositions of the analyst of those practices (Høstaker, 2005: 7). But how exactly does Latour’s self-proclaimed semiotic approach influence his analyses of science-in-the-making?

One of the crucial anthropological observations of Latour during his time at the Salk Institute, the location where the empirical work leading to the publication of Laboratory Life took place, was that the most notable output of the laboratory were written documents (Latour and Woolgar, 1986: 48; see Jones, 2010). Consequently, he starts treating those written documents as the place were alternatives are made irrelevant. Science, then, appears as ‘a form of discourse, … one effect of which is the “truth effect,” which … arises from textual characteristics’ (Latour and Woolgar, 1986: 184, note 2). This trajectory brings Latour to his semiotic approach to science-in-the-making: Semiotics appears to be a tool to study how the ‘truth effect’ is produced in scientific texts without taking recourse to the vocabulary of ready-made science.3

References to semiotics are scarce in Laboratory Life, and it is primarily in the context of his later work that Latour starts to make explicit why he considers semiotics a crucial entry-point to the study of science (e.g. Latour, 1987, 1988a, 1988b, 1993). It is well-established that it was specifically the semiotics of Greimas that was important for Latour’s studies of science (Beetz, 2013; De Vries, 2016; Høstaker, 2005; McGee, 2014).4 In Laboratory Life, the idea – one borrowed from Greimas – that the truth value of a statement is constructed internal to the text is introduced (Latour and Woolgar, 1986: 75–80). Hence, a certain statement appears as subjective or objective by virtue of modalities present in the text (Beetz, 2013: 21–26; Høstaker, 2005: 13–14). In Science in Action, Latour uses the concepts of positive and negative modalities to further elaborate on the semiotic operation by which particular statements are moved away (positive) or towards (negative) the circumstances in which they are produced. The factuality of scientific statements, then, appears as relative to the particular modalities within which they are circumscribed (Beetz, 2013: 17). For example, a statement such as ‘the primary structure of Growth Hormone Releasing Hormone (GHRH) is Val-His-Leu-Ser-Ala-Glu-Glu-Lys-Glu-Ala’ (Latour, 1987: 23) bears a positive modality, since it contains no traces of its being produced. The statement is simply a fact. In other statements, the factuality can be questioned: ‘Dr A. Schally has claimed for several years in his New Orleans
laboratory that [the structure of GHRH is Val-His-Leu-Ser-Ala-Glu-Glu-Lys-Glu-Ala]. However, by troubling coincidence this structure is also that of hemoglobin, a common component of blood and a frequent contaminant of purified brain extract if handled by incompetent investigators’ (Latour, 1987: 23). In this statement, instead of being presented as a fact, the structure of GHRH is presented as being disputable through the integration of negative modalities. The statement leads us back to a New Orleans laboratory to check the validity of Dr Schally’s work. Scientific statements are embedded within a network of other claims by citing and referring to other scientific statements that are circumscribed with particular modalities. By tracing these semiotic operations in scientific texts, it becomes possible to trace how and when certain statements attain their factuality.

In addition, scientific statements are often accompanied by visual inscriptions presented as evidence that what is written down can be straightforwardly observed. Yet, it remains possible that these inscriptions are ‘a set of semiotic actors presented in the text but not present in the flesh; … they could have been invented’ (Latour, 1987: 64). Hence, Latour’s approach to science-in-the-making forces him to move to what is external to the text. This where Latour seemingly breaks with Greimassian semiotics, the factuality of scientific statements cannot be understood only with reference to how texts are structured, but requires one to migrate from the text to the particularities of the actors that it enrolls. Using the semiotics of texts as a point of departure, Latour is thus able to move into the world to the extent that it is made relevant in the texts under examination. Because of this, Latour can characterize semiotics as the ethnomethodology of texts: by understanding the text as an event in which reality is constituted, it can follow the actor’s activity of world making by investigating how the enrollment of particular actors is constitutive for this event.

According to Latour, the following ideas crucially inform his semiotic approach: (1) the interdefinition of actors and (2) the chains of translations (or mediations) within which acts take place (Latour, 1988a: 11). The idea of interdefinition allows him to describe how particular actions situate themselves within a context, and that this particular situating allows one to understand the relation between actor and context. Actors never appear in isolation, but always as part of the relation with the network that they are part of. This suggests a primacy of the networks over actors, but by adding the idea of translation, Latour makes clear that there is no stable network that shapes actions. Networks are continuously shaped by the interdefinitions of the actors. The coming into being of scientific objects is, from this perspective, not the discovery of a stable entity, but the creation of stability through continuous movement. Latour’s approach to science-in-the-making shows that scientific objects come into being through processes of inter-definition and translation, and that underlying the ‘hardness’ of scientific facts are processes in which actors/actants continuously shape and are shaped by the network(s) in which they figure.

Latour’s approach to science-in-the-making thus bears a clear semiotic legacy to the extent that he takes the realness of the objects and the factuality of statements that appear in scientific texts to be constructed through semiotic operations within the text, such as the use of positive and/or negative modalities. However, he seems to break with literary semiotics when indicating that a study of science-in-the-making requires a
move from the text to the flesh behind it: ‘The ability of semiotics to be extended to science depends on its ability to deal with this reference that underwrites the inscription commented in a text’ (Latour, 1988b: 14). As we will show, Latour’s extension of semiotics into the flesh imposes a specific structure on science-in-the-making, leading to a particular understanding of scientific instruments that insufficiently recognizes them as actors that can speak for themselves.

**Latour, postphenomenology, and the notion of ‘mediation’**

Latour and Woolgar suggest that the processes through which reality is made can be laid bare by ‘demonstrating the “mediations” in scientific work’ (Latour and Woolgar, 1986: 258, note 1). Precisely because there has been a series of mediations, the facts and objects of science can appear as ‘purely objective’, and as not containing ‘subjective elements’. Accordingly, the perceived purity of scientific facts is in Latour’s view fundamentally dependent on the mediations that take place in the messy context of scientific practice. According to Latour, uncritically accepting the purified picture of ready-made science is to deny the work that gave rise to this apparent purity. In fact, ‘the work of purification is no more pure than that of the sanitary inspector’, and ‘to say that some procedures are pure … is to confuse a verb with an adjective’ (Latour, 1988a: 222). When scientific facts are understood in terms of the purity of scientific rationality that speaks about the pure objects of nature, purified entities are falsely interpreted as ontological givens, instead of the outcome of the processes of mediation in scientific practice. Scientific ‘objects appear because of the constant process of sorting. Thin readable traces (produced by the inscription devices) are recorded and this creates a pocket of order in which not everything is equally probable’ (Latour and Woolgar, 1986: 246).

Because Latour understands the mediations occurring in scientific practice in terms of the creation of ‘readable traces (produced by inscription devices)’, the laboratory appears as a site that is primarily concerned with the creation of inscriptions that eventually add to the factuality of scientific statements. The creation of the purity of scientific facts is fundamentally dependent on the production of readable material that increases or decreases the extent to which the objects of science are considered ‘pure’. Studying processes of mediation thus implies studying the ‘behavior’ of inscription devices, which Latour defines as ‘any item of apparatus or particular configuration of such items which can transform a material substance into a figure or diagram which is directly usable by one of the members of the office space’ (Latour and Woolgar, 1986: 51).

Latour’s concern for revealing how scientific facts and objects come into being is also one of the aims of postphenomenology. Both Latour and postphenomenology aim to study the coming into being of scientific objects in terms of the mediations through which they are constituted. Despite this apparent conceptual similarity, a Latourian and a postphenomenological approach diverge when looking closer at what they take ‘mediations’ to be. Like Latour, postphenomenologists aim to study science-in-the-making, and seek to understand how scientific knowledge comes into being from within scientific
practices. The entry-point for understanding the creation of scientific facts and objects is focusing on the technologies in scientific practice and the way scientists relate to them. Postphenomenology starts from the observation that ‘scientific knowledge is instrumentally dependent upon technologies. It is ‘constructed’ through the use of instruments which are technologies’ (Ihde, 1997: 73). For example, so it is argued, there would be no Galilean astronomy without the telescope, and no cognitive neuroscience without brain imaging technologies (Ihde, 2009: 51–61). The dependency of scientific practice on technologies is considered fundamental: ‘Instruments form the conditions for and are the mediators of much, if not all, current scientific knowledge. They are the concrete and material operators within scientific praxis’ (Ihde, 1991: 45). Accordingly, a study of science-in-the-making should focus on technological mediations (i.e. on how technologies mediate how scientific knowledge comes into being).

When technologies are interpreted as mediators, it becomes possible to understand them as actively shaping the reality which scientists study: they ‘non-neutrally transform … the project or object towards which the technology is directed, and reflexively, the human user of that technology’ (Ihde, 1997: 73–74). According to Ihde, focusing on how technologies transform the objects that are observed as well as change the subject using a specific technology, demands a phenomenological starting-point, as the non-neutrality of technologies is understood in terms of how they mediate intentional relations between human beings and the world.

Phenomenologically speaking, the concept of intentionality captures the fact that human experience and thought is always directed at something. When scientists have beliefs about an object of research, or experience a phenomenon when observing, such beliefs and experiences are constitutive of its reality. Human intentionality is the structure of the relation between the human being and the world in which the objects they relate to emerge. This structure is mediated by the technologies related to: When Galileo directed his telescope to the sky, it became possible for him to relate to ‘the full plenary richness of the Jupiterian “stars” or the spots of the sun, which changes how he understands the newly opening universe of meaning-structures not available to Aristotle, the Church fathers or the biblical editors’ (Ihde, 2016: 55).

Accordingly, the notion ‘technological mediation’ refers to the role of technologies in co-constituting the relations between scientists and the objects that they study. As indicated by the example of Galileo, both the investigating subject and the object of investigation take a particular shape within these relations. Because they co-constitute a certain type of scientist in relation with the technologically mediated object they relate to and vice versa, technologies give rise to specific scientific practices. In human-technology relations, specific forms of perception, observation, intervention, and interpretation come into being. The world that becomes interpretable comes into being in the relations between scientists and scientific instruments. The question asked when studying scientific practices is, from this perspective, how technologies structure human interpretations by mediating intentional relations. To understand the character of these relations a hermeneutic perspective is needed: The relations between scientists and phenomena are interpretive relations, and technologies mediate the character of these interpretations.

The postphenomenological concept of mediation thus has a different character than its Latourian counterpart. This difference is related to the radically ‘symmetrical’ character of
Latour’s approach versus the moderately ‘asymmetrical’ approach of postphenomenology. Latour insists that human and nonhuman agents should be approached symmetrically: Networks consist of both types of ‘actants’ and therefore they should not be taken apart ‘a priori’. From this perspective, studies of scientific practices are in fact entry-points for encountering hybrids before they are purified. Technical objects and scientific facts are, in his own words, ‘never the beginning but the end of a long process of proliferating mediators, a process in which all relevant subprograms nested one into another, meet in a “simple” task’ (Latour, 1994: 192). When we focus on purified objects, these processes of mediation – and the hybrids that are created within them – remain concealed.

The postphenomenological approach is slightly different. Even though its focus on human-technology relations gives it a similar sensitivity to hybridity, it reverses the order between hybrids and subject-object (or human-technology) relations. Rather than revealing an originary hybridity ‘behind’ subjects and objects, it reveals an originary human-technology relation ‘behind’ the ways in which human beings are related to the world around them, and therefore ‘behind’ scientific researchers and scientific objects. Postphenomenology reveals the hybridity of scientific knowledge by showing how the reality that scientists study is constituted through their relation with scientific instruments. Even though the postphenomenological approach agrees that ‘objective’ facts are in fact hybrids, based on technologically mediated human-world relations, it also aims to reveal how this hybridity in fact results from an asymmetrical relation between ‘interpreter’ and ‘interpreted’.

Both the postphenomenological approach and Latour, then, aim to study science-in-the-making, and emphasize the active role of technologies in the shaping of reality. Moreover, both postphenomenologists and Latour argue that science does not establish relations between isolated subjects and equally isolated objects. But, despite the common focus on hybridity and intricate relations between humans and nonhumans, postphenomenology develops an account of human-technology relations that is not ‘symmetrical’, but ‘moderately asymmetrical’. Postphenomenology understands scientific practices in terms of how technologies help to shape the intentionality of scientists: They mediate the ways in which scientists can relate to the reality they study (Ihde, 1990; Verbeek, 2005). Without such mediated intentional relations, there would be no objects that scientists can relate to: scientific objects are the product of human-technology relations (Ihde, 1991, 1998). Opposite to this, Latour studies science-in-the-making because it offers an entry-point for encountering the facts and objects of science before they are stabilized: ‘[T]he difference between object and subject or the difference between facts and artifacts should not be the starting point of the study of scientific activity; rather, it is through practical operations that a statement can be transformed into an object or a fact into an artifact’ (Latour and Woolgar, 1986: 236). By studying the practical operations occurring in scientific laboratories, it becomes possible to study ‘the process whereby laboratory scientists strive to make [reality] a given’ (Latour and Woolgar, 1986: 236).

Latour’s concept of mediation and the reasons he investigates processes of mediation thus differ significantly from the way the concept of technological mediation functions within postphenomenology. Whereas Latour’s interest in studying mediations is relative to the question of how scientific facts are purified, postphenomenology searches to investigate technological mediations to understand why a specific scientific fact becomes
a candidate for purification rather than another. In the next section, we show how Latour’s semiotic approach to studying mediations leads to an understanding of scientific instruments as inscription devices. Furthermore, we argue that this understanding is too narrow to capture the importance of technologies in the coming into being of scientific objects and facts.

**Scientific instruments as inscription devices**

According to Latour, the construction of facts would not be possible without the presence of scientific instruments that function as *inscription devices* that produce *immutable mobiles*. An inscription device is ‘any set-up, no matter what its size, nature and cost, that provides a visual display of any sort in a scientific text’ (Latour, 1987: 68), and ‘[t]he final end product of all these inscription devices is always a written trace that makes the perceptive judgment of the others *simpler*’ (Latour, 1983: 161). These visual displays must be interpreted as immutable mobiles because they can travel from one place to another (mobile), without their content being subject to change (immutable) (Latour, 1986). For example, graphs of chemical reactions or maps of specific areas can be shown at other places without changing the message they convey. Because of their appealing perceptual simplicity, such visualizations make it increasingly difficult to disagree with the matter at hand (Latour, 1987: 64–70). Another example of an inscription device that increases the costs of dispute that Latour offers is the mass spectrometer, which is ‘the reified part of a whole field of physics. … The cost of disputing the generated results of this inscription device *is* enormous’ (Latour and Woolgar, 1986: 242).

When understanding scientific instruments as inscription devices, they are treated as producers of readable signs of the phenomena under investigation that increase the cost of dispute because of their perceptual self-evidence. Furthermore, because scientific instruments embody previous – widely accepted – theoretical developments, the cost of dispute is further increased, because disagreement with an instrument is likely to generate many opponents. In the next two sections, we ask if Latour’s reading of scientific instruments meets Latour’s own requirements of (1) attributing equal importance to humans and nonhumans, and (2) letting the actors in scientific practices speak for themselves without relying on the external vocabulary of the analyst.

**Inscription devices and attributing equal importance to humans and nonhumans**

One of the central points throughout Latour’s work is that equal importance should be attributed to humans and nonhumans, a tenet inspired by Greimas (Latour, 2008). For example, if we want to understand how microbes were introduced as a cause of several diseases or the discovery of the hormone somatostatin, to mention two of Latour’s case-studies, ‘it is crucial to treat nature and society symmetrically and to suspend our belief in a distinction between natural and social acts. … The only way to understand this central part of the argument is to stick firmly to the semiotic definition of all actors, including the nonhuman ones’ (Latour, 1988a: 260, note 6). In fact, this was the crucial point recognized by Pasteur and his associates who understood that ‘[w]e cannot form society
with the social alone. We have to add the action of microbes’ (Latour, 1988a: 35, our emphasis). Let us try to illustrate how microbes can be understood as acting by showing how they transformed the disease of ‘morbid spontaneity’ in 19th century France.

In the second half of the 19th century, France was suffering from a contagious disease, which was referred to as ‘morbid spontaneity’ (Latour, 1988a: 21). Without the presence of any regularities in its appearance, it seemed impossible to understand this disease in terms of a single cause instantiating an effect in all these cases (Latour, 1988a: 32–34). Yet, when Pasteur and his cooperators started to understand the irregularities of ‘morbid spontaneity’ in terms of microbes, a candidate cause of the disease could be developed. This required them to add an extra invisible element to reality capable of explaining both the cause of ‘morbid spontaneity’ and the variety of occasions in which the disease occurred. Latour tries to trace the series of mediations through which microbes became an indisputable element of reality. Initially, microbes only existed in a controlled laboratory environment, which ‘was an ideal one for the microbe, since for the first time since the existence of microbes in the world they were allowed to develop alone. It was also an “ideal” condition for the observer, since in developing so blithely, the microbe, freed from the competition of other living beings, made itself visible by increasing and multiplying’ (Latour, 1988a: 63).

However, a ‘laboratory microbe is not yet a “contagious ferment”’ (Latour, 1988a: 63), because laboratories differ from the circumstances in which people actually get sick. To convince others that microbes could be the cause of ‘morbid spontaneity’, it was necessary to show that they acted outside of the laboratory. In Latour’s analysis, the Pasteurians did so by extending their laboratory into the world when the unpredictable anthrax disease threatened French cattle: ‘On the one hand, the Pasteurians moved but remained men of the laboratory. They brought their own tools, microscopes, sterile utensils, and laboratory log-books, using them in environments where their use was unknown. On the other hand, they redirected their laboratories to respond to the cause of those they visited’ (Latour, 1988a: 76). Laboratories and farm sites were made equivalent, which changed the circumstances of farm sites such that the behavior of microbes became manageable (see Latour, 1983: 144–145). Making others understand the death of cattle in terms of microbes required the translation of farm sites into laboratories, thereby interdefining the set of actors present at the farms: With the introduction of microbes, other actors, such as the farmers and cattle, also were redefined. When following trails of mediations in which both Pasteur and his associates and microbes are understood as equally important actors, we can start to see how ‘morbid spontaneity’ was translated into a controllable disease.

On Latour’s account, how the addition of microbes to reality redefined society is most clearly visible in the French colonies, making clear his interest in revealing how science and politics are intertwined (Latour, 1988a: 140). When advancing into the African tropics, the French encountered a crude enemy: the parasite. However, the establishment of laboratories in the colonies made the treatment and prevention of infectious diseases controllable such that the original inhabitants of the colonized countries lost their advantage to the French: their being immune to the parasites living in the tropics. As a consequence, the colonies appeared as a site that could be controlled better by the French, making the addition of microbes of reality crucial in the politics of colonialization (Latour, 1988a: 144).

In the above story, Latour conceptualizes both the Pasteurians and the microbes as actors. However, the ‘microscopes’ and other scientific instruments needed to observe
microbes in the laboratory are not explicitly recognized as actors. Does this imply that they do not qualify as actors in the same sense as the humans and nonhumans that Latour has in mind? In order to answer these questions, we must return to Latour’s reading of scientific instruments as inscription devices, and their role in the construction of new objects. We need to look at the laboratory of the neuroscientist Roger Guillemin in the 1960s in which the scientific object ‘somatostatin’ came into being. Nowadays, somatostatin is an object known as a specific peptide hormone involved in the regulation of the endocrine system. In Guillemin’s laboratory, however, somatostatin was no object with well-defined characteristics. Instead, ‘it was something [that] resists the trials of strength behind the instruments, something that … provisionally [could be called] a new object’ (Latour, 1987: 87).

Latour’s understanding of the construction of a new object as the taking shape of something that is resistant to trials of strength means that its emergence is due to the fact that an observed effect cannot be made less credible. In his laboratory, Guillemin thought he had developed a purified substance called ‘GRF’ that would be able to induce growth when injected into cell cultures. However, contrary to Guillemin’s expectations, the cell culture decreased when put to trial. This gave reason to doubt either the reliability of the experimenter, or of the instrument used during the trial. However, no matter the efforts to correct for these reliabilities, the effect of decreasing growth persisted. This persistent effect resisted possibilities of modification, no matter the extent to which the instruments used to produce inscriptions were challenged. Instead of ‘discovering’ GRF, a new object came into being that showed its new shape in the instrumentally provided inscriptions (Latour, 1987: 87). The ‘thing’ that emerged due to its resistance to the performed trials is what nowadays is known as somatostatin. Thus, contrary to the story of Pasteur that highlights a particular role of human actors in the extension of the laboratory, this story highlights that there is a nonhuman actor at the ‘other side’ of the scientific instrument that enforces a particular inscription (see Zammito, 2004: 194).

What can be derived from the stories about Pasteur and Guillemin is that Latour makes the role of scientific instruments secondary to either the statements uttered by scientists (human actants) or to the natural phenomena (nonhuman actants) that are visualized. If this analysis is correct, a serious issue arises regarding the way Latour approaches science-in-the-making: Latour’s understanding of scientific instruments as inscription devices threatens to black-box their role in the construction of scientific facts and objects. In Laboratory Life Latour and Woolgar (1986: 64) argue that ‘it is not simply that phenomena depend on certain material instrumentation; rather, the phenomena are thoroughly constituted by the material setting of the laboratory. The artificial reality, which participants describe in terms of an objective entity, has in fact been constructed by the use of inscription devices’. However, as our above analysis suggests, eventually, when compared to the other actants (human or nonhuman) in the construction of reality, scientific instruments are not attributed equal importance.

Inscription devices and letting the actors speak for themselves

It has been argued that because Latour’s analyses of science-in-the-making rely on the stabilized objects of ready-made science such as microbes and somatostatin, he is unable to understand scientific practices in terms of the actors’ practice of world-making (e.g.
Elam, 1999). After all, the stabilized objects of ready-made science which need explanation were not part of the world of the actors, and hence not part of their interpretational and experiential frameworks. In this section, we discuss whether Latour’s understanding of scientific instruments as inscription devices justifies the above-mentioned criticism. The question discussed in this section is the following: Does Latour’s approach to studying science-in-the-making, including his conceptualization of scientific instruments as inscription devices, indeed requires a certain fact to already have become ready-made science, thereby introducing a retrospectivity conflicting with his ambition to let the actors in scientific practices speak for themselves?7

We saw before that Latour understands semiotics as an ‘ethnomethodology of texts’, having the distinct advantage that ‘it helps replace the analyst’s restricted and limited vocabulary by the actor’s activity at world-making’ (Latour, 1993: 131). However, as Latour notices earlier, a traditional take in semiotics is unable to tell the whole story about science-in-the-making as it ‘remains inadequate because it persists in considering only texts or symbols instead of also dealing with “things in themselves” … Each time the solidity of a string of words is tested, we are measuring the attachment of walls, neurons, sentiments, gestures, hearts, minds, and wallets – that is, a heterogeneous multitude of allies, mercenaries, friends, and courtesans’ (Latour, 1988a: 183). It is only when the relation between a certain statement or symbol and another actor such as a neuron or microbe is considered that the activity of world-making in scientific practice can be analyzed. Thus, Latour asks: ‘What is behind a scientific text? Inscriptions. How are these inscriptions obtained? By setting up instruments’ (Latour, 1987: 69). What is inscribed on the window of an instrument gives, according to Latour, meaning to something ‘[that] resists trials of strength behind the instrument’ (Latour, 1987: 87). Understanding the activity of world-making in science-in-the-making thus requires to understand the semiotic relation between instruments (that provide inscriptions), the scientists relating to them, and the ‘something’ that is behind these instruments. How does Latour give all of these actors a voice?

In Science in Action, this question is addressed in terms of how understanding the construction of a scientific fact requires us to understand a scientist as a spokesperson that ‘behaves as if he or she were the mouthpiece of what is inscribed on the window of the instrument’ (Latour, 1987: 71). Scientific objects exist within a constellation of scientists, scientific instruments and that which is inscribed on the window of instruments. Scientific instruments produce visual inscriptions that are accompanied with verbal commentaries of scientists. Crucially, it is only through the addition of a specific commentary that an inscription starts to say something: ‘[I]t is … certain that the graphs … themselves would not have been enough to from the image of endorphin coming out of the brain’ (Latour, 1987: 71). It is only through their relation with scientists who function as representatives that inscriptions can be made to speak. Hence, Latour argues that while the inscriptions allow for making what is behind them speak, through making visible what was invisible beforehand, studying the verbal commentary of scientists in relation to inscriptions allows for making these inscriptions speak for themselves. Studying science-in-the-making thus requires a study of the relation between the inscription and the inscribed, and of the relation between inscription and spokesperson. It is in this sense that Latour tries to make all of these actors speak for themselves.
Latour understands ‘the inscribed’ as something generating an inscription that can be represented by a scientist, but does not address the particular way in which inscriptions come into being. That is, he does not pay attention to how specific inscriptions may visualize the inscribed in a particular manner, and how specific forms of representing come into being. This is problematic, as we will show in the next section, because it assumes that scientists already have an understanding of the reality of the specific object under study, and thus that the generated inscription is already endowed with meaning. In other words, in Latour’s understanding of scientific instruments as inscription devices, a prior existing framework that needs to be inscribed is assumed.

Latour’s analyses of laboratory practices – grounded in the idea that technologies provide inscriptions that have an immutable mobility – do not address how the content of the inscription is formed. However, what is to be inscribed is not already there, but instead the product of a specific hermeneutic processes occurring within a scientific collective. Whereas Latour’s approach to science-in-the-making is helpful for explaining how society is re-defined through science after a specific entity has been created in the laboratory, it is less successful in explaining why a certain entity rather than another has come into being. When investigating the latter, we cannot assume the outcome of specific hermeneutic processes as self-evident, but precisely need to focus on how actors speak for themselves. In the following section, we show how a postphenomenological approach focusing on technological mediations can reveal such processes.

**Technological mediations and science-in-the-making**

Ihde sees a continuity between Latour’s approach and the postphenomenological approach he advocates. In his view, ‘if Latour is right, the instrument is already a hermeneutic device. And equally, hermeneutic practice lies in the very heart of the laboratory. The laboratory has now become something like “science’s scriptorium”’ (Ihde, 1998: 149). He argues that the production of scientific knowledge, and the technological mediation thereof, should be understood in terms of the hermeneutics embodied in scientific instruments that translate instrumentally detected phenomena into readable images for an embodied observer. Accordingly, he understands science in terms of a “‘Latourean laboratory’ whereby instruments become the scriptorium of things, by which the visual hermeneutics … get[s] developed and perfected …, [resulting into] the visualization of things as scientific objects’ (Ihde, 1998: 147). Because the visual hermeneutics of science is materially mediated, Ihde suggests understanding and investigating scientific practices from the perspective of a material hermeneutics (see Ihde, 1998: 5, 2009: 64).

The question arising in the context of this article – and hence in the context of studying science-in-the-making in terms of a material hermeneutics – is whether this transformation from an understanding of scientific instruments as inscription devices into one which understands them as hermeneutic devices, is as unproblematic as Ihde imagines it to be. In answering this question, we make explicit how a postphenomenological understanding of scientific instruments as mediating technologies significantly differs from Latour’s semiotic reading of scientific instruments. This allows us to show how an understanding of scientific instruments as technologies that mediate the reality that scientists study, both attributes equal importance to humans and nonhumans, and allows actors to speak for themselves.
**Scientific instruments as mediating technologies, and attributing equal importance to humans and nonhumans**

Latour argues that it is necessary to look at what is behind the terms used in scientific literature as they are produced and move into laboratories to study scientific instruments that function as inscription devices. We suggested above that when interpreted in this way scientific instruments are not sufficiently recognized as actors. Our suggestion is that when they are instead understood as *mediating technologies*, the important hermeneutic role of scientific instruments can be acknowledged. This leads us to explicate the difference between the notions of ‘inscription device’ and ‘mediating technology’ (or ‘hermeneutic device’ in Ihde’s terms).

Ihde explicitly seeks to develop a technology-driven account of scientific practice. This account can be summarized as consisting of two related, yet distinct claims. On the one hand, he argues that ‘increasingly many scientific phenomena are technologically *carpented* phenomena’ (Ihde, 1991: 137). This implies that an increasingly large set of scientific phenomena could not be observed without the presence of technologies. On the other hand, the types of knowledge that scientists seek to gather are constituted by ‘the capacities opened up by instruments, capacities of a technological possibility leading to the productive capacities of experimental science’ (Ihde, 1991: 137). Thus, Ihde considers scientific instruments hermeneutic devices because they (1) make the phenomena which scientists study visible in a particular way, and (2) make the type of research conducted in scientific practices dependent on how scientific instruments reveal the world to collectives of scientists.

Let us start by explaining Ihde’s first claim. The phenomena scientists study are *translated* by technologies, such that they become accessible to human beings. Such translations are ‘technological transformation[s] of a phenomenon into a readable image. This is one analog to a hermeneutic process, except in this case it is a *material* hermeneutic process’ (Ihde, 2009: 56). Because of this, it is not the technology itself, but the object disclosed in our relation with the technology that is intentionally related to. For example, when a cognitive neuroscientist uses functional Magnetic Resonance Imaging (fMRI) to observe cognitive functions, an intentional relation with these phenomena, rather than with the fMRI itself, is established. Without the presence of technologies such as fMRI, the phenomena to be studied in cognitive neuroscience could not become present to scientists. The readable images – brain scans – generated through fMRI make cognitive functions present in a very specific way, and since it is only in relation with such images that the phenomenon under study can be read, scientists cannot evade this specificity. Thus, during the process of translation, a significant amount of hermeneutic work has already taken place, and it is the outcome of this hermeneutic work that becomes a candidate for human interpretation.

Let us now move to Ihde’s second claim. Precisely because scientific instruments confront scientists with non-neutral transformations, the technologically mediated images that scientists relate to are not immediate depictions of reality that speak for themselves. When reading these images, scientists must engage in a hermeneutic act: they ‘must be “read,” “decoded,” to detect … what is being presented’ (Ihde, 2009: 67). Ihde uses the term *multistability* to point out that – analogous to the hermeneutics engaged in when
reading a text – the images that scientists are confronted with allow for multiple stable interpretations. The possible interpretations of a scientific image generally exclude each other, but are in principle equally valid. How scientists arrive at a particular interpretation of a scientific image is dependent on the hermeneutic strategy engaged in the process of reading (Rosenberger, 2008, 2012). By engaging in a particular strategy, the image appears as an immediate gestalt in which certain features stand out against a background which is deemed less relevant.

The crucial point here is that the non-neutral technological transformation not only presents a scientific phenomenon in a specific way, but that in this transformation, the reality to which scientists relate, is disclosed in a particular way. Because of this, technologies prescribe what can be considered ‘real’ in the first place. This is why Ihde terms them epistemology engines that instantiate a particular technological trajectories (Ihde, 1998; Ihde and Selinger, 2004). For example, through the use of fMRI in the cognitive neurosciences, only those aspects of human cognition that can be visualized in brain scans can become candidate objects for this field of study. This requires the development of particular experimental set-ups in which particular cognitive capacities (e.g. visual attention, concentration) can be made present such that they become candidates for visualization through fMRI. As a consequence, the scientific explanations given of these cognitive capacities explain them in terms of a particular disclosing of the world necessitated through the presence of fMRI. Accordingly, besides generating scientific phenomena, scientific instruments mediate the reality which scientists study and the type of objects and explanations that are considered to be ‘real’. This is the second sense in which scientific instruments can be understood as hermeneutic devices.

Since there is nothing but a set of readable phenomena occurring within a specific technological trajectory that a scientist can have an intentional relation to, it is – phenomenologically speaking – unnecessary to postulate an entity behind the scientific instrument. A material hermeneutic perspective thus has to – and does – attribute equal importance to both human actors (scientists) and nonhuman actors (mediating technologies). This indicates that understanding scientific instruments as hermeneutic devices presupposes a different framework than when they are understood as inscription devices. Scientific instruments are not constitutive of scientific practice because they – as Latour would have it – are techniques that generate inscriptions of an already existing interpretative framework, but are engines that are generative of scientific knowledge (Carroll-Burke, 2001). To diverge from Latour, scientific instruments do not act because they make ‘the perceptive judgment of the others simpler’ (Latour, 1983: 161), but because they constitute the interpretational frameworks within which perceptive judgment takes place. That requires for us to genuinely recognize them as actors in scientific practices.

**Scientific instruments as mediating technologies, and letting the actors speak for themselves**

Postphenomenology can be a starting point for trying to understand how new interpretations of reality are constituted within the relation between scientists and scientific instruments. Such a hermeneutic perspective, then, requires a mild form of asymmetry between humans and nonhumans: while technologies take on an ‘active’ role in the constitution of
the reality that scientists study, they are also part of an intentional relation that humans have with the world (Verbeek, 2005: 169–170). Scientific instruments are not just elements in chains of actants that make it possible for a fact to exist; they help to shape the specific ways in which scientists are directed at reality and develop an understanding of the phenomena they are studying. This asymmetry is not a crypto-modernist asymmetry. It does not keep up a separation of subjects and objects, but rather claims that in the continuous dynamics between them, scientists and scientific instruments play different roles that, together, result in scientific understanding and explanation.

To what extent does this understanding of scientific instruments as mediating technologies – or hermeneutic devices – let the actors in science-in-the-making speak for themselves?

Kochan has criticized Latour’s approach to science-in-the-making because it black-boxes the concept of mediation. In his view, ‘on Latour’s account, the laboratory … is absolute: it leaves us powerless; we cannot open its black boxes; we cannot question its authority’ (Kochan, 2010: 593). Latour’s notion of ‘mediation’ reveals that apparently stable objects are in fact hybrid compositions of a variety of different entities. Postphenomenology is – on top of this – interested in how these new hybrids, which it conceptualizes as human-technology relations, give rise to new experiences, which in turn bear the possibility of creating new hybrids that allow for establishing new intentional relations with the world. Studying science-in-the-making, therefore, not only requires the revelation that scientific facts are in effect composed within a series of mediations, but also how technological mediations shape interpretations of the world. When addressing the latter question, mediations themselves can also become subjects of investigation. Postphenomenology thus helps to open the black-box of mediation by showing that the mediations occurring in the laboratory are not facts of nature that are to be taken for granted, but instead are the product of the interpretational frameworks that come into being in human-technology relations. As a consequence, the laboratory does not appear as a site of absolute truth leaving us powerless, but instead as a place where new interpretations of reality are constituted that can be scrutinized by the interested observer.

Precisely because the actors in scientific practices are hybrids (i.e. relations between human beings and technologies that cannot be entangled), a material hermeneutics should be focused on analysing the ‘behavior’ of such hybrids. As was made clear in the previous section, postphenomenological research has thus far primarily focused on the ‘technology’ part of this relation, as a counterweight to overly theory-focused philosophies of science prevalent in the 20th century (e.g. Ihde, 1991: 100). Verbeek (2016) has recently argued that postphenomenology has thus far tended to neglect the human aspect that remains at work in the interpretational work of the hybrid actors – that is, human-technology relations in scientific practice (p. 190). We therefore propose to approach science-in-the-making in terms of ‘an ethnomethodology of human-technology relations’, instead of as an ‘ethnomethodology of texts’ as Latour would have it.10

To be able ‘to let the actors speak for themselves’ in scientific practice, we must find a way to make human-technology relations speak. This implies that we have to understand the hermeneutic processes through which scientific objects are shaped, that is, the ways in which scientific collectives – collectives of hybrids – intentionally relate to the world. Such intentional relations must not be treated as isolated events, but as built from
and embedded within existing practices, structured around existing concepts and theories, and understood as an integral part of the dynamic relations between scientists and the specific infrastructure of the laboratory. It is against this background that hermeneutic strategies are developed that shape the relation between scientists and scientific instruments (Rosenberger, 2012, 2013; Verbeek, 2016). An ethnomethodology of human-technology relations can study the constitution of such hermeneutic strategies.

A recent study of real-time interactions between cognitive neuroscientists and the scientific instruments that they use can serve as an illustration of our proposal for analyzing science-in-the-making in terms of an ethnomethodology of human-technology relations (De Boer et al., 2020). The main project of the cognitive neuroscientists we studied was to causally link brain processes to cognitive processes in the study of ‘visual attention’. Doing so is critically dependent on (1) technologies that allow for the observability of brain activity, and (2) the possibility of observing cognitive processes as causally effected by brain processes. Imaging technologies such as functional Magnetic Resonance Imaging (fMRI) and Electroencephalography (EEG) are generally considered by neuroscientists to satisfy (1), but – because they work according to a correlational logic – fail to satisfy (2). Non-Invasive Brain Stimulation (NIBS) technologies, when combined with fMRI or EEG, are thought to hold the promise to satisfy both (1) and (2), because they intervene in brain processes and allow researchers to observe the corresponding behavioral change. However, because of the causal imperative that is the central epistemic theme of neuroscientific practices, it becomes crucial to determine whether the behavioral change is the result of neurophysiological changes induced by researchers, and not of other uncontrolled neurophysiological processes.

This prompts neuroscientists to ask the following question: How real is the observed behavioral change in terms of its causal relation with the induced brain stimulation? This question was not present when using only NIBS: When not being able to observe brain activity with fMRI or EEG, the researchers had no reason to question the causal relationship between intervening into brain processes through NIBS and behavioral change. However, when the brain activity induced by NIBS becomes observable through EEG, a causal relationship between stimulation and behavioral change can no longer be straightforwardly assumed. The combination of NIBS and EEG introduces a problematic that seemingly conflicts with the idea that there is a causal link between brain activity and visual attention. This, however, does not make the researchers refrain from orienting toward the norm of causality in the interpretation of experimental results. Yet, how this norm is invoked, and how it shapes the reality of the phenomenon under study (visual attention) depends on the scientific instruments that the researchers relate to, in this case NIBS, and the combination of NIBS and EEG respectively. Accordingly, the technologies used mediate how ‘visual attention’ can become present as a scientific object that can be causally reasoned about. In relation to such technological mediations, scientists develop hermeneutic strategies against the background of their epistemic project: when using a postphenomenological approach to study science-in-the-making, the relation between technological mediations and the hermeneutic strategies that scientists apply can be studied.

This brief summary serves to show how we think that the relevant actors in scientific practices can be made to speak for themselves. Within specific human-technology
relations, a specific hermeneutics of reality is instantiated that shapes the scientific objects under study. For example, scientists have a different relation with the scientific object ‘visual attention’ when relating to it only through NIBS, than they have when NIBS is combined with EEG. When a technology that can be used to intervene into brain activity is combined with a particular way of visualizing brain activity, different interpretations of the nature of the relationship between brain stimulation and behavioral change come into being. Understanding such differences requires us to recognize scientific instruments as hermeneutic actors that can be made to speak when constellations of scientists and scientific instruments are understood as ‘human-technology relations’, which is very different than understanding them solely as inscription devices. In our approach, the interpretive space in which objects that scientists can reason about appears never finished. Instead, scientific objects continuously change, as they are constituted within different human-technology relations. The proposed postphenomenological approach allows for studying these human-technology relations. In doing so, the black-box of mediation opens, since it can be shown how scientists themselves continuously revise the objects that they study and the interpretative frameworks used to make sense of them. The advantage of studying science-in-the-making in real-time precisely consists in the fact that neither the scientists nor the analyst interested in scientific practice knows what eventually will be the end-product of the scientific practice under study (Pickering, 1995: 14). In this way, scientific instruments are not only understood as delivering inscriptions, but also as constituting a specific relation with the world that allows scientists to observe new phenomena that might give rise to new interpretations of reality.

**Conclusion: Science-in-the-making: From semiotics to postphenomenology**

We have argued that because Latour conceptualizes scientific instruments as inscription devices he fails to meet his own desiderata (1) to attribute equal importance to humans and nonhumans, and (2) to let the actors in scientific practices speak for themselves. We suggested that postphenomenology can solve this problem by understanding scientific instruments as mediating technologies that shape intentional relations between scientists and the reality that they study. We have argued that technological mediations and the interpretational frameworks that come into being through them are central to understanding science-in-the-making. When the relevant actors in science-in-the-making are identified as human-technology relations, postphenomenology can help establish an ethnomethodology of human-technology relations that enables the actors in scientific practices to speak for themselves.

Latour’s use of the term ‘mediation’ is part of a narrative that aims to counter the established narrative of ready-made science, and is an explicit criticism of a narrative stating that science allows access to an already existing, but not yet discovered nature. In line with this aim, the processes that Latour identifies as mediations function to show scientific knowledge as constructed within local, collective practices. But, as Lynch (1993) has rightly asked, if ‘we agree that everything is “constructed,” does this tell us anything particular about the “constructions” that scientists make’ (p. 287)? A postphenomenological understanding of scientific instruments can, as we have shown, help
understand the specific constructions of reality that arise within human-technology relations. This requires to understand scientific instruments not so much as inscription devices, but as mediating technologies that give rise to specific human-technology relations. Understanding the reality of scientific objects, so we argued, presupposes a post-phenomenological focus on the hermeneutic processes that are constituted within human-technology relations. This shifts the focus from showing that scientific objects are constructed to the question how their existence is constituted through the hermeneutics of specific human-technology relations.

If science and society cannot be clearly delineated from one another, as is suggested in a Latourian perspective, then it matters which types of entities – and which interpretations of the world underlying them – come into being in laboratories. Since scientific instruments mediate the kinds of interpretational frameworks within the laboratory, they have a powerful ‘voice’ in what kind of world eventually will be constituted. Recognizing them as such enables scientists to be more particular about the specific entities being constructed in the laboratory, and to be more particular about how the world will be re-defined anew accordingly.

Acknowledgements
This research was made possible by VICI grant 277-20-006 of the Netherlands Organization for Scientific Research (NWO). We wish to thank the editors of Social Studies of Science and the two anonymous reviewers for their valuable and constructive feedback.

ORCID iD
Peter-Paul Verbeek https://orcid.org/0000-0001-9861-4091

Notes
1. In this article, we will not try to justify these desiderata, but assume – with Latour – that they are both requirements for studying science-in-the-making.
2. Our intent is not to criticize actor-network theory as such, nor its ambition to develop a social theory grounded in a material semiotics (e.g. Callon, 1998; Latour, 2005; Law, 2008), but rather to reveal specifically the limitations of a semiotic approach to science-in-the-making as applied by Latour.
3. Since it was Latour’s anthropological observation that the output of the scientists at the Salk Institute was a set of written documents, it has been argued that Latour’s semiotic approach to science-in-the-making is motivated by his earlier ethnomethodological commitments (De Vries, 2016; Jones, 2010). Indeed, Latour’s (2005) remarks in Reassembling the Social that it ‘would be fairly accurate to describe ANT as being half Garfinkelman [often singled out as the founding father of ethnomethodology] and half Greimas [the semiotician that Latour proclaims was of most influence on his work]’ (p. 54, fn. 54). However, Latour describes his own later analyses of science-in-the-making as being of a semiotic, rather than an ethnomethodological character. Forging an explicit link between ethnomethodology and the work of Latour is beyond the scope of this paper, since it is the (self-proclaimed) semiotic character of Latour’s approach with which we are currently concerned.
4. In this article, we are focusing on how Latour presents his own work as influenced by semiotics, and how this influence gives rise to a specific understanding of scientific instruments. For an in-depth discussion of how Latour’s work borrows and deviates from (Greimassian)
semiotics, see Beetz (2013).

5. Revealing the processes of mediation should not be understood as an *unmasking* of purification, but is better understood precisely as revealing the work that is necessary to successfully construct scientific facts (Simons, 2018: 703–704).

6. Although Latour started using the term ‘science-in-the-making’ in 1987 in *Science in Action*, we take that also his earlier work in *Laboratory Life* and *The Pasteurization of France* can be understood in line with this later term, because both Latour’s program as set out in *Science in Action* and his study of Pasteur aim to reveal the practices of mediation giving rise to the ‘discovery’ of scientific objects.

7. This is not to say that Latour is not interested in scientific practices that have ‘failed’ to make ready-made science, and hence would not be faithful to Bloor’s (1976) symmetry principle (see, e.g. Latour, 1996; Scott, 1991).

8. This narrow view on how technologies mediate human action remains present in Latour’s later work specifically concerned with technologies, for example in his *script theory* developed together with Akrich (e.g., Akrich, 1992; Akrich and Latour, 1992). On this view, technical objects and scientific facts are ‘never the beginning but the *end* of a long process of proliferating mediators, a process in which all relevant subprograms nested one into another, meet in a “simple” task’ (Latour, 1994: 192). Accordingly, the concept ‘mediation’ is used to open up the black-box of specific technical objects and scientific facts.

9. Strictly speaking, we could even say that the entire field of cognitive neuroscience can be understood as a particular technological trajectory instantiated through the introduction of brain imaging technologies.

10. Pickering also criticizes Latour for being unable to study scientific practices in real-time because of his commitment to treat humans and nonhumans in a symmetric manner. Pickering proposes we understand science as a *temporally emergent* practice, in which new phenomena arise that cannot be reduced to the intentions of scientists, nor to the scripts embodied in technologies (Pickering, 1995: 14–20). While we agree with Pickering’s criticism, our aims differ from his project, since Pickering’s studies of scientific practices – just as Latour’s – (1) still serve to explain the stability of established scientific facts, and (2) analyse the relations between humans and technologies in terms of agency, rather than in terms of how they constitute a meaningful space of interpretation.

References

Akrich M (1992) The description of technical objects. In: Bijker WE and Law J (eds) *Shaping Technology/Building Society: Studies in Sociotechnical Change*. Cambridge, MA: MIT Press, 205–224.

Akrich M and Latour B (1992) A summary of a convenient vocabulary for the semiotics of human and nonhuman assemblies. In: Bijker WE and Law J (eds) *Shaping Technology/Building Society: Studies in Sociotechnical Change*. Cambridge, MA: MIT Press, 259–264.

Beetz J (2013) Latour with Greimas: Actor-network theory and semiotics. Available at: https://www.academia.edu/11233971/Latour_with_Greimas_-_Actor-Network_Theory_and_Semiotics (accessed 5 June 2020).

Bloor D (1976) *Knowledge and Social Imagery*. London: Routledge and Kegan Paul.

Callon M (1998) Introduction: The embeddedness of economic markets in economics. In: Callon M (ed.) *The Laws of the Markets*. Oxford: Blackwell, 1–57.

Carroll-Burke P (2001) Tools, instruments and engines: Getting a handle on the specificity of engine science. *Social Studies of Science* 31(4): 593–625.
De Boer B, Te Molder H and Verbeek PP (2020) Constituting ‘visual attention’: On the mediating role of brain stimulation and brain imaging technologies in neuroscientific practice. *Science as Culture* 29(4): 503–523.

De Vries G (2016) *Bruno Latour*. Cambridge, MA: Polity Press.

Elam M (1999) Living dangerously with Bruno Latour in a hybrid world. *Theory, Culture & Society* 16(4): 1–24.

Høstaker R (2005) Latour: Semiotics and science studies. *Science Studies* 18(2): 2–25.

Ihde D (1990) *Technology and the Lifeworld: From Garden to Earth*. Indianapolis, IN: Indiana University Press.

Ihde D (1991) *Instrumental Realism: The Interface Between Philosophy of Science and Philosophy of Technology*. Indianapolis, IN: Indiana University Press.

Ihde D (1997) The structure of technology knowledge. *International Journal of Technology and Design Education* 7(1–2): 73–79.

Ihde D (1998) *Expanding Hermeneutics: Visualism in Science*. Evanston, IL: Northwestern University Press.

Ihde D (2009) *Postphenomenology and Technoscience: The Peking University Lectures*. New York: SUNY Press.

Ihde D (2016) *Husserl’s Missing Technologies*. New York: Fordham University Press.

Ihde D and Selinger E (2004) Merleau-Ponty and epistemology engines. *Human Studies* 27(4): 361–376.

Jones P (2010) Raymond Williams & Bruno Latour: ‘Formalism’ in the sociology of culture and technology. *Sociologie de l’Art* 1: 59–83.

Kochan J (2010) Latour’s Heidegger. *Social Studies of Science* 40(4): 579–598.

Latour B (1983) Give me a laboratory and I will raise the world. In: Knorr-Cetina K and Mulkay M (eds) *Science Observed*. London: SAGE, 141–170.

Latour B (1986) Visualization and cognition: Thinking with eyes and hands. *Knowledge and Society* 6(6): 1–40.

Latour B (1987) *Science in Action: How to Follow Scientists and Engineers Through Society*. Cambridge, MA: Harvard University Press.

Latour B (1988a) *The Pasteurization of France*. Cambridge, MA: Harvard University Press.

Latour B (1988b) A relativistic account of Einstein’s relativity. *Social Studies of Science* 18(1): 3–44.

Latour B (1993) Pasteur on lactic acid yeast: A partial semiotic analysis. *Configurations* 1(1): 129–146.

Latour B (1994) On technical mediation—Philosophy, sociology, genealogy. *Common Knowledge* 3(2): 29–64.

Latour B (1996) *Aramis or the Love of Technology*. Cambridge, MA: Harvard University Press.

Latour B (2005) Reassembling the Social: *An Introduction to Actor-Network Theory*. Oxford: Oxford University Press.

Latour B (2008) Where constant experiments have been provided. *Arch Literary Journal* 1: 1–8.

Latour B and Woolgar S (1986) *Laboratory Life: The Construction of Scientific Facts*. Princeton, NJ: Princeton University Press.

Law J (2008) Actor-network theory and material semiotics. In: Bryan S (ed.) *The New Blackwell Companion to Social Theory*, 3rd edn. Oxford: Blackwell, 141–158.

Lynch M (1993) *Scientific Practice and Ordinary Action: Ethnomethodology and Social Studies of Science*. Cambridge, MA: Cambridge University Press.

McGee K (2014) *Bruno Latour: The Normativity of Networks*. London: Routledge.

Pickering A (1995) *The Mangle of Practice: Time, Agency, & Science*. Chicago, IL: The University of Chicago Press.
Rosenberger R (2008) Perceiving other planets: Bodily experience, interpretation, and the Mars orbiter camera. *Human Studies* 31(1): 63–75.
Rosenberger R (2012) A case study in the applied philosophy of imaging: The synaptic vesicle debate. *Science, Technology, & Human Values* 36(1): 6–32.
Rosenberger R (2013) Mediating mars: Perceptual experience and scientific imaging technologies. *Foundations of Science* 18: 75–91.
Scott P (1991) Levers and counterweights: A laboratory that failed to raise the world. *Social Studies of Science* 21(1): 7–35.
Simons M (2018) The Janus head of Bachelard’s phenomenotechnique: From purification to proliferation and back. *European Journal for Philosophy of Science* 8(3): 689–707.
Verbeek PP (2005) *What Things Do: Philosophical Reflections on Technology, Agency, and Design*. University Park, PA: The Pennsylvania State University Press.
Verbeek PP (2016) Toward a theory of technological mediation: A program for postphenomenological research. In: Friis J and Crease R (eds) *Technoscience and Postphenomenology: The Manhattan Papers*. London: Lexington Books, 189–204.
Zammito JH (2004) *A Nice Derangement of Epistemes: Post-Positivism in the Study of Science from Quine to Latour*. Chicago, IL: The University of Chicago Press.

**Author biographies**

**Bas de Boer** is a postdoctoral researcher in philosophy of technology at the University of Twente, The Netherlands. He recently completed his PhD dissertation entitled: *How Scientific Instruments Speak: The Hermeneutics of Technological Mediations in (Neuro-)Scientific Practice*. His current research focuses on how medical technologies shape our understanding and experience of health.

**Hedwig te Molder** is professor Language and Communication at the Vrije Universiteit Amsterdam and guest professor of Science Communication at Wageningen University, the Netherlands. Her work focuses on how people attend to the moralities of science and technology in their daily lives, using the related perspectives of discursive psychology and conversation analysis. Currently, she is specifically interested in the role of experts and expertise in an alleged ‘post-truth society’. She received the Distinguished Book Award 2007 from the *American Sociological Association* for *Conversation and Cognition* (with Jonathan Potter). She was a *Visiting Scholar* at the University of California in 2009, and *Visiting Professor* at the University of Vienna in 2015. In 2017, she was *Senior Fulbright Scholar* at Rutgers University, USA. She is chair of the social-ethical committee of the scientific advisory board for the Dutch government on genetic modification, the COGEM, and co-founded the Centre for Dialogue.

**Peter-Paul Verbeek** is distinguished professor of philosophy of technology and scientific co-director of the DesignLab of the University of Twente, the Netherlands. Verbeek’s research focuses on the philosophy of human-technology relations, and aims to contribute to philosophical theory, ethical reflection, and practices of design and innovation. He is chairperson of the UNESCO World Commission for the Ethics of Science and Technology. Among his publications are *Moralizing Technology: Understanding and Designing the Morality of Things* (2011), *What Things Do: Philosophical Reflections on Technology, Agency, and Design* (2005), and the co-edited volumes *Postphenomenological Investigations: Essays on Human-Technology Relations* (2015, with Robert Rosenberger), and *The Moral Status of Technical Artefacts* (2014, with Peter Kroes). He is currently a principal investigator of a ten-year research project on the ethics of socially disruptive technologies.