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6. **Breaking up with the epochal break: The case of engineering sciences**

Mieke Boon and Tarja Knuuttila

Epochal breaks abound. After a short session on Google one learns that, apart from the break between modernity and post-modernity, epochal breaks have taken place also between the eighteenth century and Romantic literature[1], the oral Greek tradition and Hellenistic epic[2], African Christianity and its European roots[3], Ayatollah Ruhollah Khomeini's doctrine of *velayat-e faqih* and the traditional quietism of the Shi'i Muslims[4] as well as between the different monetary standards[5] and different sensorial topologies. What this apparent abundance of epochal breaks tells us is that once a handy diagnostic term gets coined, it will be used to establish and discover patterns in past, present and even future, as Hans Radder suggests in this volume.

How then to evaluate the epochal break thesis concerning science – or knowledge production? One obvious question concerns its timing. Most often the emergence of the brave new era of techno-science is located to the middle of twentieth century becoming truly pervasive,

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[1] http://www.erudit.org/revue/ron/1996/v/n4/005728ar.html

[2] http://journal.oraltradition.org/files/articles/18i/Barnes.pdf

[3] http://bulletsandhoney.wordpress.com/2005/12/

[4] www.merip.org/mer/mer242/editorial.html

[5] http://www.emeraldinsight.com/Insight/ViewContentServlet?Filename=Published/EmeraldFullTextArticle/Articles/0020260301.html

however, first since the eighties – a view with which Alfred Nordmann seems to agree. Gregor Schieman, in turn – and to our mind rather plausibly – argues that the transformation of science started already in the nineteenth century along with the development of “reality-shaping technologies”.[6]

Instead of taking the phenomenon of epochal break at face value and then arguing whether or not it took place and if so, when, we take another route. We do not wish to engage in any large-scale historical argument but rather to critically examine the distinctions between representation and intervening, and basic and applied science that seem to be crucial to the “notion” of epochal break – at least as it is suggested by Mode 2 literature. According to it, the epochal break between the two modes of research is seen as a break away from the theoretical, understanding-providing basic science towards interventional science taking place in the “context of application”. As such, the epochal break, at least when it comes to scientific knowledge production, seems to reify those distinctions that have been criticized by the recent practice-oriented studies both in science and technology studies and in the philosophy of science.

In what follows we will study whether the aforementioned distinctions are tenable from the perspective of modeling in engineering sciences, which should provide the prime example of emerging techno-science. We will argue that scientific modeling cuts interestingly across the two distinctions – i.e. ‘representing versus intervening’ and ‘basic versus applied’ – thus challenging the basis of the epochal break thesis. Having found the basic distinctions on

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[6] However, this way of doing science emerged already when scientists started to use instruments in their experiments, that is, earlier than what Schieman claims (see also Radder in this volume).

which the epochal break thesis rests untenable, at least when it comes to scientific practice, we will ask what is in fact established by the epochal break-talk.

Breaking up the divide between representing and intervening

In *Representing and Intervening* (1983) Ian Hacking claims:

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

Statements like this have been taken to intimate that there is a fundamental divide between representation and intervention, the former intending to depict the world truthfully and the latter to manipulate things and shape the world. We propose, however, a different reading of Hacking. Namely, his claim that “there is nothing there” in the nature of representation hints to a more subtle stand concerning representation. Maybe there is nothing there *in our established notion of representation* that can accomplish what is expected from it. Thus taking a cue from Hacking we suggest that the representational idiom does not describe adequately our actual theoretical practices, which instead of trying to accurately represent the world, are more tuned to our active engagement with the world than what is customarily supposed.

This entanglement of representing and intervening is particularly significant for understanding scientific research in the context of technological applications. As we will show later, a distinction can be made between *engineering sciences*, which primarily aim at scientific modeling, and *engineering*, which is more directly concerned with creating, producing, improving, controlling, or designing various devices and materials. Yet, no techno-scientific fusion of representation and technical intervention needs to follow from rejecting the customary representational idiom. But before going into this, let us first visit the recent discussion on representation and modeling which testifies to a certain intellectual insolvency concerning the traditional representational paradigm *even* when it comes to the so-called basic science.

If we are to believe the philosophers of science, the link between models and representation is as intimate as coming close to a conceptual one. Philosophers have generally agreed that models are essentially representations and as such "models of" some real target systems. Yet the accounts given of the representational character of models differ widely.

The recent pragmatist approach to representation (e.g. Bailer-Jones 2003, Suárez 2004, 2010; Giere 2004, 2009) could be seen as a critique of the structuralist notion that is part and parcel of the semantic conception, which up until recently has been the most widely held view on models. The semantic conception provides a straightforward answer to the question of how models give us knowledge of the world: they specify structures that are posited as possible representations of either the observable phenomena or, even more ambitiously, the underlying structures of the real target systems. Thus, according to the semantic view, the structure specified by a model represents its target system if it is either structurally isomorphic or somehow similar to it. (e.g., van Fraassen 1980; French and Ladyman 1999; Giere 1988). The pragmatist critics of the semantic conception have argued, rather conclusively, that the structuralist notion of representation does not satisfy the formal and other criteria we might want to affirm of representation (see e.g., Suárez 2003; Frigg 2003). The problem can be located to the attempt to find such properties both from the representational vehicle (the model) and the real object (the target system) by virtue of which a representational relationship can be established between a model and its target object.

So far, despite the numerous trials, no such even nearly adequate solution to the aforementioned general philosophical puzzle concerning representation has been presented. Hence the continued referral to representation as a putative explanatory concept seems to be philosophically unfounded. The pragmatist alternative is to circumvent the traditional problem by making representational relationship an accomplishment of representation-users. Consequently, what is common among pragmatic approaches is the focus on the intentional activity of representation users and the denial that representation may be based only on the respective properties of the representative vehicle and its target object. However, if representation is primarily grounded in the specific goals and the representing activity of humans as opposed to the properties of the representative vehicle and its target, nothing very substantial can be said about it in general (cf. Giere 2004, Suárez 2004).

Thus one largely ignored consequence of the pragmatic accounts of representation is the way they have emptied the concept of representation from much of its explanatory value. As a result, we are also deprived of an explanation of the epistemic value of models, too – that is, if we want to attribute it to representation. Consequently, Hacking can be read as not suggesting a turn away from representation but rather realizing that representation cannot accomplish what it is supposed to establish. If this were the case, how should one, then, approach the epistemic value of models? One obvious way out of this problem is not to attribute the knowledge-bearing properties of models to representation *alone*.

Interestingly, largely apart from the very interest in the topic of representation, a new discussion on models has emerged that loosens the epistemic value of models (at least partly) from representation and considers them as independent objects. The idea of models as independents objects or entities has been expressed by several recent authors in various ways.

Morrison (1999) and Morrison and Morgan (1999) have considered models as *autonomous agents* which are through their construction partially independent from theory and data. Weisberg (2007) and Godfrey-Smith (2006) in turn argue that models should be considered as independent entities in the sense of not representing any definite real target systems. According to them modeling can be viewed as a specific theoretical practice of its own that can be characterized through the procedures of *indirect representation and analysis*. With indirect representation they refer to the way modelers construct simple, ideal model systems to which only a few properties are attributed, instead of striving to represent some real target systems directly.

How are, then, models as independent objects able to give us knowledge? Morrison and Morgan as well as Godfrey-Smith and Weisberg refer back to the notion of representation. But invoking representation would once again bring in the riddle of representation. In contrast, what we find the most important point in viewing models as independent things is that it enables us to appreciate their functional characteristics.

Considering models from the functional perspective requires one to address them as *concrete objects* that are constructed in view of certain *epistemic purposes* and whose cognitive value derives largely from our *interaction* with them (Knuuttila and Merz, 2009). Consequently, models can be considered as multifunctional *epistemic tools* (Knuuttila 2005, Knuuttila and Voutilainen 2003, Boon and Knuuttila 2009, Knuuttila and Boon forthcoming). From this perspective also the material embodiment of a model is of epistemic importance: the concrete representational means through which a model is achieved gives it the spatial and temporal cohesion that enables its manipulability. This also applies to so-called abstract models: when working with them we typically construct and manipulate external representational means such as diagrams or equations. Herein lays also the rationale for comparing models to experiments: in devising models we construct self-contained artificial systems through which we can make our theoretical conjectures conceivable, articulated and workable.

Indeed, it is rather paradoxical that the representational view on models actually abstracts away from the actual representational tools with which models are constructed. Assuming that theoretical activity seeks to depict the world *as it is*, it presupposes that we already knew what to represent and how – having also the appropriate means at hand for doing that. But the very point of representing (be it a model, piece of text, or some visualization produced by an inscription device) is to find out more about the phenomenon of interest and it is more often than not guided by the available representational means (linguistic, pictorial, mathematical and diagrammatical), computational templates and modeling methods at hand, not to mention the new media, such as computers. Models are artifacts, tools for articulating, finding out and bringing about rather than depicting the world truthfully.

It is important to note that the representational means used by sciences have different characteristic limitations and affordances; one can express different kinds of content with symbols than with pictures, for example. It is already a cognitive achievement to be able to express any hypothetical mechanism, structure or phenomenon of interest in terms of some representational means. Such articulation enables further theoretical findings as well as new experimental set-ups, but it also imposes its own limitations on what can be done with a certain model. Yet the constraints built into a model also enable: As the real world is just too complex to study as such, models simplify or modify the problems scientists deal with. Thus, modelers typically proceed by turning the constraints (e.g., the specific model assumptions) built into the model into affordances; one devises the model in such a way that one can gain understanding and draw inferences from using or “manipulating” it. This feature of models is linked to another characteristic of them: especially theoretical models do importantly depict the possible and not just the actual. They are rather driven by pending scientific problems and questions than by the attempt to depict some real target system as accurately as possible.

We thus suggest that we typically learn from models by interacting with them, that is by building them, and trying out different things with them — which in turn explains why models are regularly valued for their *performance* and their *results* or *output*. From the functional perspective, rather than trying to represent some selected aspects of a given target system, modelers often proceed in a roundabout way, seeking to build hypothetical model systems in the light of their anticipated results or of certain general features of phenomena they are supposed to *bring about*. If a model gives us the expected results or replicates some features of the phenomenon, it provides an interesting starting point for further theoretical and experimental conjectures. The purposes the model is constructed for and the computability considerations often override in modeling the goal of realistic representation. Consequently, the very peculiarity of scientific modeling lies in its strategy of accounting for kinds of phenomena through the detour of constructing artificial entities in view of some scientific questions keeping simultaneously in mind such pragmatic constraints as their tractability (see Humphreys 2004).

It seems to us that this kind of conception of modeling fits especially well the engineering sciences because of their practical problem-orientation. The models in the engineering sciences are *not* first and foremost considered as accurate representations of some target systems, but rather as epistemic tools to find out how to produce, control, intervene -- or to prevent some properties of materials or behavior of processes and devices. Consequently, engineering *scientists* build models for the purposes of imagining and reasoning about how to improve the performance of the devices, processes or materials of interest. These models involve imaginable properties and processes, and they incorporate measurable physical variables and parameters (e.g. in the case of chemical engineering chemical concentrations, flow rates, temperature, and properties of materials such as diffusion, viscosity, density). Often, these models also incorporate dimensions of typical configurations of certain devices (cf. Boon and Knuuttila, 2009).

Yet studying the modeling practice in engineering sciences should make it clear that although engineering sciences can be distinguished from engineering – thus not supporting any wholesale claim for techno-science – conceiving engineering sciences as basic research that provides theories that are then applied in concrete engineering tasks gives too simplified a picture of what happens in both domains. This simplified picture is of course what is to be expected if models are considered as truthful theoretical representations of the world. Then it is possible to assume that the success of their possible applications is due their ability to depict the world truthfully (see Carrier in this volume). We believe instead that models produced in engineering science are not simply applied in engineering, but used as epistemic tools. If we were to believe that models have the ability to be applied because they represent a target system accurately, it is often unclear which target system they seek to depict, especially in the context of engineering sciences. The devices, processes, or materials do not yet exist, but must be created, i.e., are designed by using models as epistemic tools. Models, on this account, allow for reasoning about (possible) interventions with the world, for instance about how to generate a material property, how to make an efficient process, or how to avoid an undesirable phenomenon in a device.

Breaking up the divide between basic and applied

The way the Mode 2 argumentation appears to rely on the already dated contrast between theoretical representation and intervening in the world makes us doubt the epochal break thesis concerning science already on philosophical grounds. What is more, we question also empirically whether any epochal break has taken place in how scientific research is actually done (cf. Gibbons et. al. 1994, Nowotny et. al. 2003). We do not deny that there have been major institutional changes, or that there are important sociological aspects to the process of knowledge production. Neither do we doubt that political ideas on the role of science have changed in the last few decades. What we are critical about is the suggestion of Mode 2 theorists that there has been a fundamental change within scientific practices regarding their goals, scientific methodologies and epistemic criteria, i.e., to how scientists think and write, and to the academic standards of good scientific research. In contrast, it seems to us that the way in which scientific theory is taught and used, the way in which experiments are designed, and the structure and content of scientific papers has been amazingly stable.

The break between knowledge production by theory (Mode 1) and by application (Mode 2) is largely justified by another distinction, which is rather inconspicuously intertwined with the divide between representing and intervening, as we have already hinted at. Namely, Mode 2 literature presupposes that a clear distinction can be made between *basic* scientific research, which produces theories that meet academic standards, and *applied* scientific research, which produces knowledge that is highly context-dependent and that does not meet the classical epistemic criteria, but instead, solves problems. The epochal break thesis is founded on this divide. In a similar vein Carrier and Nordmann (2006) claim that in present scientific research a markedly technological orientation can be observed that has had a significant impact on the goals and methodology of science. Theoretical representation is shifted to the background as scientific research focuses on useful properties and options for intervention. Rather than understanding nature, scientific research aims at shaping it. Again, it seems to us that this apparent change of orientation exhibits a change in how scientists justify their research but not in how scientific research is actually carried out. Indeed, this can be noticed in current research proposals, which are often written as if they were merely oriented at technological applications, making invisible the amount of scientific research that they actually entail.

If anywhere, the alleged recent emergence of the techno-science should most visibly be seen in the engineering sciences. The term "engineering science" goes back at least to the mid 18th century in French, and the term in English was probably first used by W.J. M. Rankine, a Scottish engineer and scientist, in the 1850's.[7] Also later, in the late 19th and beginning of the 20th century, researchers with an interest in engineering took scientific approaches to technologically produced phenomena (e.g. scientific researchers such as Sadi Carnot and Ludwig Prandtl). Their aim was scientific interpretation of phenomena occurring in, or produced by, technological devices, such as the production of power in heat-engines examined by Carnot, and flow phenomena in technological objects examined by Prandtl, (cf. Boon 2006, Boon and Knuuttila 2009). Engineering education has incorporated such scientific approaches, which has resulted in the present "engineering sciences". Today, engineering science manifests itself in hundreds of thousands of scientific researchers, thousands of scientific research laboratories, and hundreds of specialized scientific journals. Thus the engineering sciences more or less in their present form have existed already longer, yet the putative epochal break was observed first in the 1980's by most proponents of the thesis (see however Schieman in this volume).

We suggest that the supposed break in scientific goals, methodology and epistemic standards is due to what are taken as exemplary examples of research rather than to actual changes in how science is done. Philosophy of science, for instance, used to take physics as its exemplar,

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[7] We wish to acknowledge David Channell, who gave us valuable information on the history of the notion of "engineering sciences".

in particular its mathematical approach, which however was only a minor part of science. In stressing “the context of application” the Mode 2 theorists in turn tend to take the application oriented "R&D" departments in industry as their exemplar. This change of an exemplar of what counts as research does not legitimize the conclusion that a fundamental change in scientific goals, methodology and criteria has taken place.[8]

As such, the distinction between basic and applied science is much older than Mode 2 theory of knowledge production. Many researchers themselves and especially the popular accounts of science tend to take for granted a distinction between basic scientific research that aims at theories and understanding nature, and applied science that aims at shaping nature by intervention. Wikipedia, for instance, presents a following description of applied physics:

Applied physics is a general term for physics which is intended for a particular technological or practical use. "Applied" is distinguished from "pure" by a subtle combination of factors such as the motivation and attitude of researchers and the nature of the relationship to the technology or science that may be affected by the work. It usually differs from *engineering* in that an applied physicist may not be designing something in particular, but rather is *using physics or conducting physics research with the aim of developing new technologies or solving an engineering problem*. ... In other words, applied physics is rooted in the

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[8] It is noteworthy that R&D has not been regarded as a scientific research practice in the past accounts of science. Yet, even R&D departments often do scientific research, including the publishing of scientific articles. However, as already mentioned, an important difference lies in how they present their purposes, which is partly determined by the audience to whom they have to justify their activities, such as their company, their peers, the government, the general audience, etc.

fundamental truths and basic concepts of the physical sciences but is concerned with the utilization of these scientific principles in practical devices and systems.[9]

This quote reflects how branches of the engineering sciences are commonly understood: the divide between “applied” and “pure” leaves engineering sciences in the side of applied science. The quote above suggests that scientific principles are simply used in the development of better devices. Although also scientists frequently present their work in this way, it might not give a good characterization of it as scientists often lack appropriate meta-theoretical means for observing and describing their research, causing that the traditional picture holds them captive. We suggest an alternative to this picture: the conception of models as epistemic tools fits engineering sciences as well as the “pure” sciences. This is because the possible differences between the two lie rather in the phenomena they are interested in than in their epistemic practices. The engineering sciences develop models of phenomena relevant to technological applications, which, however are not less “deep” than models of phenomena produced in “pure” sciences.

Scientific articles provide a good indicator of the prevalent scientific goals, methodology, and epistemic criteria of engineering sciences. When browsing through journals in different fields of the engineering sciences one quickly learns that scientific models are at the centre of interest. These models aim at yielding scientific understanding of the behavior of devices or the properties of materials. A classic example is how Sadi Carnot in the early nineteenth century translated the functioning of heat engines into a theoretical problem concerning the phenomenon of producing motion by heat. This lead to conceptual novelties and contributed to the consequent development of the thermodynamic theory. Thus scientific research

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[9] http://en.wikipedia.org/wiki/Applied_physics

pertaining to the functioning of devices need not be fundamentally different from what is commonly understood as “pure” science. (cf. Boon and Knuuttila, 2009; Knuuttila and Boon, forthcoming). Scientific research in chemical engineering provides another example. Very similar to Carnot’s approach, scientific researchers in this field proceed by studying the behavior of devices by interpreting them in terms of physical phenomena considered to be relevant to their proper or improper functioning, and then modeling these phenomena. Examples of such modeled phenomena are desirable and undesirable chemical reactions, the transport of liquids, gasses and solids within the device, the transport of chemical compounds by means of fluid flow or diffusion in the fluid, the transport of heat by convection or conduction, and other physical processes such as absorption, dissolution, ionization, precipitation, vaporization and crystallization. In modeling these physical phenomena, usually two different types of scientific models are produced simultaneously: models that present a causal-mechanistic understanding of the phenomenon, and models that present a mathematical description of the phenomenon in terms of relevant physical variables – in this they also resemble other natural sciences (Boon 2006, and Boon 2009)

Consequently, it seems to us that the engineering sciences do not fit very well either with Mode 2 or with Mode 1. In particular, the fact that the engineering sciences aim at *understanding* phenomena makes them to fit better with Mode 1. On the other hand, these phenomena are related to the functioning of devices or materials, which in turn better suits Mode 2. Are then engineering sciences perhaps basic or applied, or neither? We propose that engineering sciences make a case for rejecting the divide between basic and applied sciences. Their scientific goal is usually related to concrete problems, which is in accordance with Mode 2, but within scientific practice their goal is narrowed down to modeling a phenomenon, which aims at understanding it scientifically. That they should proceed in this way blurs any clear distinction between them and the putative basic sciences, which also aim at getting theoretical grasp of phenomena by modeling.

Conclusion

We have argued that the very distinctions on which the alleged epochal break between Mode 1 and Mode 2 is built do not hold up closer philosophical or empirical scrutiny. Moreover, neither do they conform even to engineering sciences that should provide the closest case of what is commonly conceptualized as techno-science. This should come as no surprise since most of the claims concerning epochal break are not being based on empirical studies. As any representations are purpose-relative, one might ask what are the purposes for representing the current scientific activity as if an epochal break has taken place there. For us it seems that this claim should be evaluated rather as a piece of political rhetoric than any serious claim about scientific practice. Or, to give it a more favorable reading, one could approach epochal break and the associated Modes as *transdiscursive concepts* that are used to reorganize and guide discourses between the research communities and policymaking.

Transdiscursive concepts aim to mobilize and empower as well as to create social consensus (see Miettinen 2002, 132–141). From this perspective the critical question concerning the alleged epochal break pertains to whether it really succeeds in its self-renowned task of empowering the problem-solving activity as regards the complex problems of the 21st century. We doubt that this is the case if only because the vision of scientific practice embedded in it is naïve to say the very least – as we have argued above. Thus we doubt whether any remarkable problem-solving ability is going to result from all those political science-policy measures that are taken in the name of transdisciplinarity. The Mode 2 talk grossly overestimates of what scientists can do in the short time spans, that is, to which extent innovative scientific research can be geared to practical problem-solving, and last but not least, it underestimates the real communicative and other difficulties involved in interdisciplinary work. This is not to say that ideologies like these would not have an effect on academic life. They do and we already see them around.

Mode 2 and related policies have offered governmental and business sectors as well as administration and various funders a good justification to exert more pressure on academic sector in terms of (short-term) accountability and commodification. Partly as a result of these pressures universities have turned into multiversities (Kerr 1966) that have taken multiple tasks upon themselves suffering simultaneously from the dearth of funding. As universities have sought to renew their financial base through contract research, educational services, consulting and the commercialization of research results the Mode 2 ideology legitimizes the status quo by offering a rosy vision of the organizational and other changes that are taking place. We wonder if not this development is rather worsening the conditions for any truly innovative research.

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