An Epoch-Making Change in the Development of Science? A Critique of the "Epochal-Break-Thesis"

Gregor Schiemann

Introduction

In recent decades, several authors have claimed that an epoch-making process of change in the development of science is currently taking place. The authors conceive the development of modern science as a continuous process that began approximately between the sixteenth and late eighteenth centuries, and that is discontinuously ending in our time. But the *epochal break* thereby formulated is only rarely dealt with on the conceptual level, and even then not in a uniform manner (see section "Assertions of Current Epochal Changes and the Problem of Their Conceptual Definition").[1]

This terminological weakness makes it more difficult to assess the various assertions of an epochal break. What is it that lends an epoch-making character to a process of change? Is there a specific dynamic that distinguishes epochal changes from other processes of change? What is the significance of the claim of discontinuity associated with the word "break"? In what way are contemporary descriptions involved in the assertions of epoch-making changes (which might occur only at a moderate pace)? In order to be able to answer these questions, I will propose a *concept of epochal change* that takes up the intuitions of the authors asserting such a change, but which also allows for a critical assessment of these claims. According to this concept, it is typical of epochal changes that they begin within a particular subarea of the sciences, that they occur in a manner that is at best partially discontinuous – the concept of an "epochal break" therefore appears inappropriate – and that they transpire over a relatively long period of time (see section "The Concept of an Epochal Change in the Development of Science").

In the interest of assessing the transformations of contemporary science asserted by the authors in question, as well as transformations that they have not taken into

G. Schiemann (✉)
Philosophisches Seminar, Bergische Universität Wuppertal, Wuppertal, Germany
e-mail: schiemann@uni-wuppertal.de

[1]The term "epochal break" is not found in all the relevant publications, but is suitable to characterize the assertion of a discontinuous process of epoch-making change.

M. Carrier, A. Nordmann (eds.), *Science in the Context of Application*,
Boston Studies in the Philosophy of Science 274, DOI 10.1007/978-90-481-9051-5_25,

consideration, I think it is sensible to stick to *societal subsystems as a frame of reference*. Given this prerequisite, differences between the subareas of science, to which the current transformations refer, become more clear: they are correlated with different societal subsystems. I will take these correlations as a guideline in assessing the historical origins and the form of progression of some transformations that are *candidates for the status of an epochal change* (see section "Candidates for the Status of Epochal Transformations in the Recent Development of the Sciences").

Assertions of Current Epochal Changes and the Problem of Their Conceptual Definition

The most recent assertions of an epochal break in the sciences appeal to developmental tendencies that have been apparent since approximately the 1980s. They concur with respect not only to their estimation of the beginning point of the changes but also to some fundamental elements of their characterization of the changes. The commonalities appear above all in the historical demarcation of the new characterizations, which are constitutive of the concept of the epochal break. For example, the *contrast to modern science*, as it developed up to the second half of the last century, is included in all the definitions of the transformation. Accordingly, the denominations often claim to distinguish a type of science that follows upon modern science. M. Gibbons et al. speak of "Mode 2", S.O. Funtowicz and R. Ravetz of "post-normal science", J. Ziman of "post-academic science", and P. Forman of the "postmodern primacy of technology". In the following, I would like to discuss some examples of the common historical positioning of the epochal break, and to show that the concept of an epochal break cannot be sustained in the cases under discussion. I will not take the conception of post-academic science into consideration.[2] In addition, I will draw upon the conception of the "Triple Helix of university-industry-government relations", as well as two descriptions of a fundamental transformation that do not assert a discontinuity, or do so only in a qualified manner.

Mode 2

Gibbons et al. identify Mode 1, which precedes Mode 2, with modern science as it goes back to early modern times.[3] They characterize it as the "complex of ideas, methods, values and norms that has grown up to control the diffusion of the Newtonian model of science to more and more fields of enquiry and ensure its compliance with what is considered sound scientific practice" (Gibbons et al., 1994, 167). They maintain that Mode 2, which arose in a discontinuous fashion, differs "in nearly every respect" from Mode 1 (loc.cit., VII). The former has not replaced the latter but, rather, appeared alongside it as a distinct system. The persistence of Mode 1 presents an element of continuity that contrasts with the idea of an epochal break. The authors characterize the difference between the two modes by appealing to characteristics of Mode 2 that share a common tendency to foster an orientation toward socially *useful applications* (loc.cit., 3 ff. and 167). While this practical component of the current transformation of science is common to the various conceptions of the epochal break, judgments of the structural changes connected to it differ and are the subject of controversy. The Mode-2 conception asserts a partial *dissolution of the boundaries* that previously separated the subsystems of society (science, the state, the market and culture), and gives special prominence to the dissolution of the separation between academic and non-academic production of knowledge. In place of these separations, it envisions the formation of new, heterogeneous structures, in which scientific, technical, economic, political and public interests are taken up in multifarious ways (Nowotny et al., 2001, 21 ff. and 245).[4]

It is claimed that these institutional changes have an impact upon the "epistemological core", which no longer consists in "irrefutable and invariant laws" (loc. cit. 196) but in "individual, social and cultural visions of science" (loc. cit. 198).[5] This *new conception of the epistemological core* is taken to reveal the fundamental character of the epochal break. There is indeed a basis for this viewpoint, insofar as epistemological characteristics represent a decisive historical constant for science over a long period of time. I group these characteristics together under the label "*classical conception of science*", according to which scientific knowledge is marked by truth, generality and necessity.[6] The new conception introduced by the notion of Mode 2 remains ambiguous, though, since it denies epistemological characteristics, claiming that the epistemological core is empty (Nowotny et al., 2001, 225), but at the same time continues to grant them significance, as is revealed in the demand for a new epistemology (loc. cit. 247 f.).

Although the authors give particular reasons for the *beginning of the epochal break* in the 1980s (Gibbons et al., 1994, 10, 17 and 44), they also trace some essential characteristics of Mode 2, such as the development of non-academic research and the retreat from traditional validity claims, back to the nineteenth century

[2]John Ziman's conception of post-academic science is related to the conception of Mode 2: cf. Ziman (2000, 81), and Nowotny (2006). Moreover, B. Latour's and D. Haraway's conception of technoscience will also be left to the side here. There are different variants of it, a comparative discussion of which is beyond the scope of this critique, which will be limited to dealing with particular examples. On Latour's and Haraway's use of the term "technoscience" as an epochal conception, see Reichle (2004), Weber (2003) and Ihde and Selinger (2003).

[3]The Mode-2 thesis is presented and elucidated in Gibbons et al. (1994, 2003), as well as in Nowotny et al. (2001). For criticism, see Elzinga (2004), Weingart (1997) and Schiemann (2009).

[4]For criticism of the supposed dissolution of the boundaries between societal subsystems, see Section "Candidates for the Status of Epochal Transformations in the Recent Development of the Sciences" below.

[5]This thesis is emphasized especially in Nowotny (1999): "What is currently at stake is nothing less than a new conceptualization of the epistemological core of science, and therefore also a central component of the image of science (loc. cit. 29).

[6]The classical conception of science was paradigmatic from antiquity until the nineteenth century, cf. Schnädelbach (1983, 106 f.), Schiemann (2009, Chapter 2).

(e.g., loc. cit. 22; Nowotny et al., 2001, 197). As an historical claim, the epochal break thesis thereby becomes questionable. What speaks against pushing back the start of the transformative process as well? What is the relationship between the factors that seemingly prepared the way for the supposed break and those which initiated it? Is it a matter of a more gradual or a more discontinuous change?

With regard to the present state of affairs, the authors assert a mutual influence between the clearly distinct forms of knowledge production: they believe that Mode 2 relies upon and also transforms Mode 1. Not much is said about the continuing development of Mode 1, except that it "will become incorporated within the larger system [... of] Mode 2" (Gibbons et al., 1994, 154). The revolutionary transformation is therefore not yet complete, and the form of science that will succeed upon modern science as it has existed until now cannot yet be characterized fully.

Post-normal Science

In contrast to the conception of Mode 2, the conception of "post-normal science" espoused by Silvio O. Funtowicz and Jerome R. Ravetz distinguishes the new form of knowledge production not only from the science that came about in early modernity.[7] The authors regard this science as belonging to a type that arose in antiquity and which could appropriately be characterized by T.S. Kuhn's concept of "normal science". While they, like Kuhn, impute a one-sided theoretical orientation to normal science, they see in the discontinuously arising post-normal science a *twofold turn to praxis*: to the praxis of knowledge production and to new objects of this production, which arise in specific contexts of application (Funtowicz and Ravetz, 1993, 118 f.). These objects – an example of which would be the ecological crisis brought about in part by the application of scientific technology (loc. cit. 95 f.) – are marked by a *complexity* which can be only partially grasped by theory. Epistemically, *uncertainty* is therefore a most salient characteristic of post-normal knowledge.[8] The processing of such new objects is, in their view, marked by conflicting values and high risks, and is only possible in direct relation to politics (loc. cit. 86 ff.). Just as Mode 2 takes over from Mode 1 its leading role, normal science is said to persist and to be substantially influenced by post-normal science (loc. cit. 110 f.). Hence, we again find an element of continuity that contrasts with the thesis of discontinuity.

In distinguishing post-normal science from a kind of science that goes back all the way to antiquity, the authors impart to the epochal break *a more far-reaching dimension* than is the case for the Mode-2 conception. With the increased historical scope, the characterization of the rift undergoes a shift toward a greater focus upon *epistemic characteristics*. The authors refer to the latter as constituting the "ideological function [of science] as the unique bearer of the True and therefore

[7]I am basing my presentation of post-normal science on Funtowicz and Ravetz (1993, 1994, 2001).

[8]Uncertainty is also a characteristic of knowledge in Mode 2. Cf. the subtitle of Nowotny et al. (2001): "Knowledge and the Public in an Age of Uncertainty".

of the Good" (loc. cit. 85, cf. 95 and 111).[9] The beginning of its destruction is dated at the beginning of the twentieth century (Gödel's incompleteness theorems, Einstein's theory of relativity, Heisenberg's uncertainty principle), and is said to have enabled the subsequent genesis of post-normal science (loc. cit. 93 ff.). In a fashion similar to the Mode-2 authors, the relationship between the appearance of the supposedly epochal break and the processes preceding it remains somewhat vague. The break can be understood as an emerging insight that the truth claims of the classical conception cannot be realized. This insight has become established in particular in subareas of science occupied with certain complex objects. But the authors do not adequately justify their denial of the possibility that the theoretical understanding of complex objects could in the future continuously improve.[10]

Even though Funtowicz and Ravetz consider modern normal science a part of the more comprehensive type, they still regard it as a historical unit that they explicitly say began with the "scientific revolution" (loc. cit. 85, 117 f.). They take the impact of the caesura at the start of the early modern era to be in fact so profound that they even compare it to the break between normal and post-normal science (loc. cit. 117). Will this break have been the final revolution? A more practice-based and de-localized science could lose the capacity for discontinuous change, which is a typical feature of normal science in Kuhn's sense. But the authors rightly distinguish clearly between the "scientific revolutions" of normal science and the revolutions that, as epochal breaks, affect the entire system of the sciences, and which cannot be ruled out for the future.

Triple Helix

"Triple Helix" is the term with which Henry Etzkowitz and Loet Leydesdorff dub the model they propose for characterizing the *new institutional interactions* among the three societal subsystems of university, industry and government.[11] Accordingly, these three distinguishable areas constitute bi- and tri-lateral networks and hybrid organizations (Etzkowitz and Leydesdorff, 2000, 111 f.), which in turn affect the definition as well as the development of each subsystem, and their relations among each other. Within this structure, there are communicative processes that are constantly re-organizing themselves and bringing about an endless innovative movement in which all the elements are, so to speak, able to switch sides, and which is illustrated by the image of the Triple Helix escalating ever upward. The authors believe that the formation of this new structure, which occurred during

[9]The conception of science that Funtowicz and Ravetz label "classical" is, with respect to the theoretical understanding of validity, related to Mode 1 (Funtowicz and Ravetz, 1993, 198 and 120).

[10]Cf. the critique in Carrier (2001, 30).

[11]The authors have presented and elucidated their model in numerous publications. For an introduction, see Etzkowitz and Leydesdorff (1998, 2000).

the second half of the twentieth century, resulted from the increasing importance of scientific knowledge for *economic development*. With respect to the university, the central feature of the model in this context is the claim that the industrial relevance of knowledge led to a *second academic revolution*. During the first such revolution, which we are told dates back to the late nineteenth century, the universities added research to their already existing function as teaching institutions. During the second revolution, the universities have, according to these authors, added a third task, namely the production of economically useful knowledge.

I would like to advance two points of criticism against this model. The first addresses the *historical localization* of the beginning of the increase in economic importance of scientific knowledge. Some elements of the interactions described by the model can be traced back to the nineteenth century. Structures of the technical universities founded at that time, for example, can be viewed as hybrids of university, government and industry. In Germany, research units at these state-financed and academically organized universities began to work more extensively and more closely with industry in the 1880s.[12] The other point of criticism has to do with the insufficient consideration that is given to the *general conditions and consequences* for the production of knowledge in the twenty-first century that result in fact from the new relations obtaining among university, industry and government. Although these relations appear more clearly here than in other conceptions, Etzkowitz and Leydesdorff do not adequately account for their scope.[13] Regarding the general conditions, the globalization of economic processes and the exponential development of information technology can be regarded as most important. As for consequences for the production of knowledge, I would point to the partial privatization and commercialization of knowledge production, as well as to the capitalization of universities and to their management according to business principles, the market-oriented direction of research, the increase of competition among individual researchers and research groups, the rise in intensity of work in knowledge production, and the standardization of education. Insofar as Etzkowitz and Leydesdorff do address these consequences, it is in relation to the increase in communication and networking. In doing so, they lose sight of aspects that are connected to the differences among the subsystems and to the criticism of the formation of the Triple Helix dominated by economic interests.

The "second academic revolution" only transforms a part of modern science. Science remains not only distinct from other societal subsystems, but also retains its academic structure. While post-normal science presents a more extensive break than Mode 2, the second academic revolution is a *comparatively more minor historical change*. Accordingly, there is hardly any relevance given to precise estimates of the point in time when the Triple Helix arose (cf. Etzkowitz, 2004). The authors in question speak of an arising *evolution* of the relations among university, industry and

[12] Manegold (1969, 395 ff.), and Wengenroth (2003, 242 ff.).

[13] Cf. Elzinga (2004, 8 f.).

government instead of an epochal break (Etzkowitz and Leydesdorff, 2000, 109). Their notion of an "endless transition" implies the onset of a period of continuous progression.

Postmodern Primacy of Technology

Paul Forman's assertion of a "postmodern primacy of technology" demonstrates that preserving the demarcations among societal subsystems within a description of the current fundamental transformation need not entail the conviction that this transformation is devoid of a discontinuous historical dynamic.[14] Forman believes he can show that there was a "sudden and drastic shift ca. 1980 in cultural presuppositions" concerning the *relationship between science and technology*. In Forman's view, the cultural primacy of science relative to technology, which persisted in the west for 2,000 years (Forman, 2007, 2), has been inverted within an astonishingly brief period of time. Rather than dissolving the boundary between technology and science, the transformation has brought about a new orientation of the relations between them and therefore a continuation of their distinguishability. While Forman's model comes close to the Triple Helix model with respect to this distinguishability between societal subsystems, it differs in that it is restricted to the *level of cultural ascriptions*. Forman is concerned with the "general discourse, of the denotative capacities of the terms 'science' and 'technology'", for which the "actual, factual relationship between science and technology is relatively unimportant" (loc. cit. 4 and 6), whereas Etzkowitz and Leydesdorff deal with real structural changes.

In focusing on cultural ascriptions, Forman is seeking to do justice to the *comprehensive character* of the epochal break he postulates – a connection that is similar to the relation between historical scope and epistemic characteristics in the conceptions of Mode 2 and post-normal science. With the onset of the modern era, which preceded postmodernity, the concept of science that arose in antiquity came to an end. Forman ascribes to science and technology each a meaning in which it is specific to an individual epoch as well as a meaning that is *constant throughout history*. According to the latter, "science" signifies conceptions of the world, while "technology" refers to things that would also exist independently of our conceptions (loc. cit. 10). As a further historical constant, Forman implies also that science is concentrated upon the processing of means, whereas technology aims to achieve ends (loc. cit. 3 and 71). In the *modern era*, the concept of science took on the historically specific character of "pure science" serving the "disinterested pursuit of truth" (loc. cit. 43, cf. 12 f.). Forman's conception of modernity is similar to the notion of a classical conception that we encountered in the discussions of Mode 2 and post-normal science. Because of its subordinate status within this conception, technology was

[14] For a presentation and discussion of Forman's thesis, see, above all, Forman et al. (2007).

apparently at risk of losing its independent conceptual definitions. It was not until the postmodern *valorization of technology*, which Forman, invoking the historically constant distinction between means and ends, dubs a "pragmatic-utilitarian subordination of means to ends" (loc. cit. 2), that the specific characteristics of technology came clearly to light. Forman's concept of technology, however, remains quite general and indeed vague. Technology, for him, is "simply the collective noun for all the many ways things are in fact done and made" (loc. cit. 10). Such a broad definition does not distinguish between everyday practices and industrial technology, which is Forman's chief concern. Moreover, it has an ahistorical character that runs counter to the thesis of a transformation of science.[15] In Forman's defence, though, one may note that the breadth of the definition is no accident. Rather, it is intended to do justice to the epoch-making content of the transformation. At any rate, according to Forman's construal of the cultural discourse, postmodern science accords primacy to theory-independent practice, which is neutral with respect to specific societal interests.

The countless pieces of evidence with which Forman seeks to substantiate the two primacy-relations reveal that he thinks of the concepts of science and technology as persistently opposing coordinates during the epochal transition. But it is questionable whether the relations among interpretational patterns, which have existed for centuries as basic definitions, can really undergo a radical shift in a comparatively brief period of time. While in Forman's description the *putatively abrupt transition* from modernity to postmodernity is quite clear, the causes of this caesura remain unclear. The "cultural revolt of the 1960s", which Forman cites as the cultural source of the reversal of primacy relations between science and technology, cannot in itself be regarded as sufficient, since it occurred 20 years before the beginning of the epochal break, and Forman gives no reasons to explain its supposedly delayed impact (loc. cit. 5). Moreover, one would have to inquire into the causes of this event as well.[16]

An assertion of an epoch-making change that is confined to cultural interpretive patterns is not plausible. Changes in the development of these patterns are indeed significant, but they constitute not sufficient conditions for epoch-making new conceptions of the sciences. Such new conceptions are *comprehensive* in the sense that they include various dimensions of knowledge production: its institutional structures, interactions with other societal systems, methods, theories and practical procedures, as well as related cultural interpretive patterns.

[15] Kline (2007) makes a similar argument against Forman's concept of technology.

[16] Forman regards the "demand for 'relevance' of science" (Forman, 2007, 5) as an aspect of the "cultural revolt of the 1960s" that helped prepare the way for the epochal break. He could have pointed to the "finalization-theory" as an example of this, but he assigns this theory to modernity in his sense (loc. cit. 47). Weingart, however, has shown that it, like Mode 2, is directed toward the context of application.

Second Modernity and Knowledge Society

Some of the prerequisites to the concept of an epochal transformation can also be encountered in descriptions of current fundamental changes in the sciences that do not claim a discontinuity, or do so only in a qualified manner. Such descriptions are well-suited to characterize the constitutive elements of an epoch and of a possible transformation within this framework.

The *conception of the "second modernity"* is a paradigmatic example of this. Its proponents speak of a profound "structural transformation of the system of science", brought about by the "displacement of the primacy of reflection to reflexivity". At the same time, they emphasize that there is "no complete break in the process of modernization" (Beck and Lau, 2004, 20 and 183).[17] In the second half of the twentieth century, they say, a process began in the sciences as well as in other societal subsystems and in the relations among them, by which the hitherto dominant reflective form of rationality itself became the object of reflection, and thereby entered into the state of reflexivity. The partial discontinuity connected with this change is understood with reference to the distinction between basic principles and basic institutions. The latter are "institutional solutions" that aim in different ways to realize the guidelines implied by the former. It is only these institutional solutions and not the basic principles that are undergoing a discontinuous transformation. In other words, modernity is marked by a set of principles that have in themselves remained constant, but which have been *understood* differently during the different developmental phases they have gone through so far – namely, during the first and the second modernity, the latter having arisen in the second half of the twentieth century. One example has to do with the institutional role of the sciences in the discourse concerning the orientational function of the distinction between nature and society. While the determination of this distinction "in the first modernity clearly counts among the tasks of science, this demarcation and its justification are pluralized in the second modernity" by the influence of other institutions, civil society, the state and the market (loc. cit. 21, cf. 65 ff.). If one accepts the theory of the second modernity, the *transformation* of basic principles would constitute a sufficient condition for an epochal break.

To name another example of a claim of continuity, the *theory of knowledge society* describes new components of the order of knowledge, which consist above all in the "increase of practical relevance of science" for society, but do not present "a fundamental or qualitative break" with the order of knowledge existing since early modern times (Weingart et al., 2007, 33). The continuities claimed by this theory are more far-reaching than those claimed by the proponents of the notion of the second modernity. They are not limited to general conditions that are related to the basic principles of the second modernity (e.g., epistemic orientation, ideological neutrality of research) in their fundamentally guiding function. Rather, they also include

[17] Programmatic presentations of this view are found in: Beck and Bonß (2001) and Beck and Lau (2004).

institutional facts, such as the system of the disciplines (loc. cit. 41 ff. and 182 ff.) and the distinction between basic and application-oriented research (loc. cit. 31 ff. and 97 ff.). It is an open question what kind of dissolution of the continuity would lead to a new order of knowledge and whether the establishment of such a new order would constitute an epoch-making event.

The Concept of an Epochal Change in the Development of Science

With the exception of Forman's conception of postmodern science, the aforementioned characterizations of current fundamental changes in the development of science make claims that are not limited to a transformation of cultural interpretive patterns. For the most part, they start out from investigations within *sociology of science* dealing with structural changes in the institutional constitution of the scientific production of knowledge, and derive transformations of the epistemological characterizations of scientific knowledge. The depth of the transformation, according to the conceptions of Mode 2 and post-normal science, is precisely reflected in the scope of the breakdown of classical epistemological characterizations of the sciences. It is worth noting, however, that this breakdown is also taken up in Forman's conception.

Having surveyed various claims of an epochal break, it is apparent that the changes that are under discussion are, as a general rule, presently in a *beginning stage*, and are focused on a *subarea of the sciences*. The authors tend to anticipate that the emerging new characteristics will *in the long run* take on a leading role in the sciences. Hence, Mode 2 and post-normal science are said to establish themselves alongside their predecessors and, without undermining a continued relevance of these predecessors, to stake a claim upon the guiding function that has until now belonged to them. The Triple Helix model starts out from a particular sphere of knowledge production, namely the areas that produce economically useful knowledge. Forman's thesis can also be understood as relating to a restricted beginning of a more comprehensive process. The epochal change is initially limited to a (former) subarea of science, namely technology, and its cultural interpretive patterns. Subsequently, the change could progress to other subareas and no longer be limited to the cultural dimensions of science.

My definition of the *concept of an epochal change in the development of science* refers in a twofold sense to the aforementioned claims. It takes up the relationship between subareas and the entirety of science (Section a) and seeks to do justice to the possible long-term character of the transformations under discussion (Section b). Moreover, the concept I am proposing incorporates conditions for the description of an epochal change (Section c). Alongside the current changes that I have been discussing, a further point of reference for the treatment of these three issues is presented by the early modern beginnings of modern science, the epoch-making character of which is largely uncontroversial in the literature on the history of

science.[18] The concept of an epochal change is specific, since it refers to particular historical events and seeks to descriptively characterize their common features.[19]

(a) *Epochal changes begin in a subarea of science and proceed to transform the entire system of the sciences.* They are comprehensive, since they change the concept of science and affect various (cultural, societal, institutional, theoretic, practical) dimensions of scientific activity. The term "subarea of science" is intended to pick out the restricted character of the beginning of epochal changes. The restriction can refer to certain disciplines, theoretical or methodical aspects, objects of inquiry, or relations to other subsystems.[20] Epochal changes that affect the entire system of the sciences from the outset may be imaginable, but they are as yet unknown in the history of science.

I would like to discuss this part of the definition using the example of the *early modern epochal transformation*. It took its departure within a subarea, namely within certain physical disciplines (above all astronomy, mechanics and optics), which subsequently rose to become the very paradigm of scientific soundness.[21] Among the new elements incorporated in the concept of physical science were the transformed understandings of the relations obtaining between nature and technology, physics and mathematics, experience and theory, as well as the invention of the experimental method. While these new elements were only partially applied to concepts of science in other disciplines, the concept of physics, on the other hand, was still compelled to make reference to existing criteria, which stemmed from the classical conception of science and were valid for other disciplines as well. The specific nature of this mutual interaction is crucial for determining whether the transformation is of an epochal nature. Hence, referring to the restricted scope of the transformation which began in physics could lead to an argument against regarding it as epoch-making. Did the early modern transformation of physics not lead more to a dissolution of the systematic connectedness of the sciences than to an upheaval of the system of the sciences? One might recall in this context the early modern formation of dichotomies, for which the conception of the two cultures has been described as an ideal-type. But, contrary to this line of thought, one could object

[18] For an overview of the literature on the history of science concerning the early modern transformation, see Cohen (1985), Cohen (1994) and Shapin (1998). The genesis of modern science can be seen as part of an epochal change that also affected other societal subsystems – an assumption which can hardly be regarded as controversial either. Skalweit (1982) gives a presentation of this broader process that is still well-regarded today.

[19] I am borrowing this characteristic from Cohen (1994, 21), where it is applied to the concept of the scientific revolution in early modern times, in contrast to the concept of scientific revolutions introduced by T.S. Kuhn as a general structural feature of scientific development.

[20] These possibilities are intended to do justice to the aforementioned conceptions of a current epochal change as well to reconstructions of the early modern epochal change.

[21] That the early modern epochal change was initially restricted to certain subareas of physics is a view that has not until recently become established in the literature on the history of science. In the middle of the twentieth century, the influential studies by Butterfield (1949) and Hall (1954) assumed that the epochal change affected the entire system of the sciences from the very outset. For a critique of this view, see Cohen (1994, 121 ff.), and Shapin (1998, 80 ff.).

that the methods of disciplines that were similar to today's humanities also underwent a profound change in the wake of the early modern epochal transformation, and thereby remained integrated in the system of the sciences. In particular, the valorization of experience vis-à-vis theory, which was initiated by this transformation, also made its way into the concept of science in these other disciplines.

Epochal transformations presuppose the existence of a *system of the sciences* and lead to its re-orientation or vitiation. With the dissolution of the system of the sciences, as it is assumed in connection with the irreducible heterogeneity of the sciences in the conception of Mode-2 or post-normal science, the concept of an epochal change in the development of science itself runs up against a limit. But, as long as this is not the case, epochal changes in the development of science are distinct from fundamental *changes within a discipline or a group of disciplines*. The latter do not have the comprehensive character of the former. Although they can effectuate the abandonment of epistemological prerequisites and the introduction of new elementary assumptions, they can not force the identity of the entire movement to an end.[22] This identity, which is set out in the very concept of science, is precisely the object of epochal changes in the system of the sciences.

(b) The fact that epochal changes consist in the unfolding of the influence of one subarea upon other areas of science has consequences for the spectrum of possible dynamics of these changes. Much *longer periods of time* can be necessary for the spread of new conceptions throughout the system of the sciences than for the appearance of fundamental changes in a subarea. In particular, the progression of an epochal change need not be entirely discontinuous. I would therefore like to *avoid committing to a specific form of progression in formulating the concept of an epochal change.*

One also finds arguments in favor of this kind of openness in the aforementioned descriptions of recent epochal changes. They only claim a discontinuous appearance of new conceptions with respect to individual subareas, not to the preceding genesis of the conditions for new forms of knowledge. Since these processes cannot be distinguished clearly from the genesis of the new conceptions, it is advisable to incorporate their element of continuity in the concept of an epochal change. Another reason for including the gradual form of progression is the fact that the descriptions I have been discussing have yet to demonstrate a break in the transformation of the entire system of the sciences. Indeed, older forms of knowledge – such as Mode 1 or normal science – are integrated into the system and assure an element of continuity. Moreover, the transformation of the entire system has generally not advanced far enough that the form of its progression could conclusively be judged.[23] Against this backdrop, the use of the term "epochal break" appears problematic. It would only

[22]Blumenberg (1976, 16), and Footnote 19.

[23]That goes for the assessment of the epochal nature of a change, not just for its form of progression: Cf. the third part of the definition of the concept of an epochal change, which follows below.

be justified if the entire impact of an initiating event upon the system of the sciences were of a discontinuous nature.

Finally, the fact that one need not conceive of the progression of an epochal change as discontinuous is demonstrated by historians' reception of the early modern epochal transformation. In general, a discontinuous form of progression is not ascribed to the transformation of early modern physics or to its consequences for the other areas of science.[24]

(c) *For contemporaries, epochal changes in the development of the sciences might be observable only to a limited extent.* The concept refers to observations of individual events, which can only be attributed an epochal character once they have been brought into connection with a presumably comprehensive transformation.[25] Insofar as the epochal character depends upon the consequences of new conceptions upon the entire system of the sciences, it can only be evaluated once these consequences have reached a certain stage of development. If the epochal changes are spread out over a long period of time, it can be problematic for contemporaries to observe them. The transformation can proceed so slowly that its epochal character cannot be inferred in an unqualified sense.[26]

Epoch-making transformations in the production of scientific knowledge go hand in hand with observable structural changes, but also include the appearance of new patterns of interpretation, which evaluate states of affairs in novel ways and are incorporated in the description of the structural changes. This *normative element* makes its way into the conceptions under discussion as well. These conceptions ascribe great importance to the changes they describe and call for support – as the paradigmatic title "Re-Thinking Science" illustrates (Nowotny et al., 2001) – for the completion of the transformational process. Their descriptions, which are meant to refer to a desirable concept of science that so far only applies to certain branches of science, are understood as part of the transition (cf. loc. cit., 64, 168, 180, 184 and 192).

Hence, observers of epoch-making transformational processes not only bear witness to but are also potential creators of these processes. In order to do justice to the relations obtaining between descriptive and normative elements of the concept of an epochal change, it is advisable to include in the concept the *conditions for witnessing it*. A good point to set out from in this direction is I.B. Cohen's distinction

[24]Cohen (1994, 147 ff.), discusses the relationship between continuous and discontinuous elements; Shapin (1998) denies that the entire beginning of early modern science had a revolutionary character; Cohen (1985), on the other hand, ascribes just such a character to this episode in the history of science.

[25]The conditions for observability of a transformation include not only objective conditions that cannot be influenced but also subjective conditions. The latter are discussed in Nordmann (2008). The two, taken together, allow the observation of a transformation only when there is a suitable distance between the epistemic subject and its object.

[26]I think Blumenberg goes too far with his claim that there can in principle be no witnesses to such events since epochal changes proceed at a slow pace (Blumenberg, 1976, 20). But one must agree with him when he claims that an epochal change can have a discontinuous progression even if it proceeds too slowly to be observed.

of four types of observations of scientific events: 1. The "judgment of scientists and non-scientists" [of the period in question . . ., 2. the] examination of the later documentary history of the subject [. . ., 3.] the judgment of competent historians [. . .and 4.] the general opinions of working scientists in the field today (Cohen, 1985, 41 ff.). Cohen applies these types "quite generally to all of the more significant scientific events of the last four centuries", and thereby also to fundamental changes within a discipline as well as to changes that effect the entire system of the sciences (loc. cit. 40 f.). The latter kind of change is exemplified by the early modern scientific change (loc. cit. 77 ff.). He refers to his types as tests for assessing whether a fundamental change occurred in a discontinuous fashion. They can also be invoked to determine whether a given change is of an epochal nature. The presence of an epoch-making change should be corroborated by all four types. The absence of one of the types would call for special justification.

Applied to the claims of a current epochal transformation, the first and fourth type partly collapse into one another, while the second and third are only available in a limited sense. Regarding the third type, the judgment of competent historians, Cohen mentions only examples of presentations that appeared long after the relevant events (loc. cit. 43). But there is no reason why one could not also look at contemporary presentations. To a certain extent, current descriptions being offered by sociologists of science, which I would classify as belonging to type 1 or 4, overlap with historical studies.[27] In general, though, the question whether epoch-making changes in science are currently taking place is not a central topic in the literature on the history of science.[28]

In summary, we can hold on to certain features of the concept of an epoch-making change: it is a matter of a comprehensive, not necessarily discontinuous, transformation of science, which starts in a subarea of science and spreads from there. Epoch-making changes lead to new concepts of science. They must be attested to in various ways, and can only be evaluated satisfactorily when the interactions between the subarea and the entirety of science have sufficiently taken shape. Insofar as the phenomena invoked in current descriptions of epoch-making changes have not yet affected the entire system of the sciences, these claims take on a *hypothetical character*. The discontinuity-claim in these descriptions refers only to a subarea of science and can only be demonstrated for this subarea. In other words, current observers lack the requisite distance to be able to assess conclusively whether a discontinuous form of progression and an epoch-making character can be ascribed to a process comprehending the entire system of the sciences.

[27] Historically oriented arguments are given above all by P. Forman, as well as B. Latour and D. Haraway in their conceptions of technoscience.

[28] In the historiography of science, people do not speak as much of an epochal break in current science as they do of certain recent transformations in the historical description of science (e.g. the experimental, practical and cultural turns), cf. Hagner (2001).

Candidates for the Status of Epochal Transformations in the Recent Development of the Sciences

It is characteristic of the subareas of science to which the aforementioned claims of an epochal transformation refer that they *are correlated with other societal subsystems*. This commonality expresses the *orientation toward praxis* that is typical of the current transformational process in general. Mode-2 science is connected in the context of application to various societal subsystems (technology, industry, the state, the public, culture, etc.); post-normal science is policy-related research; in the Triple Helix model, the significance of the relationships obtaining among science, the state and industry is reflected in the title of the conception; Forman's thesis places the relationships between science and technology at center-stage. Regarding the areas of physics from which the early modern epochal transformation took its departure, one can also establish the mark of an orientation toward practical contexts. Astronomy, mechanics and optics, for example, were closely tied to technical traditions of craftsmanship, which were of fundamental importance in developing experimental science. Although the transformational processes in science cannot be fully grasped simply by appealing to their relations to other societal subsystems, and although multifarious internal conditions also played a constitutive role, these relations are nevertheless *helpful guidelines* in investigating the possible epoch-making character of the current changes in science.

In order to make use of this orientational function, I would first like to clarify the extent to which the structure of societal subsystems is itself the object of a fundamental transformation. Do the traditional or *modern classifications* of these subsystems still present a suitable basis for describing the interaction of society and science? As I have already mentioned, the authors of Mode 2 believe that they can demonstrate "the erosion of modernity's stable categorizations – states, markets and cultures" (Nowotny et al., 2001, 245). The context of application has, in their view, taken the place of a part of the previously existing structure of interactions between science and society. But they themselves are not fully able to make good on the claim of a dissolution of the demarcations. Science and society remain separate insofar as their transformation is described as a "co-evolutionary" process (loc. cit. 30 ff.). The state, the market and culture have not so much fundamentally declined as categories but instead have become invested with new definitions (loc. cit. 22 ff.).

Other conceptions of a recent epoch-making transformation appeal – in my view, rightly – to the categories of modernity in characterizing the changes they observe. That is obviously true of the Triple Helix, the postmodern primacy of technology and the knowledge society.[29] It is less obvious for post-normal science and for second modernity. The conception of post-normal science describes border infractions between science and neighboring subsystems, which bears a certain resemblance

[29] The conception of the knowledge society separates the production of knowledge from the areas of politics, economics, the media, the law and technology (Weingart et al., 2007, 13 ff.).

to Mode 2.[30] But it remains focused on a new concept of science that does not significantly affect the traditional definitions of technology, industry, politics and the public.[31] These definitions are still not given up by proponents of the second modernity either; rather, they lose their uniform character and are pluralized in ways depending on different discourses and decision procedures.

If one differentiates the current transformational processes in science according to the societal subsystems to which they relate, differences in the *respective historical origins* of the processes appear. In the following, I will be guided by an ideal-type schema, which takes up not only the changes addressed by the conceptions I have been discussing, but also changes not taken into consideration within these conceptions. My account groups the societal relations of science into the *areas of technology, industry, the state and the public.*

Science and Technology

The relationship between science and technology that is largely constitutive of today's concept of science can be traced back to the *early modern epochal transformation.* Among its essential achievements is the insight that technology, just like nature, can be made an object of scientific investigation. Looking at the ensuing relationship between science and technology, people have labeled these two societal subsystems twins.[32] The characterization of the current relations obtaining between science and technology as "technoscience" can also be traced back to early modern times.[33]

Forman's thesis, according to which technology has won primacy over science, does not have an epochal dimension insofar as it is limited to cultural interpretive patterns. It does however take on certain aspects of a transformed concept of science, which indeed can be regarded as aspects of *a possible future epochal transformation.* In Forman's view, science, given the primacy of technology, is no longer governed by the epistemological goal of truth or by methodological provisions, but by pragmatically established ends. To put it succinctly, truth becomes a means to technical ends. This kind of pragmatism has not been established within the currently dominant concept of science.[34] Furthermore, one must bear in mind that the

[30] For example, Funtowicz and Ravetz (1990, 752 f.), cf. Elzinga (2004, 10).

[31] Cf. Funtowicz and Ravetz (1993), in which technology, culture and science are separated early on (loc. cit. 85); while science is distinguished from policy (loc. cit. 87 and 90 ff.) and professional consultancy (loc. cit. 96 ff.) and brought into relation with the public (loc. cit. 109 f.).

[32] Jacob (1997, 9), Layton (1971), cf. Wegenroth (2003, 230 and 244).

[33] Carrier (2008).

[34] In determining the current concept of science, one can refer to the types of observation sketched by I.B. Cohen (cf. section "The Concept of an Epochal Change in the Development of Science" above), above all to the judgment of scientists, including philosophers of science. Representative presentations that discuss the concept of science are offered by Bartels and Stöckler (2007), Schurz (2006) and Carrier (2006).

relation to technology only marginally determines the concept of science in some disciplines, such as literary theory, history and religious studies.

Science, the State and Industry

The formation of the current structural relations among science, the state and industry *began in the nineteenth century.* Scientific knowledge, at that time, was systematically built into large-scale industrial production-processes (above all chemistry and electrical engineering). The state founded the organization of the professional education of young scientific and technical researchers, and began the massive funding of experimental research. State institutions regulated the use of scientific and industrial technology. As I have argued elsewhere, the formation of the relations among science, the state and industry were closely tied to criticism and relativization of the meaning of the classical features of science. The classical conception lost its previous validity earlier than is supposed by current assertions of an epochal break.[35] In a nutshell, one could say that the real epistemic insight in science in the nineteenth century was the discovery that science can be socially quite useful even if epistemological questions, which had the highest priority in the classical conception, were left unanswered.

In my view, though, it is not yet possible to determine whether the transformational process in science, which goes hand in hand with the formation of relations among science, the state and industry, can be considered in its own right an epoch-making transformation of science. It appears not yet to be clear whether the orientation of science toward the realization of its potential social or economical utility might in fact be a *continuation of the early modern relationship between science and technology.* One point that speaks against this possibility is the connection that exists between the formation of the relations among the three subsystems and the criticism of the classical conception of science that was paradigmatic from antiquity until the nineteenth century. The loss of validity of the classical conception points back to an epoch-making dimension of the transformational process at work in science in the nineteenth century. It is worth asking, though, whether the consequences of this process upon the system of knowledge *reach all the way into the present* and therefore cannot yet be regarded as a completed development. Hence, some features of science that are demonstrated by the Triple Helix model, for example, can be understood as consequences of the relations that were brought about in the nineteenth century.[36] Moreover, the discussion over the classical conception has persisted into the present. Some tendencies of the debate suggest a renaissance of this conception of science – among them, for example, would be Positivism, which restricts scientific knowledge to observable phenomena, Pragmatism, which derives

[35] Cf. Schiemann (1995, 2008, 2009).

[36] See above, section "Triple Helix".

truth from the success of scientific theories, and Scientific Realism, according to which scientific knowledge gradually approaches the truth.

It would constitute a new, perhaps epoch-making constellation in the context of the relations among science, the state and industry, if one of the subsystems involved were to take over the *leadership* and if its boundary to science were to be vitiated. Some of the phenomena under discussion – such as privatization, commercialization, and commodification of knowledge production – suggest that the economic influence arising from industry could attain primacy.

Science and the Public Domain

The relationship between science and the public domain has come to the center of interest in recent years in disciplines reflecting upon science.[37] The current attention could have to do with a transformation that in particular Mode 2 describes. At the center of the new structures that are taking shape, in which scientific, technical, economic and political forces come together in various ways, the authors of Mode 2 place the so-called "*agora*". The agora is conceived as the space of an informed public, highly influenced by the media, which demands socially useful knowledge from science, and before which science presents and sometimes justifies its activities. The public domain and science not only act upon each other, but also face each other as different discourse systems.

In this constellation, which goes back to the second half of the twentieth century, we can perhaps see a re-organization or even a *reversal of the previous relationship between science and society*. Early modern science was initially an elitist endeavor, which was only accountable to itself (cf. the "House of Solomon" in Francis Bacon's "New Atlantis"). Through the formation of the relations obtaining among science, industry and the state, the institutional autonomy of science was restricted in the nineteenth century, but the definitional power which shielded it from external criticism was not. On the contrary, scientific knowledge enjoyed a great reputation.[38] It was not until the pluralization of knowledge in the twentieth century, as described in the theory of the second modernity, that the presently typical acknowledgment of the equal validity of various kinds of knowledge came about. Through this process, scientific methods and projects became disputable objects of public debate.

The discussion of the social utility of scientific knowledge that arose in this context took shape, as various authors have noted, in such a brief period that it does not

[37] For the history and philosophy of science, this widespread interest is reflected in the numerous entries on "science and the public domain" in relevant databases for journal articles. For the history of science, that would be, for example, "Eureka", organized by the History of Science Society, and for the philosophy of science, "The Philosopher's Index 1940–2007". For sociology of science, cf. Weingart (2005).

[38] Cf. Daum (1998).

seem far-fetched to speak of a discontinuity.[39] This beginning phase can be characterized with reference to the issues of depletion of natural resources (beginning the 1970s with the oil crisis and the movement against nuclear energy) and – closely connected with this – the destruction of the natural environment (especially in the context of the discussion of climate change since the 1980s).[40] The focal points of debates up until now reveal that *existential questions for humanity* constitute an important impulse for public interest in scientific knowledge. It is not only the hope of a solution to existing life-threatening problems, but also the fear that the application of scientific knowledge could threaten the foundations of human existence, that leads non-scientists to participate in the public discourse on science.[41]

It is indeed only since the previous century that scientific technology has the (epoch-making new) potential to threaten the continuance of human life at a global level. It has made possible planned and irreversible transformations of nature, which could to a large extent destroy the conditions of life on earth.[42] The paradigmatic example of the qualitatively higher-order means of intervention is the scientifically constructed potential for destruction by means of *military weaponry*, which could undermine the further existence of the human species with one stroke. Insofar as science is among the societal subsystems that have participated in the construction and the implementation of this potential for violence, the relationship between science and the public domain is still asymmetrical. Public discourse offers the opportunity to counteract this asymmetry.

In what way could public discourse contribute to a re-organization of the relationship between science and society, such that the concept of science would thereby be changed? Instead of discussing this far-reaching question here, I would like to limit myself to referring to two approaches to bringing to light the possibility of a transformation of our understanding of science by way of the public discourse. The first approach is presented by *participatory models*, in which the individuals affected by a line of research are involved in the production and application of relevant scientific knowledge. The participation of the affected individuals has an influence, in turn, upon the structure of the production and application of knowledge exactly when the participation is mediated by the public domain, as is paradigmatically illustrated by the formation of "recursive learning processes" in the so-called "real world experiments".[43] On the other hand, public discourse can contribute to the choice of goals for the application of scientific knowledge and to the transformation of the ethical attitudes of scientists. These potentialities of the relations between science and the public domain can be observed in the case of Janet Kourany's program of *socially*

[39] Beck (1986, 254 ff.). Funtowitz and Ravetz (1993, 109 f. and 117).

[40] Nowotny et al. (2001, 15 ff.), Funtowicz and Ravetz (1993, 95 and 110 ff.).

[41] Cf. Office of Science and Technology and Wellcome Trust (2000), EU-Kommission (2001).

[42] From among the conceptions that I have been discussing, it is especially the second modernity that addresses the "irreversible endangerment of the life of plants, animals and humans" (Beck, 1986, 17).

[43] Groß et al. (2005).

engaged and responsible science.[44] In this context, public discourse is a forum in which non-epistemic values involved in knowledge are formulated, demands for the production of socially relevant knowledge are made, and scientists report on the utility of their results. In order to be efficacious, though, the relationship between the public domain and science would have to be incorporated in the institutional structure of science.

Conclusion

The epochal-break-thesis is based on verifiable, probably quite far-reaching, changes that have recently been occurring in the production of knowledge and in our understanding of what it means to be scientific – at a global level, but especially in the developed industrial countries. On the whole, there are enough phenomena to make it appear not implausible to think of a fundamental transformation, perhaps even of an epoch-making discontinuity in the development of science. Scientific objects, for example, have attained to new levels of complexity; they permeate ever more areas of life; on the other hand, science, by being subjected to economization and to public criticism, is losing the autonomous status that it has enjoyed since antiquity.

Nevertheless, there are substantial reasons that speak against the claims of a current epochal break. The prerequisite of my criticism is a more precise concept of an epoch-making transformation than is currently in use. The concept I propose takes up the relations obtaining between, on the one hand, the subareas from which new conceptualizations of science emerge, and on the other hand, the entirety of science, to which the concept of an epoch-making transformation is applied. It also incorporates the conditions of observability of transformational processes. Applied to the current changes at issue, it becomes apparent that some of them do indeed have an epoch-making character, but that they have historically earlier origins. Other changes are so recent that it is not yet possible to tell whether they have an epoch-making character. In part, the current changes involve discontinuous factors, but there are also opposing indices pointing to the far-reaching influence of continuous elements in the development of science.

Hence, it is difficult to attain a comprehensive overview of the situation. The convoluted, even contradictory, relations can at least be regarded as possible signs of a transformation of the whole system of the sciences. At present, there are different conjectures that can be made about the future development. I have grouped together some hypotheses about this development according to the relations between science and other subsystems. Roughly, the results can be summarized in two conclusions. *First*, the relations obtaining among science, technology, the state and industry can essentially be traced back to the nineteenth century or to earlier phases of modernity. Fundamental re-conceptualizations could come about in these contexts if one of the non-scientific subsystems were to take over a position of priority vis-à-vis science. Forman assumes that this has already taken place for technology. The conception of the Triple Helix addresses phenomena that suggest that an economic interest emerging from industry could assume primacy vis-à-vis science. *Secondly*, certain aspects of the current public discourse on science do not have a comparably early historical origin. Although the sciences have been an object in the public domain since the beginning of modern times, the ways of understanding science that have been formulated in this discourse since the twentieth century cannot be reduced to those origins. In their social orientation, the viewpoints presented in the public domain stand in contrast to economic interests. Hence, it seems that divergent directions are open to the further progression of the transformational process of science.

[44] Kourany (2003) formulates this program, which refers to science as a whole, with the help of the example of philosophy of science. The public dimension is introduced through the reference to the feminist critique of science, which she develops throughout.

References

Bartels, A., and M. Stöckler. 2007. *Wissenschaftstheorie: ein Studienbuch*. Paderborn: Mentis.

Beck, U., and C. Lau (eds.). 2004. *Entgrenzung und Entscheidung: was ist neu an der Theorie reflexiver Modernisierung?* Frankfurt am Main: Suhrkamp.

Beck, U., and W. Bonß (eds.). 2001. *Die Modernisierung der Moderne*. Frankfurt am Main: Suhrkamp.

Beck, U. 1986. *Risikogesellschaft: auf dem Weg in eine andere Moderne*. Frankfurt am Main: Suhrkamp.

Blumenberg, H. 1976. *Aspekte der Epochenschwelle: Cusaner und Nolaner*. Frankfurt am Main: Suhrkamp.

Butterfield, H. 1949. *The Origins of Modern Science: 1300–1800*. London: Bell.

Carrier, M. 2001. Business as usual: On the prospects of normality in scientific research. In *Interdisciplinarity in Technology Assessment. Implementation and its chances and limits*, ed. M. Decker, 25–31. Berlin: Springer.

Carrier, M. 2006. *Wissenschaftstheorie zur Einführung*. Hamburg: Junius.

Carrier, M. 2008. "Knowledge is power," or: How to capture the relations between science and technoscience. Manuscript.

Cohen, H.F. 1994. *The Scientific Revolution: A Historiographical Inquiry*. Chicago, IL: Chicago Press.

Cohen, I.B. 1985. *Revolution in Science*. Cambridge, MA: Belknap Press.

Daum, A. 1998. *Wissenschaftspopularisierung im 19. Jahrhundert: bürgerliche Kultur, naturwissenschaftliche Bildung und die deutsche Öffentlichkeit, 1848–1914*. München: Oldenbourg.

Elzinga, A. 2004. The New Production of Particularism in Models Relating to Research Policy: A Critique of Mode 2 and Triple Helix. Contribution to the 4S-EASST Conference, Paris. www.csi.ensmp.fr/WebCSI/4S/download_paper/download_paper.php?paper=elzinga.pdf. Accessed 21 August 2008.

Etzkowitz, H., and L. Leydesdorff. 1998. The endless translation: A Triple Helix of university-industry-government relations. *Minerva* 36:271–288.

Etzkowitz, H., and L. Leydesdorff. 2000. The dynamics of innovation: From national systems and "Mode 2" to a triple helix of university-industry-government relations. *Research Policy* 29:109–123.

Etzkowitz, H. 2004. The evolution of the entrepreneurial university. *International Journal of Technology and Globalisation* 1:64–77.

Europäische Kommission, Generaldirektion Forschung. 2001. Wissenschaft und Technik im Bewusstsein der Europäer: Eurobarometer 55.2. Brüssel. http://ec.europa.eu/public_opinion/archives/ebs/ebs_154_de.pdf. Accessed 21 August 2008.

Forman, P. et al., 2007. Responses to Forman. *History and Technology* 23:153–184.

Forman, P. 2007. The primacy of science in modernity, of technology in postmodernity, and of ideology in the history of technology. *History and Technology* 23:1–152.

Funtowicz, S.O., and J.R. Ravetz. 1990. *Uncertainty and Quality in Science for Policy*. Dordrecht: Kluwer.

Funtowicz, S.O., and J.R. Ravetz. 1993. The emergence of post-normal science. In *Science, Politics and Morality: Scientific Uncertainty and Decision Making*, ed. R. von Schomberg, 85–123. Dordrecht: Kluwer.

Funtowicz, S.O., and J.R. Ravetz. 1994. Uncertainty, complexity and post-normal science. *Environmental Toxicology and Chemistry* 12:1881–1885.

Funtowicz, S.O., and J.R. Ravetz. 2001. Post-normal science. Science and governance under conditions of complexity. In *Interdisciplinarity in Technology Assessment. Implementation and its chances and limits*, ed. M. Decker, 15–24. Berlin: Springer.

Gibbons, M. et al., 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. London: Sage.

Gibbons, M. et al., 2003. Introduction: 'Mode 2' revisited: The new production of knowledge. *Minerva* 41:179–194.

Groß, M. et al., 2005. *Realexperimente: ökologische Gestaltungsprozesse in der Wissensgesellschaft*. Bielefeld: Transcript.

Hagner, M. (ed.). 2001. *Ansichten der Wissenschaftsgeschichte*. Frankfurt am Main: Fischer.

Hall, A.R. 1954. *The Scientific Revolution 1500–1800: The Formation of the Modern Scientific Attitude*. London: Longmans, Green.

Ihde, D., and E. Selinger (eds.). 2003. *Chasing Technoscience: Matrix for Materiality*. Bloomington, IN: Indiana Press.

Jacob, M.C. 1997. *Scientific Culture and the Making of the Industrial West*. New York, NY: Oxford Press.

Kline, R. 2007. Forman's Lament. *History and Technology* 23:160–166.

Kourany, J.A. 2003. A philosophy of science for the twenty-first century. *Philosophy of Science* 70:1–14.

Layton, E. 1971. Mirror-image twins: The communities of science and technology in 19th-century America. *Technology and Culture* 12:562–580.

Manegold, K.-H. 1969. *Zur Emanzipation der Technik im 19. Jahrhundert in Deutschland*. München: Bruckmann.

Nordmann, A. 2008. The age of techno-science. Manuscript.

Nowotny, H. et al., 2001. *Re-thinking Science: Knowledge and the Public in an Age of Uncertainty*. Cambridge, MA: Polity Press.

Nowotny, H. 1999. *Es ist so. Es könnte auch anders sein: über das veränderte Verhältnis von Wissenschaft und Gesellschaft*. Frankfurt am Main: Suhrkamp.

Nowotny, H. 2006. Real science is excellent science – How to interpret post-academic science, Mode 2 and the ERC. *Journal of Science Communications* 5(4). http://jcom.sissa.it. Accessed 21 August 2008.

Reichle, I. 2004. Transgene Körper. Kunst im Zeitalter der Technoscience. www.muthesius-dmi.de/react/media/MKN_TransgeneKoerper.pdf. Accessed 21 August 2008.

Schiemann, G. 1995. Am Ende der Endgültigkeit. Friedrich Engels' Kritik des Geltungsanspruches der naturwissenschaftlichen Erkenntnis. *System und Struktur* III(1):83–98.

Schiemann, G. 2008. We are not witnesses to a new scientific revolution. Manuscript.

Schiemann, G. 2009. *Hermann von Helmholtz's Mechanism: The Loss of Certainty. A Study on the Transition from Classical to Modern Philosophy of Nature*. Dordrecht: Springer.

Schnädelbach, H. 1983. *Philosophie in Deutschland 1831–1933*. Frankfurt am Main: Suhrkamp.

Schurz, G. 2006. *Einführung in die Wissenschaftstheorie*. Darmstadt: Wissenschaftliche Buchgesellschaft.

Shapin, S. 1998. *The Scientific Revolution*. Chicago, IL: Chicago Press.

Skalweit, S. 1982. *Der Beginn der Neuzeit: Epochengrenze und Epochenbegriff*. Darmstadt: Wissenschaftliche Buchgesellschaft.

The Office of Science and Technology Policy (OSTP). 2000. Science and the public: A review of science communication and public attitudes to science in Britain. http://www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_peda/documents/web_document/wtd003419.pdf. Accessed 21 August 2008.

Weber, J. 2003. *Umkämpfte Bedeutungen: Naturkonzepte im Zeitalter der Technoscience*. Frankfurt am Main: Campus.

Weingart, P. et al., 2007. *Nachrichten aus der Wissensgesellschaft: Analysen zur Veränderung der Wissenschaft*. Weilerswist: Velbrück.

Weingart, P. 1997. From "finalization" to "Mode 2": Old wine in new bottles? *Social Science Information* 36:591–613.

Weingart, P. 2005. *Die Wissenschaft der Öffentlichkeit: Essays zum Verhältnis von Wissenschaft, Medien und Öffentlichkeit*. Weilerswist: Velbrück.

Wengenroth, U. 2003. Science, technology, and industry. In *From Natural Philosophy to the Sciences. Writing the History of Nineteenth-Century Science*, ed. D. Cahan, 221–253. Chicago, IL: Chicago Press.

Ziman, J. 2000. *Real Science: What It Is, and What It Means*. Cambridge, MA: Cambridge Press.

VOLUME 274

For further volumes:
http://www.springer.com/series/5710

SCIENCE IN THE CONTEXT OF APPLICATION

Edited by

MARTIN CARRIER
and
ALFRED NORDMANN

Springer

Editors
Prof. Martin Carrier
Bielefeld University
Department of Philosophy
Institute for Science and Technology Studies
33501 Bielefeld
Germany
martin.carrier@uni-bielefeld.de

Prof. Alfred Nordmann
Darmstadt Technical University
Department of Philosophy
64283 Darmstadt
Germany
nordmann@phil.tu-darmstadt.de

ISSN 0068-0346
ISBN 978-90-481-9050-8 e-ISBN 978-90-481-9051-5
DOI 10.1007/978-90-481-9051-5
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2010934513

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)