Epistemic Innovation

How Novelty Comes About in Science

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1 Introduction[1]

Recent scholarship in the social sciences subsumes the entire range of social innovations under the concept of innovation (e.g., Hutter et al., this volume; Rammert 2010, 2014; Passoth and Rammert, this volume). In this literature a concept of innovation oriented towards scientific and technical progress and its economic dimension serves as a counterfoil for such an expanded understanding of innovation. In so doing, technical innovations in particular but also scientific innovations are presumed to be adequately understood and rarely considered explicitly. The present text addresses innovation in the sciences against this backdrop. It focuses on the question of what concepts of epistemic innovation predominate in science studies. The term *epistemic innovation* is intended to express the focus on the generating of scientific knowledge. Accordingly, neither the social dynamics of the development and establishment of new fields of research[2] nor the institutional innovations that originate in science will be addressed.[3] The focus will instead be on constructivist and practice-oriented science studies with an emphasis on a selection of central concepts and debates.

1 For stimulating and wide-ranging discussions, I would like to thank Werner Rammert, Barbara Grimpe, and Thomas Völker.

2 On this see, e.g., the chapters in Merz and Sormani (2016a, 2016b).

3 Examples include technological platforms, new practices of computer-supported co-operation, and the Internet and its forms of use.

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It should first be noted that the concept of innovation is not prevalent in science studies; or rather, when it occurs, it refers to technical innovations (artifacts, processes, and systems) and/or the interaction between science and the economy. In this respect, this text will be less about a semantic analysis of the debates on innovation of whatever kind in science studies; it concerns instead the question of how the production and establishment of novelty in science (with regard to its conditions, modalities, etc.) is dealt with conceptually.[4] I speak here of science studies rather than, more comprehensively, of science and technology studies (STS) only to emphasize that technology-oriented innovation research will be disregarded.

Starting with a short reflection on Thomas Kuhn's seminal works on scientific revolutions (2), I will take a selective look at (early) laboratory studies with their micro perspective on knowledge generation (3). On this basis, two prominent object-centered perspectives of epistemic innovation are presented (4). A related perspective, the argument goes, is also fruitful for the analysis of computer simulation as a new innovation practice: accordingly, simulation is examined both as a practiced and as a productive entity with a view to the computer models on which simulation is based (5). The text concludes with a comparison of the concepts of epistemic innovation presented, particularly as regards the ideas associated with them on how scientific innovations are established and stabilized (6).

2 Essential Tension Between Tradition and Innovation

Kuhn's concept of scientific revolutions and his criticism of the idea that science develops only by accumulating new insights are among the most prevalent and well-known positions in more recent science studies (Kuhn 1970). Nonetheless, it is worth taking a fresh look at his observations on how novelty comes about in science. In so doing, I would like to start with an assessment by Kuhn on the significance of scientific revolutions that may at first be surprising. He writes:

> Novelty for its own sake is not a desideratum in the sciences as it is in so many other creative fields. (ibid.: 169)

This statement is to be interpreted in the context of the central and ambivalent significance that Kuhn attributes to 'normal science' for creating the new. On the one

4 The basis is a concept of innovation that is not associated with new developments per se but rather implies the establishment, stabilization, and institutionalization of novelties (see, e.g., Rammert 2010; Passoth and Rammert, this volume).

hand, Kuhn writes, normal science "often suppresses fundamental novelties because they are necessarily subversive of its basic commitments" (ibid.: 5). On the other hand, "the very nature of normal research ensures that novelty shall not be suppressed for very long" (ibid.). How can this apparent contradiction be resolved? The starting point is the assertion that an 'anomaly' must first be recognized as such before a crisis manifests itself; as a consequence, new theories can arise. In Kuhn's words this context is as follows:

> Anomaly appears only against the background provided by the paradigm. The more precise and far-reaching that paradigm is, the more sensitive an indicator it provides of anomaly and hence of an occasion for paradigm change. (ibid.: 65)

The cumulative concentration of the knowledge base in the normal science mode consequently creates an increasingly secure reference system, as well as reliable expectations by which an anomaly can distinguish itself. Of great significance for this process of manifesting itself is the 'elaborate equipment' that develops within a paradigm through the progress of research, for example, terminology appropriate to the paradigm, an interaction between theory and data that is specific to each case, and special skills. Normal science therefore promotes the creation of the new through, among other things, its routines and the advancement of the practices and instruments upon which they are based. In the process, Kuhn situates the creation of the new in science in the interplay between 'convergent' and 'divergent' modes of scientific research—an interplay that is fraught with tension (Kuhn 1977: 226). What is significant here for the understanding of scientific innovation but has until now rarely been accorded attention in the literature seems to me Kuhn's idea of, and emphasis on, *normal science* as one "of two complementary aspects of scientific advance" (ibid.: 227).[5]

Outside of science studies, Kuhn's name is primarily associated with the idea of scientific revolutions and mutually incommensurable paradigms. However, scholars of more recent science studies who see Kuhn as being one of their founding fathers have not placed these two concepts at the heart of their work.[6] Instead, in the dispute with the dominant positions of a rationalist philosophy of science, they mobilized Kuhn primarily as someone who focused his attention on "the cultures

5 Kuhn writes that "revolutions are but one of two complementary aspects of scientific advance" (Kuhn 1977: 227). I have made normal science—the implicitly mentioned second aspect in the quotation—the subject of the sentence.

6 See on this Edge et al. (1997), Pinch (1997), and Sismondo (2012).

and activities of scientific research" rather than "formalist accounts" (Sismondo 2012: 415).[7]

3 Micro Perspective on Epistemic Innovation

The early 'laboratory studies', the authors of which refer positively to Kuhn, have changed our view of science, at first methodologically.[8] In contrast to Kuhn's historical approach and the analytically reconstructing methodology of the philosophy of science, an ethnographic and often ethnomethodological approach has come to the fore that goes hand in hand with the program of analyzing science in terms of its practices *in situ*. In the early works, this perspective was primarily applied to the observation of scientific practices in laboratories. It is associated with a specific concept of how novel insights come into being that has (at least) three key characteristics.

First, the view that laboratory studies takes of science is *dynamic*: science is not identified with its facts and/or final products, as is found, for instance, in publications or textbooks, but rather analyzed as an activity and a practical accomplishment. As a consequence, a process is at the heart of the analysis: the process of manufacturing (or 'fabricating' or 'constructing') scientific facts.[9]

Second, this process is dismantled from a *micro perspective*. That means in particular that the scientific production process is "broken down" in laboratory studies "through multiplication" (Knorr Cetina 1995: 109, my translation), which reveals a great number and variety of incremental decisions, interactions, and interventions (see also Latour and Woolgar 1986). In early laboratory studies, such a micro perspective served less to characterize the innovations arising in that way or the possibilities of their increase; the interest was aimed instead at the social constitution of the process and its individual elements. Thus, for example, Karin Knorr Cetina identifies "contextual contingency as a principle of change" (Knorr Cetina 1981: 10), thereby referring to the fact that the contextuality of any decision (in terms of its dependency on place and time etc.) is not at odds with a success-

7 See on this critically Jasanoff (2012).

8 I will not go further into other precursors of the laboratory studies, particularly the sociology of scientific knowledge. For an overview of laboratory studies, see, e.g., Merz (2005).

9 See on the metaphor of fabrication Knorr Cetina (1981) and on the equivocal concept of 'construction,' inter alia, Sismondo (1993), Hacking (1999), and Merz (2006).

ful scientific innovation.[10] In this respect, 'constructiveness' can be understood in a dual sense: on the one hand, as already noted, as an explication of the social construction mechanisms; on the other hand, as an indication that the "products of fabrication" are "purposefully 'new' products" (ibid.: 12). Here it should not be overlooked that the expression 'constructiveness' exhibits an interesting tension that is likely to be typical of constructivist approaches. The idea that something new is produced in a targeted construction process is promptly counteracted by the author's distancing emphasis (the quotation marks). The new is thus characterized as an attribution, an emic construction, towards which the analyst acts agnostically in a conscious and demonstrative manner.[11]

Third, Knorr Cetina's micro perspective on scientific innovation is closely associated with the *scientific laboratory*, whereby the contextuality of scientific activity is first articulated in terms of its socio-material and spatially specific embedding. But the concept of the laboratory goes beyond the idea that it is the place from which experiments obtain the necessary resources. Instead, the laboratory has been turned into a theoretical concept and is considered "an important agent of scientific development" (Knorr Cetina 1992: 116). The focus here is the idea that the laboratory constitutes an "enhanced environment which improves upon the natural order in relation to the social order" (ibid.). The key process is the transformation of natural objects into scientific objects in the laboratory: these are miniaturized, enlarged, accelerated, slowed down, or the like to such an extent that they become more manageable, which thus promotes or enables the creation of new insights in the first place (ibid.; also Latour 1983). This approach moves beyond the micro perspective outlined above in that the local production of research objects and their relationship to research subjects shifts into focus. Typically, it is not explicitly discussed by means of what *specific* transformation and adaptation processes insights from the laboratory can become effective beyond this local context.[12] In this regard, these are primarily innovations *within* the laboratory.

In conclusion, the micro perspective of knowledge production of laboratory studies shows only little interest in an explicit notion of innovation. Instead, it is directed toward the unfolding of the various social processes and practices of

10 On the different concepts of the relationship between contingency and innovation in Knorr Cetina, Collins, and Pickering, see also Pickering (1987) and Zammito (2004: 160f.).

11 Presumably, one is less likely to come across such a distancing from claims of novelty in the innovation literature.

12 Latour (1983) gives a general answer to this question: scientific facts are only valid outside of the laboratory where the conditions and practices of the laboratory are applied (i.e., where 'society' is transformed into a laboratory). See also Merz (2006).

knowledge production and the constitution and nature of the research objects in the context of the laboratory.

4 Object-Centered Perspectives of Epistemic Innovation

In the following, two approaches are presented that explicitly address the dynamics of epistemic innovation from an object-centered perspective. The first concerns Rheinberger's concept of experimental systems (4.1); the second is Knorr Cetina's concept of epistemic objects in the context of an object-centered sociality (4.2).

4.1 Experimental Systems and Their Innovation Dynamics

Like the authors of the early laboratory studies, Hans-Jörg Rheinberger also starts with a critical examination of the concept of experiments long predominant in the philosophy of science. He criticizes a theory-dominated understanding of science, as a result of which experiments are understood as "singular, well-defined empirical instances" (Rheinberger 1997: 27). One example of this is Popper's idea that the experiment serves to test theoretical hypotheses. In a study on the history of molecular biology, Rheinberger develops as an alternative the concept of the *experimental system*, inspired by work by Fleck and Bachelard as well as by ideas and metaphors he comes across in his specific area of investigation, namely, biology.

An experimental system, as Rheinberger writes about the case of molecular biology, is a system "designed to give unknown answers to questions that the experimenters themselves are not yet able clearly to ask" (ibid.: 28). It is constitutive for innovation in science: as a 'surprise generator' and a space of emergence. This characteristic of an experimental system is based on the dynamic interweaving of its two components, which are functionally separated from each other: the epistemic things and the technical (or technological) objects. *Epistemic things* are thus material research objects that "embody what one does not yet know" (ibid.). In their indeterminacy they are 'question-generating machines.' By contrast, the experimental conditions that are designated as *technical objects* are 'answering machines.' They 'embed' the epistemic things, 'restrict and constrain' them (ibid.: 29).

The concept of the experimental system contains a model of the dynamics of epistemic innovation. These dynamics are set in motion by the interplay between its two components: epistemic things and technical objects. First, it is significant for this that the research objects that materialize in the scope of an experimental system require an instrumental setting so that the constantly newly raised questions are answered. Second, a dynamics of innovation is driven forwards through a transformation movement. Epistemic things can transform into technical objects and thus become a component of that set of instruments with the help of which new research questions in turn can be dealt with. Thus an analytical separation of the two functions is necessary

> because otherwise we are not able to name and to denote the game of innovation, the occurrence of *events* within the epistemic field. [Footnote discarded] Scientific activity is scientific only and just in that it aims at producing future. (Rheinberger 1992: 311)

Rheinberger (1992, 1997) traces such a dynamics of innovation exemplarily based on the history of the protein biosynthesis system. In his next step (Rheinberger 2007), he expands the concept of the experimental system to that of experimental cultures that he understands as ensembles of experimental systems associated with each other. In accordance with Bachelard's concept of culture (1949), he ultimately understands scientific cultures as "milieus in which the new can be revealed, in which things occur which cannot be anticipated"—i.e., as "contexts of innovation" (Rheinberger 2007: 138, my translation).

4.2 Epistemic Objects in the Context of an Object-centered Sociality

Epistemic innovation in Rheinberger's conception is achieved through the interplay and the reciprocal effect between epistemic things and technical objects *within* an experimental system. In contrast, Knorr Cetina (1997, 2001) stresses the particular significance and the special character of today's objects of knowledge or 'epistemic objects,' as she also calls them. In the process, she does not start, as Rheinberger does, from the interaction of different types of objects but rather expands the concept of epistemic objects itself. She upgrades this object category in accordance with the justification that present-day technologies (e.g., in computer hardware and software) are not pure answering machines in terms of instruments functioning in an unproblematic way but are also in the category of epistemic objects. Starting from Rheinberger's concept of epistemic things and strongly rooted in Heidegger, the author characterizes objects of knowledge through their "lack in completeness of being" (Knorr Cetina 2001: 181). The objects are continuously becoming; they have the "capacity to unfold indefinitely" (ibid.) and change their characteristics in the process. It is this indisputable incompleteness and the 'unfolding ontology' of epistemic objects that supplies the dynamics of epistemic innovation:

> Only incomplete objects pose further questions, and only in considering objects as incomplete do scientists move forward with their work (ibid.: 176).

The author combines the notion of epistemic object with the conception of a new social form: a 'sociality with objects' (Knorr Cetina 1997). Condensing a complex argument, the idea behind this is that, for the case of science, the objects' lack of completeness has an equivalent in the object relations of the researchers:

> The idea of a structure of wanting implies a continually renewed interest in knowing that appears never to be fulfilled by final knowledge. (Knorr Cetina 2001: 186)

In this respect, epistemic innovation would presuppose an "object-oriented sociality" that is expressed in an "orientation towards objects as sources of the self, of relational intimacy, of shared subjectivity, and social integration" (Knorr Cetina 1997: 23).

5 Computer Simulation as a New Practice of Epistemic Innovation

An object-centered perspective as associated with the approaches referred to above is, as I would like to show, fruitful for understanding computer simulation as a new epistemic practice with its own dynamics of innovation. Computer simulation has in recent decades attained extraordinary significance in the most varied science and technology fields. A few examples would include climate research, astronomy, particle physics, ecology, molecular biology, and industrial development and production. Against the backdrop of its widespread use, the question arises of the innovation potential of computer simulation—that is, of its ability to raise new questions and answer existing ones.

The epistemic significance of simulation, as well as of modeling in general, is explained and positioned in varied ways in science studies (cf. Knuuttila, Merz, and Mattila 2006; Merz and Hinterwaldner 2012). One central position in the philosophy of science, for instance, attributes the effectiveness of models to their ability to 'represent' a research subject more or less precisely. *Practice-oriented* approaches, which have gained ground since the 1990s in the sociological, historical, and philosophical debates waged over models in science studies, draw attention more strongly to the location, role, and use of (computer) models in specific scientific contexts. Such a focus is also fruitful for discussing the specific contribution that computer simulation can make to epistemic innovation, and thus forms the starting point for the following arguments.

It is beneficial to the analysis to take an object-centered perspective here as well. Simulation is accordingly to be considered at the same time in its practical use and with a view to the objects on which it is based, that is, the computer models. Thus, our main argument is that computer models are *productive entities* that create explicit as well as implicit knowledge (for a detailed account, see Knuuttila and Merz 2009). That means that models are not only effective in a depictive role—as 'models of'—but just as much in a performative, instrumental role—as 'models for'—as Evelyn Fox Keller (2000) so succinctly described the crux of the matter.

The productivity of computer models—and thus their innovation potential—is associated with their characteristic as autonomous and materially embodied artifacts. The *autonomy* of models was first addressed as regards their relative independence from both theories and data. This partial independence makes them mediators between the two poles and enables models to be deployed as instruments in order to investigate these two areas (Morgan and Morrison 1999). Correspondingly, computer simulation is considered an independent and qualitatively new scientific practice that constitutes a third aspect between (and also to a certain extent beside) theory and experiment. As an *applied theory*, it processes abstract entities and mathematical procedures. In *virtual experiments*, it enables the exploration of natural phenomena and instrumental settings through the deliberate variation of parameters, followed by observation of the effects produced in this way. Models are not only autonomous; they are also in their own specific way *materially embodied*, concrete, and resistant (Merz 2002). The computer models on which the simulation is based are embodied in the form of software and require a hardware environment to become productive.

On the basis of these characteristics, researchers can interact with computer models in different ways. Models activate learning effects and generate knowledge of a theoretical, implicit, or practical nature in a great number of possible interaction situations that are geared toward developing and improving the models as well as applying them for instrumental or exploratory purposes. This observation refers to two additional characteristics of particularly complex simulations or computer models that additionally increase their innovation potential.

Especially complex computer models are characterized by constant unfolding and a '*multiplex*' character (Merz 1999). This means that the same simulation model can fulfill distinct functions for different actors and in different contexts of use. In one context it might raise new questions as an object of research; in a second context, it might at the same time generate answers as an instrument; and in a third context, it might be applied in yet other ways. It should be stressed that this *co-occurring multifunctionality* of constantly unfolding objects can be of lasting duration without, as described by Rheinberger, resulting in a transformation into (purely) technical objects.

Lastly, computer simulation may make a contribution to epistemic innovation through its potential to generate and present *alternative futures*, whereupon it is possible to explore these future options, evaluate them, and compare them with each other. An initial example is climate change research with its scenario calculations of future global warming, which have attracted much public debate. A second example are the accelerator experiments of elementary particle physics, which would not be possible today without computer simulation. Simulation is here both a future and a surprise generator (for details see Merz 1999). Just a few indications will be given below about their efficacy in this field of research.

As a future generator, computer simulation enables *on the one hand* generation of knowledge about the functioning of material structures (e.g., accelerators, detectors, and their components) that have not been realized so far. Physicists explore various design options and optimize them in terms of often conflicting scientific, technical, political, or economic priorities. In the preparatory phases of an experiment, simulation has great significance for mediating and negotiating among very different fields of practice and actors.[13]

The generation of the future refers *on the other hand* to the research objectives, which target specific physical processes and phenomena (e.g., the search for supersymmetry). Various *theoretical scenarios* are encoded into simulation programs, the consequences of which are tested by means of simulation and can be extrapolated with a view to the planned experiments. For example, it can thus be seen whether certain theoretical assumptions can be explored at all in the planned experiment.

As a consequence, simulation is a generator for (possible) future equipment as well as for (conceivable) alternative theories. At the same time, it is a generator for the knowledge associated with the individual scenarios. Thus, from the interplay between the two complementary poles—experimental setting versus theoretical framework—results the particular efficacy of simulation, which lies in the fact that

13 With 'collaborations' involving 3,000 people working together on a single experiment, elementary particle physics also constantly needs important institutional innovations, for example, as regards issues of authorship in publications or the organization of a peer review system within the collaboration.

simulation can mediate between the paradoxical requirements of an experiment to be open-ended and at the same time to adjust the equipment in accordance with previously defined scientific assumptions. As a future generator, computer simulation is therefore effective in particle physics both as a thinking tool and as a tool for material intervention, as a generator of new questions as well as a generator of reliable answers.

6 Conclusion

To conclude, I would like to juxtapose the analytical perspectives of epistemic innovation presented in this chapter. In accordance with an innovation concept that implies not only the *generation of* innovations but their *implementation, stabilization, and institutionalization* as well (cf. Rammert 2010; Passoth and Rammert, this volume), particular attention shall be paid to the tension between these two poles.

According to Kuhn, epistemic innovation is rooted in the interrelationship between a 'normal' and a deviating mode of research. The occurrence of anomalies is an initial indication of possible innovations. However, anomalies are not sufficient to help an epistemic innovation to be established. There need to be veritable crises that are capable of destabilizing the prevailing paradigm and can trigger the negotiation of a new one. A scientific revolution, substituting one paradigm for another, is accompanied by a reconstruction of the entire field, one that involves its key characteristics, its objectives, methods, and theoretical generalizations (Kuhn 1970).

Kuhn's *macro perspective* on epistemic innovation provides an interesting comparative foil for a new look at laboratory studies, with their interest in constructing scientific facts from a *micro perspective*.[14] First of all, a surprising analogy between the two perspectives stands out. The routine processes, procedures, and interactions observed in laboratory studies seem for the most part to originate from the sector of 'normal science' (Kuhn). Extraordinary events such as crises were not of much interest, at least for the early laboratory studies, because the authors were interested in reconstructing the day-to-day processes of knowledge generation. The associated innovations are, one could say, *epistemic micro innovations*. Their stabilization does not take place at a subsequent point in time—in contrast

14 On the difference between micro and macro perspectives of innovation, see, e.g., Braun-Thürmann (2005).

to Kuhn's macro conception—but rather as a central component of the generation process.[15]

Object-centered perspectives of knowledge generation that are at the same time practice-oriented in turn yield new aspects of the dynamics of epistemic innovation, whereby the approaches considered differ in their focus. The playing field of epistemic innovation envisaged by Rheinberger is neither the scientific community (Kuhn) nor the laboratory (laboratory studies) but rather the *experimental system*, which is also the key concept for this approach. Of significance for the discussion of epistemic innovation here is on the one hand that the conditions for generating new questions are also explicitly considered. "What is genuinely new must come to pass, and one has to create favorable conditions for it to be able to do so" (Rheinberger 2006: 3, my translation). Precisely these conditions are given by an experimental system. What is of interest on the other hand is the positioning of the stabilizing of innovations within an experimental system. Specifically, it is about the shift of transforming epistemic things into technical objects. One could also say it is about the sedimentation of epistemic innovation in the form of technical equipment and as a component of an infrastructure that blazes the trail for further innovations.

Also alternative object-centered approaches such as Knorr Cetina's or the approach we developed in the case of computer simulation (Merz 1999; Knuuttila and Merz 2009) emphasize that epistemic innovations have a *material (or medial) dimension* and that they are at the same time *technical* innovations. The approaches differ, however, in their idea of how scientific innovations become established. Whereas Rheinberger assumes a stabilization through transformation, Knorr Cetina stresses the ongoing openness, mutability, and unfolding of epistemic objects, as I analogously claim for the case of computer simulation. These object characteristics have as a consequence that the production process of innovations is spread over time and concurrently distributed across different actors and contexts. This being the case, a stabilizing of innovations remains essentially partial and temporary.

In an interesting way, such a concept of scientific objects and the associated object-centered perspective of epistemic innovation shift the time references. In this case, one is dealing with a dynamics of innovation predominantly aligned towards *future and potentiality* rather than towards the "relationship between old and new" (Rammert 2010: 29, my translation). Here computer simulation offers an instructive example, as I have endeavored to show.

15 The existence of more advanced processes of stabilizing and institutionalizing epistemic innovations, for example, by means of specific forms of representation when disseminated beyond the context of origin, is only mentioned here (on this, see Latour and Woolgar 1986; Lynch and Woolgar 1990).

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