Historical Epistemology and the Advancement of Science

Jürgen Renn
e-mail: renn@mpiwg-berlin.mpg.de

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(Talk given at the "Workshop on Current Trends in the History,
Philosophy, and Social Studies of Science," Collegium Budapest, November 6, 1995)

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(Talk given at the the interdisciplinary workshop,
"The Changing Metaphysics of Science", Internationales
Forschungszentrum Kulturwissenschaften and Erwin Schrödinger
International Institut for Mathematical Physics, Wien, March 14 - 16, 1996)

ZUM STRUKTURWANDEL DER WISSENSCHAFTLICHEN ÖFFENTLICHKEIT
DURCH ELEKTRONISCHE MEDIEN 19

(Erschienen als "Kommentar", MPG-Spiegel 1/96, S. 2-4)

Jürgen Renn
e-mail: renn@mpiwg-berlin.mpg.de

History of Science as Historical Epistemology

Historical Perspectives and their Determinants

The questions of today

History of science is a field with a relatively recent theoretical branch that is rapidly evolving, perhaps too rapidly. One observes in fact a quick succession of theoretical questions which enter the center of the international debate and which disappear from it long before their intellectual potential has been exhausted. Examples are the structure of scientific revolutions, the role of methodological anarchy, the notion of experimental cultures, the social processes governing standardization, etc.. Critics of a theoretical orientation of the history of science have argued that the tides of this theoretical debate are actually determined by social processes which are comparable to those governing the marketing of fashions. Although there may be some truth in this observation, given the fragmented and institutionally still fragile nature of the professions of history and philosophy of science, this critique nevertheless misses the core of the matter. The various and quite heterogeneous attempts to address questions of the history of science by appealing to topics and methods of the social sciences and of the humanities respond in fact to an urgently felt need to conceive science as a human enterprise not dissociated from its social, economic, and cultural conditions. Clearly, only such a richer concept of science in its contexts promisses to adequately capture the science of our days which is so obviously interwoven with the conditions of our existence and the fabric of our culture. Hence, if we look into the history of science also with the aim to find resources for reflection on science in its present state, then we have to avail ourselves of this richer concept of *science in context* as an analytical tool in our historical investigations as well. No wonder then that the approaches to a theoretically guided history of science are as many as the possibilities to link the pressing questions of our present situation to historical investigations.

Approaches motivated by the present state of science

Let me remind you of some examples for the stimulation of recent approaches to the history of science by features and problems of our scientifically and technologically dominated culture. The emergence of big science in this century has made it impossible to overlook the role of institutions, of cooperation, of division of labor also in the history of science. The institutional history of science has challenged the traditional emphasis on single men making singular discoveries; it has also challenged the traditional concentration on scientific texts as the principal source of knowledge in the history of science. The dominant role of science in the power struggles of this century, including its industrial and military applications, has similarly strengthened the interest in the interplay between science and power also in the history of science. But only the decreasing credibility of the normativ, rationalist accounts of science in the tradition of analytical philosophy has opened up the possibility to conceive the role of social structures for the scientific enterprise not only as belonging to the context of application but also to the context of the constitution of the validity of scientific knowledge. Also the presently much debated role of experimental cultures in the history of science shows traces both of a concern with the present state of science, which is often characterized by large-scale experimental systems which evolve semi-independently from theoretical endeavors, and of the lost faith in the centrality of language and logic for understanding science as it was proclaimed by analytical philosophy. Finally also the present interest in the historical evolution of second-order concepts of science, that is, of its norms, methods, and images bears the mark of both the preoccupations and doubts concerning the rationality and adequacy of present scientific and technological developments, and of the problems of the traditional philosophy of science to establish universal norms of scientific rationality.

Institutional history and its weaknesses

The approaches listed above - and several which I have not mentioned - have dominated discussions in theoretically oriented history of science in the recent past. The most „old-fashioned“ among these approaches is perhaps the history of scientific institutions, not because it has been exhaustively pursued or because it has lost its relevance, but because it leaves space for clinging to traditional and largely superseded distinctions such as that between internalist and externalist history of science and in particular because it lacks the analytical tools for studying the mechanisms by which the cognitive structures of scientific knowledge evolve and interact with the other dimensions of the historical development of science, including the institutional dimension.

Postmodernity as a new challenge for the history of science

The most recent debates on the postmodern physiognomy of scientific developments in the second-half of the twentieth century are shifting, on the other hand, the attention back to the cognitive dimension of scientific knowledge. This shift will probably not remain without impact also on a theoretically oriented history of science. Theoretical physics, to give just one example, has, while attempting to establish a reductionist theory of everything, in fact given rise to insights into the relative independence of different layers of physical behavior. These layers are separated by different scales of energy or of length and have each their own characteristic physical laws which cannot be deduced from the laws of any single fundamental layer. As a consequence, also the knowledge about any given physical system in nature, such as a chemical molecule for instance, is now more generally recognized to be a patchwork like complex structure divided into different levels with complicated modes of interaction between each other. In the case of a molecule these different layers of knowledge may comprise those of chemistry, quantum mechanics, perhaps of biological processes relevant to the molecule, perhaps also of cosmology, and certainly of the experimental circumstances in which knowledge about a given molecule is generated. Which consequences does this new view about the complex, non-linear and non-reductive composition of knowledge in modern science have for the history of science? I would like to suggest that it opens up new perspectives not only on recent developments but also on features of the history of science in general which have been neglected in more traditional approaches, just as the autonomy of the experimental dimension was neglected until it became all too evident in recent science. But before coming back to the implications of this postmodern perspective on the history of science, I will first comment on the relationship between the different dimensions of the history of science which I have mentioned.

Historical Epistemology and the Intellectual Coherence of the History of Science

The lack of intellectual coherence of the history of science

In the beginning I have argued that only an analysis of science in its economic, social, and cultural contexts has a chance of capturing those dimensions that make the history of science worthwhile as a field of study relevant for reflections on the present situation. But while the orientation of a field of historical studies by particularly pressing questions coming from the present is certainly legitimate, it does not incorporate any guarantee for practical success, and not even one for the intellectual coherence of the enterprise. Nevertheless, perhaps because of the strong orientation of parts of the history of science towards the present, or perhaps because of the past failures of philosophy to provide a synthetical view of science, the search for this intellectual coherence is presently not a prominent preoccupation among historians of science, not even among those who are theoretically oriented. For instance, although cultural, social, institutional, material, and intellectual dimensions are clearly all relevant to the history of science, some of the approaches mentioned above simply neglect one or more of these dimensions or attempt to reduce it to the others. Furthermore, although certain branches of the social sciences and the humanities clearly have a bearing on some of the problems raised by historians of science, for instance sociology on the problems studied by the institutional history of science or cognitive psychology on those studied by the history of ideas, the systematic application of such methods is still not common in the history of science.

The role of historical epistemology

In this situation, historical epistemology, as we pursue it in my department at the Max Planck Institute for the History of Science, attempts to open up a space for exploring the relationship between all relevant dimensions of the development of scientific knowledge. Our goal comprises the reconstruction of central cognitive structures of scientific thinking, the study of the dependence of these structures on their experiential basis and on their cultural conditions, and the study of the interaction between individual thinking and institutionalized systems of knowledge. Historical epistemology in this sense requires an integration of social, cultural, and cognitive studies of science. While methods and results of the cognitive sciences, for instance, or of the structuralist tradition of psychology, or of philosophical theories of concept development can help to compensate theoretical deficits in the history of science in a narrow sense, in particular when it comes to explaining thinking processes, the history of science can, inversely, contribute to overcoming the limitations of theoretical approaches whose claims have never been systematically confronted with the results of historical research. The theoretical questions we study are thus stimulated by a variety of different disciplines which are not all necessarily historical in character. But only detailed and systematic historical reconstructions can provide the empirical grounding of our work.

Dimensions of an Historical Epistemology: Longitudinal Studies

Innovative approaches - overview

I will now attempt to briefly sketch some of the innovative approaches to the history of science suggested by historical epistemology. In particular, I will point to the significance of longitudinal studies of scientific developments; I will then explain the concept of a cultural system of knowledge as the principal object of studies in historical epistemology, and, in this context, I will emphasize the necessity of analyzing the deep-structures of knowledge; finally, I will comment on the different dimensions of scientific change suggested by these approaches.

For longitudinal studies in the history of science

Let me begin with the project of longitudinal studies of scientific developments. Concepts such as force, motion, space, and time play and have played an important role in the cognitive organization of scientific knowledge from antiquity until today. While the history of some of these concepts in general human culture or in the humanities has been studied in an exemplary way, for instance that of the concept of time in studies by Norbert Elias and Helga Nowotny, the available studies in the history of the natural sciences have not yet reached a comparable level. In fact, the history of these fundamental concepts in science is either treated in terms of the traditional history of ideas, as if individual scientists pick up such concepts from time to time, mould them according to their personal ideas, and then hand on the modified concepts to the next great scientist in line, or these fundamental concepts are treated in cultural context but only with respect to a specific case study, thus leaving open the questions of long-range patterns of development and of a comparative evaluation of the impact of different contexts on the development of knowledge. Longitudinal studies of the history of fundamental structures of knowledge which conceive these structures not only as the characteristic property of a few great individuals but as part of socially transmitted and intersubjectively shared knowledge are still the exception.

Science in context requires longitudinal studies as well

Longitudinal studies should indeed not only concern the history of disembodied ideas. Also the pressing questions of present history of science, such as that of the role of cultural or social contexts - be they images of science or scientific and political institutions - on the formation of science in a given historical situation, can only be answered on the background of such studies. What do the specific political and cultural circumstances of Galileo's career, for instance, really teach us about the origins and about the crucial role of his contribution to mechanics in the history of science, a role which it continued to play long after these circumstances have ceased to play a significant role for the practice of science? The answer to this question must remain open as long as we ignore other factors shaping Galileo's science, be they of a local or of a more global character. Mechanics is indeed a particularly good example in point both for the longivity of certain structures of thinking as well as for the possibility of rapid but lasting changes with intersubjective impact.

The interplay between local and global structures of science

The emphasis of recent historical studies on the local circumstances of the practice of science have certainly helped us to question the universals superimposed on the history of science by a dogmatic and normative philosophy of science but they should not induce us to consider the microscope alone to be the legitimate instrument of historical analysis, when there are obviously structures that can only be identified with a telescope. Here perhaps is a first lesson to be learned from a postmodern perspective on science: we should neither think in terms of a strict distinction between internal and external determinants nor in terms of an alternative between local and universal structures governing the historical development of scientific thinking, but in terms of a manifold of structures living on different time-scales and crossing - each in its own way - the borders between science and its contexts. But only long-range studies of scientific development will be capable of revealing this interplay between its local and its more global structures.

CULTURAL SYSTEMS OF KNOWLEDGE

Structures of context and structures of knowledge

Let me now come to the problem of how the scientific object of an historical epistemology should be conceptualized, a problem that will lead me to the introduction of the notion of a cultural system of knowledge. The present concentration on the contextual conditions of science often tends to neglect that the history of science deals with a most remarkable process of the development of *knowledge*, in whatever way the notions of „development“ or of „knowledge“ may be conceived. In fact, even when external social or cultural factors are emphasized as explanations, they are usually introduced with the aim to give an account of an important *intellectual* development. But when it comes to the task of analyzing precisely this intellectual aspect of the development of science, even contextualist approaches often merely employ the traditional narrative descriptions of the history of ideas. Take the example of early modern science. Its religious background, its image of nature as being governed by laws, the introduction of systematic experimentation, the use of mathematics for describing natural laws, the creation of new institutions, a particular constellation in the relationship between science and power and many other general characteristics have alternatively been proposed as explanations for the important intellectual developments brought about by early modern science. Usually these explanations come out differently, however, in dependence of which author of the early modern period is in the center of interest, Galileo, Descartes, Newton or others. I believe this is so not only because history of science is still a field dominated by idiosyncratic expertise. In my view, the more important reason for this incoherence is the fact that the advancement of knowledge in early modern science is rarely considered as a process within a cultural system of knowledge of which all these authors are participants and protagonists. In other words, even if it is now widely recognized that the external conditions of science can be conceptualized in terms of more or less general social and cultural structures, this structuralist view is rarely applied to the organization of knowledge itself.

For a study of cultural systems of knowledge

As a second innovative approach suggested by historical epistemology I would therefore like to propose the study of cultural systems of knowledge, a concept which comprises both external and internal aspects of the development of science. By a „cultural system of knowledge" I intend the knowledge available in a given culture or society, comprising the cognitive structures of knowledge, the material forms of its external representation, as well as the forms of its social transmission. In fact the texts of the individual authors which are usually in the center of attention of historians of science only reflect very specific aspects of the socially available knowledge. And even these texts cannot be properly understood without taking into account their specific role in the larger cultural system of knowledge. In a given culture, knowledge about bodies in motion, for instance, is built up and transmitted by ordinary experiences with unspecific objects accompanied by every-day language, but also by specific, socially determined experiences with the material artefacts of that culture, such as machines, experiences which are reflected in technical language, and finally also by appropriating and exploring the theoretical constructs represented by the writings usually studied in the history of science. Since the knowledge of an individual scholar partakes in some or all of these currents of the socially available knowledge in a given culture, the individual knowledge itself is, as a rule, composed of various cognitive layers, each with its own specific structures. The insight into this multi-layered structure of knowledge may be considered a second lesson to be drawn from a postmodern perspective on science for the history of science. I shall return to this deep-structure of knowledge in a moment.

Different boundaries in historical epistemology and history of science

The introduction of cultural systems of knowledge as the scientific object of historical epistemology also implies some methodological changes with respect to traditional history of science. The systematically conceived relationship between the various dimensions of a cultural system of knowledge, for instance, points to the necessity for an historical epistemology to impose boundaries on the historical material which are different from those familiar from ordinary historical studies. If one wants to study, for instance, the impact of material tools on the development of knowledge about bodies in motion as it is represented in mechanics, one cannot limit the field of study to the early modern period or to scientific texts alone. The so-called simple machines, for example, played a decisive role in the development of mechanical knowledge. Already in antiquity simple machines were at the roots of the first theoretical explorations of mechanical laws, such as those of Archimedes or Pappus. It is well known that the transmission of this antique knowledge provided an important starting point for early modern mechanics; the inclined plane, for instance, is in the center of Galileo's attempt to create a new science of bodies in motion. At the same time early modern mechanics was developed against the background of new technological developments such as the introduction of ballistics which hence have to be also taken into account when analyzing the scientific texts of the period. But exactly how such diverse factors as the heritage of antiquity and contemporary technological developments can be systematically taken into account when studying the development of a cultural system of knowledge is a difficult methodological problem which I will address now.

The Deep-Structures of Knowledge

A methodological problem

It seems difficult indeed to analyze the interaction between various cognitive factors which is usually described, in a somewhat simple-minded fashion, as the effect of so-called „intellectual influences." Such an analysis is clearly impossible just by working with philological methods which refer, after all, only to the textual representation of thinking structures, or by using the intuitive narrative descriptions of the history of ideas which are not bound to any theoretical coherency. An analysis in the sense of an historical epistemology rather requires a more coherent account of the complex, multi-layered cognitive structures involved in the transformation of cultural systems of knowledge. This brings me to the third innovative approach suggested by historical epistemology, the study of these deep-structures of knowledge.

For a study of the deep-structure of knowledge

Analytical tools for such a more systematic and coherent account of thinking structures and their transformations are offered in particular by cognitive science. As a rule, it is, however, impossible to directly transfer theories of cognitive science to problems of historical epistemology since these theories were developed without paying sufficient attention to the historically and culturally changing determinants of thinking. But, on the other hand, the theoretical constructs of cognitive science are saturated with empirical knowledge about thinking processes which cannot be directly obtained from historical sources. I would argue, in other words, that we are confronted with the possibility for a genuine and fruitful integration of different scientific disciplines, the history and philosophy of science, on the one hand, and the various sciences studying human thinking, on the other, from pedagogy to cognitive psychology.

Qualitative thinking in cognitive science

Let me give you an example for the potential implications of such an integration. Cognitive science has taught us, in particular, to take qualitative reasoning much more seriously than it was usually taken under the dominance of the idea of a universal logic governing human thinking or at least scientific thinking. Cognitive scientists have reconstructed surprisingly coherent and powerful but also diversified inferential structures of every-day thinking, for example in the case of qualitative reasoning about physical processes. Such structures which are organized in „mental models“ or „frames“ provide the underpinning of thinking on physical processes even in the presence of a developed theory such as that of classical mechanics because they are required to relate the abstract constructs of a theory to our handling of the material objects to which the theory must ultimately refer. It is a well known fact of science teaching that the difficulties of applying an abstract theory to a concrete problem are often due to incongruences between the mental models governing the qualitative thinking about the problem and the conceptual structures of the theory. It has been observed, in particular, that even now every-day thinking about the causation of motion often resembles more closely the medieval and early modern thinking in terms of impetus than classical mechanics.

A simple mental model of causation

This mental model of causality assumes that every motion is caused by some agent: external or internal; there is hence no equivalent to our inertial motion in this model. In some cases, such as that of a man pushing a car, the moving cause can clearly be identified with an external agent, the person. But in other cases, such as that of a woman throwing a ball, the impetus model of causality explains the continued motion of the ball, after it has left the woman's hand, not by an external but rather by an internal agent, the so-called impetus. The impetus was, according to this model of causality, conferred upon the ball by the throwing hand of the woman. Note that this impetus model is just one among several such mental models capable of structuring qualitative causal reasoning about motions; the Aristotelian model according to which all motions are caused by an external agent is one alternative.

A mental model as background for different scientific theories

Now this elementary impetus model may not only represent a structure of every-day thinking but also forms the background for a scientific exploration of motion. But wherever this model shapes the systematic causal explanation of motions, it brings up, by its very nature, a number of theoretical questions, for instance: which qualities of the original motion by the throwing hand are conferred upon the ball by the impetus after the ball has left the hand, the speed, the acceleration, the direction, the curvature, or all or some of these properties? Does the motion eventually cease as a consequence of the tiring of the internal agent or due to some external conditions? Although different theories of motion would result from the different possible answers to these questions, they would nevertheless agree in their assumption of the same fundamental model of causality and thus share an important deep-structure of knowledge. Precisely because the traditional history of science tends to neglect such deep structures of knowledge, this elementary circumstance is often overlooked, with very limiting consequences for historical explanations.

Mental models in the history of science

Let me therefore try to briefly illustrate the potential relevance of mental models for explanations in the history of science. Mental models governing qualitative physical thinking played a crucial role, for instance, in organizing mechanical knowledge in early modern times when a stable theory such as classical mechanics was not yet available to gauge the scientific understanding of bodies in motion. Even attempts at a theory of bodies in motion such as Galileo's mechanics cannot be fully understood without taking into account mental models such as the understanding of causation in terms of impetus. Indeed, on this level of thinking, Galileo's mechanics shares common structures with contemporary theories of nature which, to traditional history of science, have appeared to be fundamentally different because it looks at individual authors rather than at a cultural system of knowledge. But the conceptual tools of cognitive science become even more relevant for the analysis of such questions as the one raised above, concerning the relationship between theoretical and practical knowledge in the emergence of classical mechanics. Clearly, while the practical knowledge of early modern engineers was certainly not dominated by any science of mechanics, it was not completely devoid of cognitive structures such as those governing every-day thinking. If these structures are described and analyzed as mental models, they can systematically be compared to those underlying the contemporary theoretical works on mechanics, even where contemporary engineering experiences are not directly thematized. Possible influences of contemporary practical experience on concept formation in early modern mechanics can adequately be discussed only on this level of comparison - where the theoretical aspects of practical knowledge and the qualitative aspects of theoretical knowledge come into focus and can be treated on equal footing.

Dimensions of Scientific Change

By way of conclusion, I would like to come back very briefly to the different dimensions of a cultural system of knowledge and to the basis they provide for explaining scientific change. Indeed, in all of its dimensions, that of social organization and transmission, material representation, and cognitive organization, a cultural system of knowledge may undergo significant historical changes. For instance, different aspects of the knowledge available in a given society are usually transmitted by different social groups; and their contact or lack of contact may have a decisive impact on the development of knowledge. Clearly this is a relevant dimension for explaining the integration of various traditions of knowledge, in particular of scholastic learning and engineering knowledge in early modern mechanics. The development of material artefacts which are capable of generating new knowledge may similarly have an important effect on a cultural system of knowledge. The impact of ballistics for studying projectile motion in early modern mechanics may serve as an example for the innovative role of the material means available to scientific thinking. Finally, a cultural system of knowledge may also undergo a transformation on the level of its cognitive organization, for instance, by changing hierarchical structures in this organization in the course of a process of reflective thinking. The fact that the new concepts of classical mechanics such as the concept of inertia do not result from the introduction of a new paradigm *ex nihilo* but from exploring the theoretical limits of preclassical mechanics and from reinterpreting marginal results obtained within its traditional conceptual framework as the key elements of a new conceptual framework may provide an example for this type of change.

From the perspective of an historical epistemology, accounting for a „scientific revolution“ such as the creation of classical mechanics requires, in summary, a systematic analysis of all dimensions of a cultural system of knowledge, and not just an idiosyncratic emphasis on the most fashionable aspects of scientific change.

Living with Diversity and Unification in Science

A Clash between Images of Knowledge

Anderson in Context

About twenty-five years ago the solid-state physicist Philip Anderson wrote: „the more the elementary-particle physicists tell us about the nature of the fundamental laws, the less relevance they seem to have to the very real problems of the rest of science, much less to those of society. The constructionist hypothesis breaks down when confronted with the twin difficulties of scale and complexity." In a time in which high-energy physics finds it increasingly difficult to publicly defend its traditionally high budgets, and in which exciting new scientific developments take place in areas traditionally not considered as pertaining to fundamental science, these words sound prophetic and have the ring of the motto of a new era in physics. In fact, if we listen to scientists such as Anderson, a new diversity, a new modesty, an independence of layers of knowledge within physics comes into perspective which is unknown from traditional accounts of traditional physics.

Doomsday Reductionism.

But we also hear, perhaps even more loudly, the voices of those not less contemporary scientists who believe in a differently conceived new physics, and against whom Anderson's remarks seem to be directed. According to Penrose, for instance, it is precisely „our lack of understanding of the fundamental laws of physics that prevents us from coming to grips with the concept of mind in physical or logical terms." According to Hawking, we can „hope to find a complete, consistent and unified theory which combines all partial theories as approximations ... Possibly we are shortly before the end of the search for the most fundamental laws of nature."

These physicists do not share Anderson's opinion that the laws of fundamental physics are of no direct relevance to our lives. Freeman Dyson, taking issue with Steven Weinberg about the meaning of the universe, intends to make eschatology into a branch of physics. Tipler even develops a physics of immortality in which he writes: „I suggest to equate the universal wave function (of quantum cosmology), which satisfies the Omega-point boundary condition with the Holy Ghost.“ I will skip the definitions of purgatory and hell and rather refer you to the penetrating analysis of this “doomsday reductionism“ by my physicist colleague Hubert Goenner.[1]

Images and Body of Knowledge

My point here is to provide some more context to Anderson’s statement about the failure of what he calls the „constructionist hypothesis.“ This context should indeed be helpful in clarifying the status of this debate: are we dealing here with a methodological controversy over the role of reductionism in physics, a philosophical discussion about the relation of physics to values and ideas of general culture, a dispute among scientists of different specializations over the priorities of future research in their field, or the ideological reflex of a political struggle over social status, power and resources? Clearly the debate involves, implicitly or explicitly, all of these aspects and several more. Think of Tipler’s claim that “progress of science may be measured by the extent to which physicists conquer other departments.“ It is precisely this mixture of motivations which shows that this debate is in fact one over “images of knowledge,“ following Yehuda Elkana’s illuminating terminology. Images of knowledge, that is, reflections on what knowledge is or should be like, play an important role in mediating between ideas and interests present in society, on the one hand, and the body of scientific knowledge, on the other.

Naturally, a change in the predominant image of knowledge is as important for our understanding of science as a change in the body of knowledge, and very often such changes go hand in hand with each other. But it is not for this reason that we can allow ourselves, as historians, philosophers, or sociologists of science, to simply conflate the epistemological distinction between image and body of knowledge, as much as the debate among the scientists themselves tempts us to do so, in particular when it concerns the intricacies of very recent science.

Physics underneath the Sunday Outfit

This may seem to be a pedantic point. It is, however, crucially relevant to the endeavor of assessing whether present physics presents us indeed with a postmodern condition. In fact, if we ignore the distinction between image and body of knowledge we have to face the following dilemma: Many of those features of recent physics which are claimed to be fundamentally novel and supposedly indicative of a postmodern condition turn out, on closer inspection, to be in fact

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1 Hubert Goenner, “The quest for ultimate explanation in physics or, reductionism on the advance,” internal colloquium at the Max Planck Institut for the History of Science, Berlin, January 31, 1996, (to be published). The quotations are taken from this paper.

old hats of the history of science, at least on the level of the body of knowledge. The reason that we are not so familiar with these old hats is not that they were not worn in past times, but that they were just not part of the Sunday outfit, and that they were only discovered when history and philosophy of science took a look beyond the images of knowledge to study more closely the every-day working conditions of past science.

HAVE WE ALWAYS BEEN POSTMODERN?

Numerical Experiments 350 Years Ago

Let me give you examples. It has been claimed that numerical experimentation has added a new dimension to physics, opening up vistas of a world in its own, perhaps metaphysical rights, in addition to the realms of theory and experiment. But recent historical research has, on the other hand, shown that “numerical experimentation“ played a significant role in the emergence of early modern physics, 350 years ago. It is indeed not difficult to find in the manuscripts and the correspondence of some of its principal actors such as Galileo or Descartes systematic numerical explorations by which these authors attempted to evaluate theorems in physics. Such “numerical experiments“ were then just as important for transcending the limits imposed by the theory of proportions on the exploration of functional dependencies in physics, as modern computer simulations are for transcending the limits of analytical methods in quantum field theory.

From Kadanoff to Mach and Back

Here is another example. Take Kadanoff’s statement that “Physicists have begun to realize that complex systems might have their own laws, and that these might be as simple, as fundamental, and as beautiful as any other laws of nature.“ I will not deny that the emphasis on complex systems is indeed something rather recent in the history of physics, even if perhaps not in that of science in general. But the further going metaphysical and epistemological conclusions which are drawn from such statements are in fact not specific to recent developments in physics. There just cannot be any doubt that physics, let alone chemistry or biology, always had to live with different layers of knowledge, “with the ontology and dynamics of each layer essentially quasi-stable and virtually immune to whatever happens in other layers.“ (Schweber and Nowotny)

Think only of the three major branches of classical physics in the late 19th century, mechanics, electrodynamics, and thermodynamics. In each of these branches, a set of interconnected physical problems is treated on the basis of a relatively stable and distinct theoretical foundation. After mechanics had ceased to be the only conceivable conceptual foundation for physics, physicists and philosophers at the end of the 19th century were indeed entitled to claim, as did Ernst Mach: “We cannot yet know which of the physical phenomena are going most into the depth, whether not perhaps just the mechanical phenomena are the most superficial ones, or whether indeed not all phenomena are going equally into the depth.“ He might have just as well continued with an adaption of Kadanoff’s statement to the physics of his time.

Unification and Borderline Problems

But perhaps, one might object, this factual independence of layers of knowledge in classical physics simply remained without serious consequences for the further development of physics, because it was overpowered by a monolithic image of knowledge according to which the search for unification had absolute priority over the acknowledgement of diversity. Indeed, this objection is supported by the search at the end of the 19th century for alternative and mutually exclusive “world pictures,“ which all share the same monolithic and reductionist understanding of scientific knowledge, that is, the mechanistic, the electromagnetic, and the so-called “monistic“ world picture of energetics.

The objection is not supported, however, by the history of the further advances in physics because they are based on an acknowledgement, rather than on a suppression of the independence of layers of knowledge in classical physics. In fact, all the major “unifications“ in early 20th century physics go back to borderline problems located right at the frontiers between the different branches of classical physics. Think of the theory of relativity and the problem of the electrodynamics of moving bodies, which requires the application of both the laws of electrodynamics and the laws of motion of mechanics. Or think of quantum theory and the problem of heat radiation, which requires the application of the laws of radiation - covered by electrodynamics - and of the laws of thermodynamics. In this sense, the histories of relativity and of quantum theory share an important genetic similarity with each other, but also with the history of the more recent, supposedly postmodern physics of renormalization, which also emerged as a borderline problem, in this case between statistical mechanics and quantum field theory.

Historical Epistemology versus New Metaphysics

Nothing new under the sun - this may seem to be the message of the examples from the history of physics I have given, to which I could, of course, add many more, in particular if I were allowed to include disciplines other than physics as well. As a matter of fact, however, these examples do point to something new, not about a new metaphysics of science, but about recent advances in understanding science as a historically contingent human enterprise, dependent on its culturally determined and accordingly diverse material tools of knowledge. Think of the notion of computability which, in this understanding, is not part of any metaphysics but must always refer to an historically given mathematical tool, be it the instruments of Euclidean geometry or a Turing machine. These advances point to an historical epistemology of knowledge which is itself non-reductionist and which treats cognitive, material, and social structures of science on an equal footing. Since such an historical epistemology is still in its infancy, I find it somewhat premature to rush to any conclusions about the advent of a new era of science. But because this workshop is supposed to set an agenda for action, I will not withdraw myself from taking on my share of this responsibility, as well as I can do in the remaining few minutes.

The Future of Knowledge Integration

Integration of Knowledge as a Condition for Unification

Let me just take the future of unification in science as an example for the consequences which can be drawn from an analysis in terms of a non-reductionist historical epistemology. A first basic insight is that unification, understood as a cognitive development, always presupposes an integration of knowledge, both in a material and a social sense. The emergence of borderline problems and their transformation into germs of unification, in particular, requires both, a material representation, be it an experimental arrangement or a paper tool such as a formalism, which can be assimilated to concepts belonging to two different branches of science, and a social organization allowing to actually bring to bear on such borderline problems the combined knowledge of the different branches. This point may be crucial for evaluating the promise of future research ventures. For instance, it may be the case that the difficulties of unification in the case of quantum gravity are not due to the historical obsoleteness of unificatory programs after the advent of postmodernism, but simply to the scarcity of borderline problems which can be assimilated to both quantum field theory and general relativity, quite in contrast to the situation for quantum field theory and statistical mechanics.

Electronic Media as the Material Condition for a New Integration of Knowledge

What else follows from the significance of material and social conditions for an integration of knowledge, as a necessary but not sufficient condition for unification? From the perspective of an historical epistemology, computers and electronic media are indeed the hallmarks of a new era in science, but not so much because they facilitate traditional tasks such as numerical calculations, but, among other reasons, because a world-wide electronic network of interconnected chunks of information provides hitherto unknown material preconditions for the integration of knowledge. The real challenge is that of using this new potential by developing adequate social and cognitive forms of organization for electronically available knowledge.

A New Culture of Mediation as a Social Condition for Knowledge Integration

Finally, I would like to come back to the two images of knowledge opposed to each other in the beginning. Neither of these two images provides a satisfactory response to the social problems of integrating scientific knowledge, which are growing due to an escalating specialization and diversification of science. Doomsday reductionism simply claims to eliminate the tensions of diversity by promissing to eventually reduce everything to a single origin. Postmodernism suggests an almost “postmortal“ indifference to the conflicts of origin, dynamics, and scale, as well as with regard to other unsolved conflicts of modernity. A third way must be possible. Within the sciences, in particular, a beginning could be made by developing a new culture of mediation, in which knowledge integration is fostered across disciplines, but also between the scientific community and other communities, by making conceptual diversity not only acceptable but also intellectually accessible. An effort of translation, which always involves an understanding of context and historical contingency, may teach us, as a first step, to sustain the inherent conflicts rather than to suppress or deny them. In this way, we might even learn how to live with diversity as well as with unification.

Zum Strukturwandel der wissenschaftlichen Öffentlichkeit durch elektronische Medien

Einleitung

Die zunehmende Verwendung elektronischer Medien führt langfristig zu einschneidenden Veränderungen der wissenschaftlichen Produktivität und Kommunikation und damit zu einem Strukturwandel der wissenschaftlichen Öffentlichkeit. Obwohl zur Zeit erst ein Bruchteil der für die wissenschaftliche Arbeit relevanten Informationen elektronisch zur Verfügung steht, sind die langfristigen Veränderungen aus wissenschaftshistorischer Sicht nur mit der Einführung des Buchdrucks und seinen Auswirkungen auf die Wissenschaft der frühen Neuzeit zu vergleichen. Die gegenwärtige Diskussion über diese Veränderungen tendiert zu einer ausschließlichen Konzentration auf die technischen Aspekte und zu einer Vernachlässigung der Konsequenzen für die kognitive und soziale Infrastruktur der Wissenschaft. Die technischen Veränderungen haben andererseits wissenschaftliche und wissenschaftspolitische Handlungszwänge entstehen lassen, die nur von Wissenschaftlern, EDV-Spezialisten, Bibliothekaren und Wissenschaftspolitikern gemeinsam bewältigt werden können.

Die Globalisierung wissenschaftlicher Resourcen

In der internationalen wissenschaftlichen Kooperation hat schon längst eine Entwicklung stattgefunden, die mit der Entwicklung der Weltwirtschaft vom internationalen Handel zur internationalen Produktion vergleichbar ist: vom internationalen Austausch von Informationen zur internationalen arbeitsteiligen Erzeugung und Verwendung von Informationen. Diese Entwicklung ist durch die elektronische Kommunikation und Verarbeitung von Informationen erheblich beschleunigt worden und ist inzwischen eine Selbstverständlichkeit des wissenschaftlichen Alltags, von der Recherche in Datenbanken über die gemeinsame Abfassung von Artikeln mit Hilfe des Internets bis zur Fernbenutzung wissenschaftlicher Großgeräte. Dabei vollziehen sich erhebliche strukturelle Veränderungen dieses Alltags, die nicht zuletzt auch wissenschaftspolitisch relevant sind.

Eine dieser Veränderung läßt sich als Delokalisierung von Forschungsresourcen beschreiben.

Wissenschaftliche Großgeräte wie z. B. Teleskope lassen sich z. T. unabhängig von ihrem Standort mit Hilfe elektronischer Kommunikation von einer weltweit verteilten Wissenschaftlergemeinde benutzen, sei es durch Zugriff direkt auf das Instrument oder auf die vom Instrument erzeugten Beobachtungsdaten. Bei einigen Forschungsprojekten wie dem Human-Genom Project ist diese Delokalisierung von Resourcen geradezu die Voraussetzung für eine neue Art der wissenschaftlichen Arbeitsteilung, die ohne die elektronischen Medien nicht denkbar wäre. Auch die weltweit koordinierte Beobachtung des großen Supernova-Ausbruchs von 1987, bei der Hunderte von Beobachtern und Theoretikern in ständigem Kontakt miteinander den Einsatz von Instrumenten abgesprochen und den sich innerhalb kurzer Zeiten verändernden Prioritäten angepaßt haben, wäre ohne elektronische Kommunikation kaum möglich gewesen. Solche Beispiele illustrieren zugleich die geringer werdende Bedeutung des Unterschieds zwischen nationalen und internationalen Forschungsprojekten, da auch nationale Investititionen von vorneherein als Beteiligung an einer internationalen Arbeitsteilung geplant werden müssen. Insbesondere wird sich die Partizipationsfähigkeit lokaler Forschungsprojekte an der internationalen, durch elektronische Kommunikation vermittelten Arbeitsteilung zunehmend zu einem entscheidenden Kriterium ihres Erfolges entwickeln.

Die genannten Veränderungen betreffen nicht nur die Natur- sondern auch die Geisteswissenschaften, wie sich an den Auswirkungen der elektronischen Medien auf Bibliotheken besonders deutlich ablesen läßt. Schließlich wird nicht nur die neuere wissenschaftliche Literatur sondern werden auch historische und literarische Dokumente zunehmend in elektronischer Form verfügbar und damit zu einer nicht mehr lokalisierten sondern global in elektronischen Netzen verfügbaren Resource der Forschung, die den Anlaß für das Stichwort der “virtuellen Bibliothek” gegeben hat. Obwohl sich diese Entwicklung schon seit geraumer Zeit vollzieht, befindet sie sich immer noch in einem Anfangsstadium, in dem die Auswirkungen auch auf die Geisteswissenschaften zwar im Prinzip absehbar werden, aber vor allem in Ermangelung einer kritischen Masse elektronisch verfügbarer und wissenschaftlich relevanter Information keineswegs in großem Maßstab alltagsrelevant geworden sind. Insbesondere sind in den Geisteswissenschaften Forschungsprojekte, die auf den durch die elektronische Informationstechnologie geschaffenen neuen Möglichkeiten der Arbeitsteiligkeit beruhen, noch die Ausnahme. Damit aus der prinzipiellen Möglichkeit dieser neuen Kooperationsformen Wirklichkeit wird, bedarf es nicht nur technischer Weiterentwicklungen, sondern auch der Gestaltung einer angemessenen Infrastruktur. Es geht dabei z. B. um die Festlegung von Standards, die die Struktur von Texten unabhängig von bestimmten technischen Systemen festzulegen gestatten, um die technische Implementierung dieser Standards, um die Lösung neuartiger Fragen des Urheber- und Verwertungsrechts, das die neuen Entwicklungen in seiner gegenwärtigen Form weitgehend blockiert, und um die Steuerung einer internationalen Arbeitsteiligkeit bei der Erstellung und Verfügbarmachung von elektronischen Resourcen wie Text-, Bild- und Softwarearchiven. In den USA ist z. B. das Center for Electronic Texts in the Humanities ein zentraler institutioneller Ort, an dem die Diskussion über diese Fragen geführt wird, während es in Deutschland an einem solchen institutionellen Forum noch fehlt.

Die problematische Ökologie des Informationsmeeres

Die globale elektronische Kommunikation bewirkt nicht nur eine veränderte, arbeitsteilige Nutzung lokaler Forschungsresourcen, sondern stellt ihrerseits eine neuartige Resource dar. Das Internet, an das fast 40 Millionen Benutzer angeschlossen sind, hat gewissermaßen ein "Informationsmeer" geschaffen, dessen "Ökologie" sich noch vorwiegend naturwüchsig entwickelt, langfristig aber nicht ohne Regulierung auskommt. Die Bedeutung dieser Resource läßt sich besonders deutlich an dem einfachen Phänomen der vielfach schnelleren Reaktionsmöglichkeit auf eine elektronische Publikation ablesen. Neue wissenschaftliche Ideen und technische Entwicklungen sind in elektronischen Informationsnetzen unmittelbar einem weltweiten spontanen Äquilibrationsprozeß ausgesetzt, der sie im Umfeld der verfügbaren Informationen und Erfahrungen überprüft, weiterentwickelt, korrigiert und eventuell zurückweist. Die Entwicklung komplexer Software wäre ohne diesen Äquilibrationsprozeß heute kaum noch denkbar. Elektronisch verfügbare Preprints sind in bestimmten Wissenschaftsbereichen bereits eine Selbstverständlichkeit; auch sie nutzen wegen der billigen Herstellbarkeit und der kürzeren Wartezeit auf Reaktionen das intellektuelle Potential der an der Kommunikation beteiligten Wissenschaftler effektiver aus als herkömmliche Publikationsstrategien. Ein schlagendes Beispiel für diese Effektivität ist die Diskussion um die sogenannte kalte Fusion. Während sich in der Diskussion im Internet schon etwa einen Monat nach Bekanntgabe der vermeintlichen Resultate im Frühjahr 1989 die Schlußfolgerung durchzusetzen begann, daß es sich bei den durchgeführten Experimenten keineswegs um eine bei Zimmertemperatur stattfindende Kernfusion handeln konnte, wurden bedeutende Investitionen in die Erforschung des zweifelhaften Effektes erst nach dieser Anfangsphase getätigt. In der Tat setzte sich die negative Bewertung der kalten Fusion in den maßgeblichen gedruckten Zeitschriften erst mit der für diese Medien charakteristischen Verspätung von ein bis zwei Jahren durch.

Käme es bei der Ausnutzung dieses Potentials ausschließlich auf die schnelle Verfügbarkeit von Informationen an, dann wären Hochleistungsnetze der einzig relevante Beitrag zur Infrastruktur des elektronischen Informationssystems. Die zumindest tendenziell erhebliche Vergrößerung des lokal und aktuell verfügbaren Wissensreservoirs stellt allerdings auch neue

Anforderungen an die Organisation des Wissens und damit an die kognitive und soziale Infrastruktur des elektronischen Informationssystems. Auch dafür gibt es bereits vielversprechende Ansätze im Internet, wie elektronische Zeitschriften, Preprint Server, Fachinformationsserver, moderierte und nicht moderierte Diskussionsgruppen, Suchinstrumente etc.. Angesichts der Tatsache, daß die Kommerzialisierung der elektronischen Kommunikationsnetze noch in einem Anfangsstadium ist, gibt es hier zur Zeit ein weites Experimentierfeld. Im Interesse der Forschung muß dieser Freiraum unbedingt erhalten bleiben und sollte dringend für die bewußte Gestaltung der weiteren Entwicklung genutzt werden. Dazu sind u. a. internationale Vereinbarungen zur Sicherung der nicht-kommerziellen Kommunikation und der nicht-kommerziellen Nutzung wissenschaftlich relevanter elektronischer Resourcen wie Bild- und Textarchive im Rahmen einer Anpassung von Urheber- und Verwertungsrechten erforderlich.

Innerhalb der Wissenschaft bedarf es zum einen einer Diskussion darüber, wie die Normen und Standards wissenschaftlicher Kooperation in den neuen Medien implementiert werden sollen, z. B. im Rahmen eines Referee-Systems für elektronische Veröffentlichungen. Dabei müssen auch die neuartigen Formen berücksichtigt werden, die elektronische Veröffentlichungen annehmen können. Sie müssen nicht mehr notwendigerweise den Charakter eines Artikels haben, sondern können u. a. in der Vernetzung bisher unkorrelierter Informationen bestehen. Eine elektronische Veröffentlichung könnte z. B. einem bereits publizierten Artkel eine wichtige Fußnote hinzufügen oder eine Datenbank um einen neuen Eintrag ergänzen. Zum anderen kann die Informationsflut nur durch neuartige Filterungs-, Klassifizierungs-, und Vernetzungsoperationen bewältigt werden, die zum Teil Gegenstand der normalen wissenschaftlichen Tätigkeit und zum Teil Gegenstand eines neuartigen Informationsmanagements werden. Die Rollenverteilung zwischen wissenschaftlichen Institutionen, Bibliotheken, Fachinformationszentren und Verlagen wird dabei zwangsläufig neu definiert werden.

Da sowohl die lokale Verwendbarkeit international verfügbarer Informationen als auch die internationale Verbreitung lokaler Informationen und mit beidem die Qualität der nationalen Forschung langfristig wesentlich von der Effektivität des Zugangs zum Informationssee abhängen wird, ist insbesondere die Weiterentwicklung von dezentralen Fachinformationssystemen, wie sie zur Zeit von verschiedenen Fachgesellschaften in Deutschland geplant wird, ein dringendes wissenschaftspolitisches Anliegen. Aber der Aufbau und die Betreuung einer solchen Informationsinfrastruktur setzt auch eine institutionelle Infrastruktur voraus, die bisher an Universitäten und Instituten oft mit knappen Mitteln improvisiert werden muß und die deshalb einer weitergehenden Förderung bedarf, z. B. im Rahmen des vom BMBF gegenwärtig vorbereiteten Programms mit dem Titel “Information als Rohstoff der Innovation”. Zu den ebenfalls aus forschungspolitischer Perspektive wünschenswerten strukturierenden Eingriffen in das Rauschen des Informationsmeeres kann auch die Gründung elektronischer Zeitschriften gehören.

Zu Recht hat z. B. der Vorsitzende des wissenschaftlichen Rates der MPG, Prof. Baltes, kürzlich darauf hingewiesen, daß die Gründung mehrsprachiger elektronischer Zeitschriften dazu beitragen könnte, die europäischen Traditionen bestimmter Forschungsgebiete wie der Psychologie wieder stärker in das Zentrum der internationalen Diskussion zu rücken.

Langfristig ist damit zu rechnen, daß die zunehmende elektronische Vernetzung wissenschaftlicher Informationen auch die Strukturierung der Inhalte wissenschaftlicher Arbeit und nicht zuletzt ihre Aufspaltung in disziplinäre Kompetenzen betreffen wird. Wenn wissenschaftliche Informationen nicht nur technisch sondern - durch die angesprochene Informationsinfrastruktur - auch intellektuell vielfältiger verfügbar werden, dann können sie auch leichter als bisher die Grenzen zwischen Disziplinen überwinden. Die “aktiven” Eigenschaften der neuen Techniken der Informationsverarbeitung können dazu wesentlich beitragen: Das amerikanische Perseus-Projekt z. B. macht altgriechische Texte in elektronischer Form zugänglich, und zwar zusammen mit modernen Übersetzungen und Programmen für ihre grammatische und lexikalische Analyse, so daß sich auch Tiefendimensionen dieser Texte nicht erst nach einem langen altphilologischen Studium erschließen sondern auch Fachfremden zugänglich werden. Weil zudem die wesentlichen Texte der griechischen Literatur in Verbindung mit tausenden von archäologischen Bilddokumenten präsentiert werden, bietet das Projekt insbesondere auch Studenten die Chance Philologie und Archäologie von vorneherein als Teilaspekte des Studiums der einen griechischen Kultur wahrzunehmen, statt sie nach ihren schriftlichen und nicht-schriftlichen Äußerungen zu zerteilen. Themenbezogene Umschlagplätze elektronischer Informationen verschiedenster disziplinärer Provenienz im Internet, wie z. B. das “Clearing House Project” zum Forschungsprojekt “Altern und Kognition” des Max-Planck-Instituts für Bildungsforschung, bilden ebenfalls mögliche Kristallisationspunkte für eine die traditionelle Disziplinenteilung überschreitende Organisationsform wissenschaftlichen Wissens.

Obwohl die bisherige Entwicklung, wie erwähnt, das Resultat eines weitgehend naturwüchsigen Wachstumsprozesses von Wissenschaft und Technik ist, erfordert die Ökologie des Informationssees in Zukunft vermehrt wissenschaftspolitische Interventionen angesichts entscheidbarer Alternativen, z. B. über die Begrenzung der Kommerzialisierung der Kommunikation und die Durchsetzung bestimmter Standardisierungen. Allerdings fehlt es wegen der an einem Kreuzweg von Wissenschaft, Technik, Wirtschaft und Politik liegenden Problemstellung, aber auch wegen der internationalen Dimension des Bedingungsgefüges bisher weitgehend an geeigneten institutionellen Akteuren. Das Problem der neuen Kommunikationsstrukturen der Wissenschaft ist ein typisches Beispiel für Probleme, in denen wissenschaftliche Expertise, Erwägung wirtschaftlicher Möglichkeiten, und politische Entscheidungsfindung nicht in einem sequentiellen Verhältnis zueinander stehen können. Wünschenswert sind daher neben der Schaffung von geeigneten Diskussionsforen insbesondere Modellversuche, die gerade die avancierteren Möglichkeiten der elektronischen Kommunikation in ihren technischen, sozialen und kognitiven Möglichkeiten unter realistischen Bedingungen ausloten.