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1 / Toward a More Developed Philosophy of Scientific Experimentation

1. The Philosophy of Scientific Experimentation

The development of the philosophy of scientific experimentation over the past twenty years has two main features. After a rapid start in the 1980s (see Hacking 1989a), it seems to have lost much of this momentum during the next decade. At the very least, the expectation that the study of experiment would become a major issue within received traditions in philosophy of science has not been fulfilled. To verify this, it is enough to glance through the recent volumes of well-known journals, such as *Philosophy of Science*, *British Journal for the Philosophy of Science*, *Erkenntnis,* and the like. Alternatively, one may look at recent anthologies, which could be supposed to represent the core readings in present-day philosophy of science. For example, the six-volume set of collected papers in philosophy of science (Sklar 2000) contains no contributions that focus on experimentation. And in the voluminous *Companion to Philosophy of Science* (Newton-Smith 2000) the explicit analysis of experimentation is almost completely limited to one chapter. Thus, the fact that many scientists, perhaps even the majority of them, spend most of their time doing experiments of various kinds is not reflected in the basic literature in the philosophy of science.

In this respect, a strong contrast can be seen between philosophical and historical or social scientific studies of science. This contrast marks the second feature of the present state of the philosophy of scientific experimentation. A brief perusal of recent volumes of leading science studies journals confirms the claim.

Studies in History and Philosophy of Science and *Social Studies of Science,* for example, offer many detailed historical and social scientific articles on experimental practice. In addition, a major recent anthology (Biagioli 1998) includes many contributions that explicitly deal with empirical and theoretical issues of scientific experimentation.

Thus, the philosophy of experimentation is still underdeveloped, especially as compared to historical and social scientific approaches (Radder 1998). Given this state of affairs, many philosophers of experiment agree that the field needs a new impulse (see Lelas 2000, 203; Harré, this volume, chap. 2; Hon, this volume, chap. 9). In this spirit, in June 2000 a workshop was held in Amsterdam, also entitled "Towards a More Developed Philosophy of Scientific Experimentation." The following chapters are the reworked and expanded results of that workshop.

Having described the present state of the art in the philosophy of experimentation in these terms, two qualifications are in order. The first is that, of course, the noted characteristics of contemporary philosophy of experiment represent a trend, not an exceptionless regularity. Thus, the volumes edited by Buchwald (1995) and by Heidelberger and Steinle (1998) contain a number of philosophical chapters of experiment, in addition to primarily historical studies. A perhaps more significant and promising fact is that a surprisingly large number of the papers presented at the recent 2000 Biannual Meeting of the Philosophy of Science Association addressed issues in the philosophy of scientific experimentation.

A second qualification has to do with the fact that historical and social scientific work on experimentation is often relevant to, and sometimes contains explicit discussions of, philosophical issues. So, proponents of a science studies approach might say, What is the problem? A comprehensive answer to this question would require a discussion of methodical and substantive similarities and dissimilarities between a philosophical and a historical or sociological approach to the study of science and, in particular, scientific experimentation. I cannot address this question in its full generality here.[1] Instead, I shall illustrate the need for a more developed philosophy of scientific experimentation by way of example.

Consider, for instance, the notion of stability. Within the science studies approach, a major feature of experimental practice is claimed to be the emergence of an interactive stability between a variety of heterogeneous elements of experimental practice; for example, material procedures, models of the instruments, and models of the phenomena under study (Pickering 1989). In such accounts, "stability" functions as a descriptive term for a situation that displays certain constant features (at least for a relatively long period). But in fact, the notion of stability is richer than mere lack of change, and a more developed philosophy of scientific experimentation should exploit this surplus meaning. If being stable implies being robust against actual and possible disturbances, then further philosophical questions immediately suggest themselves: What kind of disturbances are involved? What characteristics of the stabilization procedures can explain this robustness? Are those characteristics only of a factual or also of a normative nature? Generally speaking, dealing with such questions requires the more theoretical approach that is typical of philosophy.

As a second example, consider Latour's (1987) definition of an instrument as any setup that produces an inscription in a scientific text and, more generally, his interpretation of a laboratory as an "inscription factory." This definition and interpretation are discussed in the chapters by Rom Harré and Davis Baird. One of the criticisms put forward is that Latour's account of instruments is superficial because a comprehensive analysis of the role and function of scientific instruments is lacking. Hence, one of the goals of the present volume is to contribute to a more adequate account of the nature and role of instrumentation in experimental science (see also section 7). Another characteristic of Latour's approach is that it does not offer a conceptual account of the difference between an adequate and a useless instrument. Here we touch upon the issue of the evaluative and normative nature of philosophical accounts of science. Thus, in his contribution, Giora Hon argues that, for methodological reasons, there should be a clear distinction between the theories of the apparatus and material procedures, on the one hand, and the theoretical interpretation of the result of an experiment, on the other. Now, it is true that quite a few contemporary philosophers are naturalists who claim to be value-neutral and nonnormative. In spite of this, and rightly so, within philosophy the normativity issue is still alive and well, and here a further contrast with historical or sociological studies of science applies.

In this book, we focus on six central themes in the philosophy of scientific experimentation, which run through the entire volume: the material realization of experiments; experimentation and causality; the science-technology relationship; the role of theory in experimentation; modeling and (computer) experiments; and the scientific and philosophical significance of instrumentation. Each chapter deals with some of those themes, while each theme is discussed by various authors. In part, the themes are approached from complementary perspectives, and, in part, authors address each other's accounts of a relevant theme. The latter means that sometimes they use the same results or endorse the same views (for example, the chapters by Harré and Rothbart and by Baird and Kroes) and sometimes they challenge each other's accounts (for instance, the chapters by Woodward and Lange and by Heidelberger and myself). Wherever appropriate, I will highlight those agreements and disagreements. In the following six sections, I introduce and discuss our central themes. The final section briefly addresses some further issues that should be included in a mature philosophy of scientific experimentation.

To conclude, I would like to make one further observation. This book is a plea for a philosophy of experimentation as a subject in its own right. Yet, the philosophy of scientific experimentation should not degenerate into a philosophical "-ism"; in this case, "experimentalism." That is to say, taking full account of scientific experimentation does not commit one to the doctrine that all philosophical problems regarding science can be completely resolved on the basis of an analysis of experiment only.[2]

2. The Material Realization of Experiments and Its Philosophical Significance

In experiments we actively interfere with the material world. In one way or another, experimentation involves the material realization of an experimental process (the object[s] of study, the apparatus, and their interaction). The question, then, is this: What are the implications of this action and production character of scientific experimentation for philosophical debates on ontological, epistemological, and methodological issues about science?

A general ontological lesson appears to be the following. The action and production character of experimentation entails that the actual experimental objects and phenomena themselves are, at least in part, produced by human intervention. For this reason, if one does not want to endorse a full-fledged constructivism—according to which the experimental objects and processes are nothing but artificial, human creations—one needs to go beyond an actualist ontology and introduce more differentiated ontological categorizations.[3] This is precisely what is at issue in several chapters. Thus, Rom Harré argues that an adequate ontological interpretation of experimental science needs some kind of dispositional concepts, namely Gibsonian affordances. In the same spirit, Daniel Rothbart analyzes the practice of experimental design, the role of experimental reproducibility, and the conception of nature as a machine. He concludes that the use of pictorial symbols, the procedure of "virtual witnessing," and the role of the specimen in instrumentation entail the need to include nonactualist notions, such as possibility, capacity, and tendency, into the ontology of experimental science. Peter Kroes starts from a different problem context, namely the question of whether the distinction between natural and artificial objects and processes still makes sense for modern physical science. Kroes concludes that experimental interventions do create the actual, artificial "instances" of phenomena, but not the natural phenomena as such. Thus, by making such a distinction, he in fact presupposes a nonactualist ontology as well.

Next to ontological problems, the interventionist character of experimentation engenders epistemological questions as well. An important question is whether scientists, on the basis of artificial experimental intervention, can acquire knowledge of a human-independent nature. According to Harré, such back inferences, from the artificial laboratory systems to their natural counterparts, are possible in a number of cases, but their justification is different for different types of apparatus.

Another approach accepts the constructed nature of much experimental science but stresses the fact that its results acquire a certain endurance and autonomy with respect to both the context in which they have been realized in the first place and later developments. In this spirit, Davis Baird offers a neo-Popperian account of "objective thing knowledge," the knowledge encapsulated in material things. Illustrations of such knowledge are Watson and Crick's material double helix model, Davenport's rotary electromagnetic motor, and the indicator of Watt and Southern's steam engine.[4] Baird suggests analogues of the standard epistemological notions of truth, justification, and delocalization for the case of thing knowledge. On this basis, thing knowledge is claimed to be objective in the sense of transcending its context of creation. This idea of transcendence can be seen as complementary to Popper's account of objective propositional knowledge, according to which human ideas, problems, arguments, and the like can transcend their context of discovery toward an autonomous ontological domain.

A further epistemologically relevant feature of experimental science is the fact that scientific apparatus often works in the absence of an agreement on exactly how it does so. An example discussed by Baird is Faraday's electromotor in its early days. Thus, in scientific practice a significant distinction obtains between the working of apparatus and their theoretical accounts. More particularly, the claim is that variety and variability at the theoretical and ontological level may well go together with a considerable stability at the level of the material realization of experiments. Such claims can be used for philosophical purposes; for example, to vindicate an instrumental realism, as is done in Jim Woodward's contribution, or a referential realism, as I have proposed elsewhere (Radder 1988; 1996, 4.2).

Given the arguments and views set out so far, a natural question is whether they license or perhaps even entail a full-fledged materialism, in the ontological sense of that term. Although not all of the authors mentioned discuss this question in an explicit way, the answer is certainly not an unambivalent "yes." Baird, for one, explicitly leaves room for theoretical knowledge and abstract Popperian world-3 entities. Kroes emphasizes the indispensability of functions and their irreducibility to physical structures, and he argues that experimental and technological objects, being simultaneously physical and functional entities, possess a dual nature. The critical issue, then, is whether the methodologically indispensable notion of function should, or should not, be taken into account ontologically.

3. Experimentation and Causality

Theoretical and empirical studies of experimentation are preeminently suited to an investigation of the issue of causality. Conversely, the philosophy of scientific experimentation may fruitfully employ insights gained in the debate on causality (see, for example, Guala 1999b). In the following chapters, at least three different approaches can be found.

First, the role of causality in experimental processes and experimental practice may be analyzed. Both Rom Harré and Michael Heidelberger advocate a differentiated account of this role. Harré speaks of causally based instruments and distinguishes these from other types of apparatus. Following Cartwright (1983) and Hacking (1983a), Heidelberger intends to make a clear contrast between a causal and a theoretical level in scientific experimentation.

An issue that is relevant here is whether experimentation can be characterized as fully causal or whether free or intentional action is important as well. This issue is explicitly addressed in the contributions by Peter Kroes, Jim Woodward, and Rainer Lange. Interestingly, Niels Bohr, in his analyses of experimentation in atomic physics, has already dealt with this issue. He claimed that experimenters need a free choice of, first, where to put the necessary boundary between the instrument and the object under investigation and, second, which one of two complementary phenomena they decide to realize (Bohr 1958, 1963; Scheibe 1973, 25; Radder 1979, 427–428). In a different tradition, Peter Janich has emphasized the indispensability of free and intentional action—as contrasted with caused behavior—for an adequate account of scientific experimentation (Janich 1998, 102–107). The basic point, for both Bohr and Janich, is that in experimental interventions, we intentionally bring about certain states of affairs that would not have arisen without our interference, while we could have chosen to realize other states instead.

A second approach involves analyzing the role of experimentation in interpreting and testing causal claims. This is the approach chosen by Jim Woodward. Building on methodological literature on causation in the biomedical, behavioral, and social sciences, he introduces a specific version of the idea of (experimental) intervention. On this basis, he develops his view that causal inferences can only be justified through (possibly hypothetical) experimental interventions and not through "passive" observations. Basically, a causal claim is about what would happen if certain experiments were to be performed. Hence, this approach goes beyond the Humean regularity theory, in which the causal relation is reduced to a constant conjunction of two actually occurring events of a particular type. Woodward emphasizes that what he offers is a criterion of causality. Because the explanation of the notion of intervention itself employs the concept of causal processes, we do not have a reduction of causality to experimental intervention. From Woodward's perspective, a disadvantage of such a reduction would be that it makes causal processes in nature dependent on human action, and hence the resulting account would be anthropomorphic and subjectivist.

A third approach, however, just tries to do this: to explain the notion of causality on the basis of the notions of action and manipulation. This view is represented by Rainer Lange (see also Von Wright 1971; Janich 1998, 107–110). The central idea is to make use of a distinction between the intentional bringing about and the causal coming about of the states of experimental systems. Lange claims that this version of the manipulability account of causality need not be subjective or anthropomorphic, and that it contrasts with Woodward's version in being noncircular.

4. The Science-Technology Relationship

In my introductory section I pointed out that a decisive breakthrough of the topic of scientific experimentation within the philosophy of science has not yet been accomplished. The reason may be that many philosophers deem a topic significant to the extent that it contributes to reaching what they see as the aim, or the aims, of science. Traditionally, philosophers of science have defined the aim of science as, roughly, the generation of reliable knowledge of the world. Moreover, as a consequence of explicit or implicit empiricist influences, there has been a strong tendency to take the production of empirical knowledge for granted. From this perspective, then, the only interesting philosophical problems concern theoretical knowledge and its relationship to this taken-for-granted empirical base.

However, if we take a more empirical look at the sciences, both at their historical development and at their current condition, this perspective must be qualified as quite one-sided, to say the least. After all, from Archimedes' lever and pulley systems to the cloned sheep Dolly, the development of science has been intricately interwoven with the development of technology (see Tiles and Oberdiek 1995; Joerges and Shinn 2001). Hence, if one wants to attribute any aims to science, making a contribution to technology should certainly be one of them. From this alternative perspective, the relevance of experimentation for philosophy hardly needs any further justification. After all, experiments make essential use of (often specifically designed) technological devices and they often contribute to technological innovations. Moreover, there are substantial conceptual similarities between the realization of experimental and that of technological processes, most significantly the implied possibility and necessity of the manipulation and control of nature (see Radder 1987; 1996, chap. 6; Lee 1999, chap. 2).

In sum, if philosophers keep neglecting the technological dimension of science, experimentation will continue to be seen as a mere data provider for the evaluation of theories. If they start taking the science-technology relationship seriously, however, doing experiments can be studied as a topic in its own right, which poses—as we hope to show in this volume—many interesting and important philosophical questions.

One obvious way to study the role of technology in science is to focus on the instruments and equipment employed in laboratory experiments. Several chapters of this book take this route, and I will return to this approach in section 7. Here, I would like to focus on the general philosophical significance of the experiment-technology relationship. Quite a few philosophers who emphasize the relevance of technology for science endorse a "science-as-technology" account. That is to say, they advocate an overall interpretation in which the nature of science—not just experimental but also theoretical science—is seen as basically or primarily technological (see, for instance, Dingler 1928; Habermas 1978; Janich 1978; Latour 1987; Lelas 1993, 2000; Lee 1999).

Most chapters of this book, however, take a less radical view. As we have seen, Davis Baird argues for the importance of thing knowledge on a par with theoretical knowledge. Rainer Lange emphasizes the conceptual and historical proximity of (experimental) science and technology primarily through his notion of a reproducible experimental instruction; but he also argues that scientific laws cannot be reduced to technological operations. Michael Heidelberger distinguishes a theoretical level, where interpretation and representation take place, from a relatively independent causal level, where (technological) production and construction of phenomena prevail. In my own chapter, I take account of two essential aspects of scientific experimentation, its material realization and its theoretical interpretation. In particular, I offer an argument for the irreducibility of the theoretical meaning of replicable experimental results. Thus, while stressing the significance of the technological—or perhaps more precisely, the action and production—dimension of science, these views nevertheless see this dimension as complementary to a theoretical dimension.

5. Theory and Theoretical Knowledge in Experimental Practice

We are now led to a further central theme in the philosophy of scientific experimentation, namely the relationship between theory and experiment. The theme can be approached from two sides. First, one may study the role of existing theories, or theoretical knowledge, within experimental practices. This will include a discussion of the view of experiments as (mere) tests of theories. The overarching issue concerns the claimed (relative) autonomy of experimental science from theory.

The most far-reaching position is that, basically, experimentation is theory-free. The German school of "methodical culturalism" seems to come close to this position (Janich 1998; for a review, see Lange 1999, chap. 3). A more differentiated view is that, in important cases, theory-free experimentation is possible and occurs in scientific practice. Hacking (1983a) and Steinle (1998) make this claim primarily on the basis of a number of case studies from the history of experimental science. In his contribution, Michael Heidelberger aims at a more systematic underpinning of this view. He discusses the notions of theory ladenness put forward by Hanson, Duhem, and Kuhn and shows that they differ significantly. In particular, he argues that, for Hanson, theory ladenness primarily means "causality ladenness." Next, Heidelberger suggests that causal issues in experimentation can and should be distinguished from theoretical issues. The same distinction returns in his classification of scientific instruments. While experiments with "representative" instruments are theory-laden, the use of "productive," "constructive," or "imitative" instruments is causally based and claimed to be theory-free.

Still another view admits that not all concrete activities that can be discerned in scientific practice are guided by theories. Yet, according to this view, if certain activities are to count as a genuine experiment, they require a theoretical interpretation. This is the view I argue for in my own contribution (chapter 8), both on the basis of systematic philosophical arguments and on the basis of a criticism of cases of claimed theory-free experiments. Something like this view seems to be implied in Giora Hon's chapter. In the spirit of Francis Bacon, he proposes a systematic theory of the types of errors that may arise, and hence should be avoided, in performing and interpreting experiments (see also Hon

1989b, 1998a). This typology of errors is based on an account of scientific experimentation in which both theoretical knowledge and material realization play an indispensable role, and it is meant to illuminate the epistemic structure of experiments.

Two points, briefly discussed in my chapter, are crucial in settling the issue of the role of theory in scientific experiments. The first is that even posing the question of whether or not theory-free experiments are possible presupposes some notion of what we understand by "an experiment." Second, since nobody seems to deny that some kind of interpretation plays a role in performing and understanding experiments, the critical question is whether this interpretation is "theoretical" or not. Can we distinguish different kinds and levels of (theoretical) interpretation and, if so, what are the philosophical implications of such a "compartmentalization"? As I mentioned in section 1, Hon takes the view that the theories of the apparatus and material procedures can and should be distinguished from the theoretical interpretation of the result of the experiment. My own view is that such a compartmentalization of theories—if possible at all—may be helpful in dealing with some philosophical problems (in particular, the issue of circularity in testing theories) but not with others (primarily, the realism problem).

The second major approach to the experiment-theory relationship addresses the question of how theory may arise from material experimental practices, or, in Hon's terms, how to conceptualize the transition from the material process to propositional, theoretical knowledge. And, of course, even if experimental research is not merely a means to theoretical knowledge, experiment does play an epistemic role with respect to the formation of scientific theories. A balanced philosophical study of this issue may profit both from "relativist" science studies approaches (for example, Collins 1985; Gooding 1990) and from "rationalist" epistemological approaches (for example, Franklin 1986, 1990; Mayo 1996).

One aspect of the transition from experimental practices to theoretical knowledge is discussed in David Gooding's chapter. He argues that the mathematical nature of scientific theories is intrinsically connected to the possibility of quantitative measurement. Moreover, often the precision and repeatability required for quantification cannot be found in nature but has to be technologically manufactured.

My own approach to this issue—see chapter 8—is by means of a novel notion of abstraction. Abstraction, as a first major step toward the formation of theories, plays a significant role in experimental practice. It occurs whenever experimenters attempt to replicate experimental results by means of completely different processes. That is to say, a replicability claim entails an abstraction from the particular material circumstances and procedures through which the experiment has been realized so far.[5] I argue that such claims possess a nonlocal, theoretical meaning that cannot be reduced to the meaning of a fixed set of material realizations. By way of example, I briefly discuss the role of abstraction in the experiments that contributed to Edison's invention of the incandescent lamp.

6. Experiment, Modeling, and (Computer) Simulation

Over the past decades, the scientific significance of computer modeling and simulation has increased greatly. Many scientists nowadays are involved in what they call "computer experiments." Apart from its intrinsic interest, this development invites a philosophical discussion of what is meant by these computer experiments and how they relate to ordinary experiments.

The chapters by Evelyn Fox Keller and Mary Morgan deal with this topic. Both offer a classification of computer modeling and simulation. Keller proposes a historical typology, primarily derived from the development of the physical sciences during the last half century but with applications in the biological sciences. Within this development she distinguishes three different stages. The first uses of computer simulation were meant to provide an alternative to (cumbersome or unfeasible) mathematical methods. They are sometimes called "experimental" because of their nonanalytical and exploratory nature: they aim to solve certain problems in mathematical physics, which have proved to be intractable so far, by means of novel computational techniques. In the second stage we meet with "computer experiments" proper. Here it is the physical systems (for example, the molecular dynamics of gases or liquids) that are being simulated by theoretical models. The experiments, then, consist in varying certain parameters (for example, density or temperature), noting what happens in the model, and comparing the outcomes to observed features of the systems. The third stage tries to model phenomena for which no theory exists so far. Here Keller discusses "artificial life" studies, in which the modeled phenomena exhibit certain patterns that are similar to global processes of biological self-reproduction or evolution. Again, it is the opportunity for artificial manipulation of parameters of the model objects that motivates scientists to call this approach "experimental."

In section 2 I emphasized, with most of the authors of this volume, the significance of material realization for scientific experimentation. Scientists, however, often use the term "experiment" in a looser and more varied sense.[6] This is quite clear in the examples of model and computer experiments discussed in the chapters by Keller and Morgan. Here, the relevant models are conceptual or theoretical, in contrast to the physical or material models dealt with in Harré's and Baird's contributions. This raises the obvious question of the relationship between ordinary experiments and such model or computer experiments. This question is discussed in detail in Mary Morgan's contribution. In contrast to the historical approach by Keller, she offers a systematic typology of modeling and simulation experiments. It is based on a theoretical analysis in which the types are distinguished according to their kind of controls, their mode of demonstration, their degree of materiality, and their representational validity. Morgan discusses a number of experiments in mechanics, biology, and economics and classifies them on a continuum: from setups that materially intervene in a straightforward sense to the types of virtually, virtual, and model experiments. In this order, these types of experiment exhibit an ever decreasing amount of material intervention, while the ways in which they represent the world can be seen to vary as well.

Thus, in scientific practice we find various sorts of hybrids of material interventions, computer simulations, and theoretical and mathematical modeling techniques. Often, more traditional experimental approaches are challenged and replaced by approaches based fully or primarily on simulations or mathematical models (sometimes this replacement is based on budgetary considerations only). This development raises interesting questions for a philosophy of scientific experimentation. Prominently, there is the epistemological question of the reliability of the results of the new approaches. Mary Morgan suggests that experiments with a substantial material component should remain the standard because, generally speaking, they possess the greater epistemic power. Evelyn Fox Keller's assessment is more implicit, but she does seem to be wary of overly simplistic identifications of simulated reality with the real world, suggested by seductive computer imaging techniques (for instance, in the area of artificial life).

A further question raised by these chapters is metaphilosophical. How should the philosopher's notion of experiment relate to scientists' usages? Of course, this is just one example of a quite general hermeneutical issue: to what extent should scholars in the human sciences take into account the concepts and interpretations of the people who are being studied? When scientists use the notion of experiment in a broad sense—for example, by speaking of computer experiments—should philosophers follow them? Answers to these questions depend on the conception of philosophy one adheres to. Thus, if one aims at descriptive adequacy with respect to scientific practice, it is natural to be alert to actor uses and meanings and to the way these uses and meanings change over time (for example, Galison 1997). If one aims to uncover and evaluate general features or underlying principles of science, one will look for fruitful theoretical concepts, plausible generalizations, and reliable research standards. This approach is exemplified in Giora Hon's chapter, which proposes a general theory of experimental error based on a systematic and normative account of scientific experimentation. I myself see philosophy as primarily a theoretical, normative, and reflexive activity (Radder 1996, chap. 8). From this perspective, philosophy retains a relative autonomy vis-à-vis scientific practice (Radder 1997). Thus, as I argue in my own chapter, if we put forward philosophical claims about scientific experiments we need to make explicit what we understand by "experiment." In doing so, we draw on insights gained from descriptive studies of scientific practice, but we go beyond those studies by taking into account philosophical concerns and conceptions as well.

7. The Scientific and Philosophical Significance of Instruments

Both the older literature (for example, Gooding, Pinch, and Schaffer 1989) and the present collection of papers show that the study of scientific instruments is a rich source of insights for a philosophy of scientific experimentation. The chapters of this book exhibit a variety of features of the design, operation, and wider uses of instruments, and they discuss many of their philosophical implications. To give some idea of those features and implications I will briefly sum up the various descriptive and interpretive accounts, in as far as they have not yet come up in the previous sections.

Daniel Rothbart focuses on the design process. He points out the importance of schematic, pictorial symbols in designing scientific instruments, and he analyzes the perceptual and functional information that is being stored in those images. Philosophical themes of his chapter include the nature of visual perception, the relationship between thought and vision, the role of reproducibility as a norm for experimental research, and the ontological conception of nature as a nomological machine.

The contribution by David Gooding deals with the modes of representation of instrumentally mediated experimental outcomes. Gooding contrasts visual and verbal modes of representation with numerical and digital ones. His principal claim is that over the past centuries the former modes of representation seem to have been superseded by the latter, but a complete replacement of qualitative sensation and conceptual interpretation with quantitative measurement and formal calculation is neither possible nor desirable. A premise of this claim is the view that, ultimately, human beings are and will remain analogical by nature. Gooding illustrates his account with examples taken from experimental science and from research in artificial intelligence.[7]

Several authors propose classifications of scientific instruments or apparatus. As we have already seen, both Davis Baird and Michael Heidelberger suggest a typology of instruments with respect to their epistemic function. Baird distinguishes between instruments that generate material representations, instruments that present phenomena, and measuring instruments. Heidelberger identifies productive, constructive, imitative, and representative types of instruments. In drawing philosophical conclusions Heidelberger employs his typology of instrumentation to argue for the possibility of theory-free experiments, while Baird focuses on the notion of thing knowledge as a complement to propositional knowledge. Finally, Rom Harré's classification is based on distinct ontological relationships between laboratory equipment and the world. In his case, the epistemic functions of this equipment are derived from these ontological relationships. His prime distinction is that between "instruments" and "apparatus." Instruments are characterized by their causal relation to the (outside) world, and they enable a clear separation between the natural object and its measuring device. In contrast, apparatus are said to be "part of nature" because they either are inseparable from or (almost) identical to natural objects.

Thus, we have a variety of classifications of scientific instrumentation. They form, I think, an excellent starting point for investigating further questions. Do these classifications, taken together, exhaust the types and uses of scientific instruments? Where exactly do they overlap and where do they differ? To what extent are they compatible or complementary? And, last but not least, how plausible are the philosophical conclusions inferred from these classifications?

In concluding this section, I would like to add one point of comment. Surely, an analysis of instruments is indispensable for the philosophy of scientific experimentation; yet, an exclusive focus on the instruments as such may tend to ignore two things. First, an experimental setup often includes various "devices," such as a concrete wall to shield off dangerous radiation, a support to hold a thermometer, a spoon to stir a liquid, curtains to darken a room, and so on. Such devices are usually not called instruments, but they are equally crucial to a successful performance and interpretation of the experiment and hence should be taken into account. Second, a strong emphasis on instruments may lead to a neglect of the environment of the experimental system, especially of the requirement to realize a "closed system." I stress this point in my own chapter, in the account of Boyle's air-pump experiments. The point also arises in Rainer Lange's treatment of experimental disturbances and in Mary Morgan's discussion of experimental controls (see also Boumans 1999). In sum, a comprehensive view of scientific experimentation needs to go beyond an analysis of the instrument as such by taking full account of the specific setting in which the instrument needs to function.

8. Further Issues for a Mature Philosophy of Scientific Experimentation

Even if we have made an effort to address the most important themes from the philosophy of scientific experimentation, a volume like this cannot claim to offer a complete account (if such a thing exists). Further research is possible and desirable. In my view, a mature philosophy of scientific experimentation should systematically address, at least, these additional issues: the relationship between scientific observation and experiment; experimentation in the social and human sciences; and the various normative and social questions of scientific experimentation.

The study of the relation between experiment and observation may be pursued in several ways. First, we need to develop a philosophical account of how observations are realized in scientific practice and to what extent they differ from experiments. Here some work has been done already (see, for example, Pinch 1985; Gooding 1990). What has been shown as well is that, in actual practice, making scientific observations often includes doing genuine experiments. This is quite clear in the case of solar and stellar astrophysics (see Schaffer 1995; Hentschel 1998).

Next, the results of such studies should be used to develop a new conception of scientific experience, a conception that leaves behind all empiricist accounts in which experience is somehow seen as foundational and hence as philosophically unproblematic.[8] Such a novel view of experience should also be informed by knowledge of ordinary perception that has been developed within the cognitive sciences. Examples of such an approach can be found in Daniel Rothbart's use of Gibson's theory of perception and in David Gooding's discussion of the interaction between qualitative, ordinary experience and quantitative, technologically enhanced experience.

Finally, there is the question of whether or not significant epistemic differences exist between observation and experiment. With respect to causality, Jim Woodward's contribution affirms the epistemic importance of the observation-experiment contrast. He claims that causal inferences based on purely observational evidence often prove to be spurious. Something analogous has been done by Ian Hacking regarding the issue of scientific realism. In this case, it is claimed that observation alone cannot justify our belief in the reality of theoretical entities, while experimental manipulation can (Hacking 1989b). These claims certainly do not exhaust the range of views that can be taken with respect to this question, and further contributions are most welcome.

A second issue that merits more attention is the role of experimentation in the social and human sciences, such as economics, sociology, medicine, and psychology. Practitioners of those sciences often label substantial, or even large, parts of their activities as "experimental."[9] So far, this fact is not reflected in the philosophical literature on experimentation, which has primarily focused on the natural sciences. For example, the *Routledge Encyclopedia of Philosophy* (Craig 1998) has an entry on "Experiment" and one on "Experiments in Social Science," and the remarkable fact is that the two accounts appear to be almost totally unrelated. A sign of this is that their reference lists are completely different. Thus, one challenge for future research is to connect the primarily methodological literature on experimenting in medicine, psychology, economics, and sociology with the philosophy of science literature on experimentation. In the present volume, Mary Morgan has made a start with taking up this challenge, and Jim Woodward's chapter includes relevant material, but of course much more can be done.

One subject that will naturally arise in philosophical reflection upon the similarities and dissimilarities of natural and social or human sciences is the problem of the double hermeneutic. Although it is true that the nature of this problem has been transformed by the more recent philosophical accounts of the practices of the natural sciences (cf. Rouse 1987, chap. 6), the problem has by no means been resolved. Its point is this: in addition to the interpretations of the scientists, in experiments on human beings the experimental subjects will often have their own interpretation of what is going on in these experiments, and this interpretation may influence their responses over and above the behavior intended by the experimenters. As a methodological problem (of how to avoid "biased" responses) this is of course well-known to practitioners of the human and social sciences. However, from a broader philosophical or sociocultural perspective, the problem is not necessarily one of bias. It may also reflect a clash between a scientific and a life-world interpretation of human beings.[10] In case of such a clash, social and ethical issues are at stake, since the basic question is who is entitled to define the nature of human beings: the scientists or the people themselves? In this form, the methodological, ethical, and social problems of the double hermeneutic will continue to be a significant theme for the study of experimentation in the human and social sciences.

This brings us to our last issue. So far, within the philosophy of scientific experimentation the study of normative and social questions is clearly underdeveloped. This applies to the present volume as well. To be sure, the subject of epistemic normativity—primarily related to the proper functioning of instruments—is briefly mentioned in some of the chapters, but questions regarding the connections between epistemic and social or ethical normativity are hardly addressed. Posing such questions, however, is not at all far-fetched, and they often relate to ontological, epistemological, or methodological concerns quite directly (see Radder 1996, chaps. 6–7). Following are some examples.

First, those experiments that use animals or humans as experimental subjects are confronted with a variety of normative questions. In the case of humans, some of these came up in the above discussion of the double hermeneutic, but there are many more. By way of illustration, consider medical research, where experimental tests of therapies and drugs are increasingly carried out in developing countries. In addition to the question of the realizability of adequate testing conditions in those countries, this shift leads to many serious ethical problems resulting from the tension between the well-being of the subjects and the methodological requirements of the experimental trials (see, for example, Rothman 2000). The actual and potential conflicts arising from the increasingly intimate connections between medicine and the pharmaceutical industry constitute another area for future research. In these cases, the conflicts often involve clashes between commercial interests and methodological or ethical standards (see, for example, Horton 2001).

The issue of causality is socially and normatively relevant as well. Just think of the case, discussed in Woodward's chapter, of the social scientific claim that there is a link between being female and being discriminated against in hiring and salary. Here, it makes a social and normative difference whether this link is genuinely causal or a mere correlation due to an underlying common cause. More generally, proposed policies and interventions often seek a causal underpinning in order to be seen as really effective. A clear case is drug testing, where statistical results of observations gain credibility if they can be supported by causal accounts of experimental tests. Yet, in medicine an exclusive focus on objective, causal mechanisms is also being contested (for example, Richards 1991). One type of argument refers to the placebo effect, which, somewhat paradoxically, is one of the prime reasons for the practice of double-blind trials. Another argument stresses that causal knowledge of laboratory experiments does not automatically lead to successful therapeutic uses outside the laboratory.

Finally, consider the question of the contrast between the natural and the artificial, mentioned in section 2. This question is often discussed in environmental philosophy, and different answers to it may entail different environmental policies (see Lee 1999). More specifically, the issue is crucial to debates about patenting, in particular the patenting of genes and other parts of organisms. The reason is that discoveries of natural phenomena are not patentable, while inventions of artificial phenomena are (see Sterckx 2000).

Although philosophers of experiment cannot be expected to solve all of those broader social and normative problems, they may be legitimately asked to contribute to the debate on possible approaches and solutions. In this respect, the philosophy of scientific experimentation could profit from its kinship to the philosophy of technology, which has always shown a keen sensitivity to the interconnectedness between technical and social or normative issues (see, for example, Mitcham 1994).

NOTES

1. For a detailed discussion of this issue, see Radder (1996, chap. 8).

2. See, with respect to the issue of experimental realism, Radder (1996, 75–76).

3. On experimentation and the ontology of actualism, see Bhaskar (1978), Harré (1986), and Radder (1996, chap. 4).

4. According to Baird, the idea of "reading" an instrument points to a hermeneutics of material (in contrast to textual) representation. This subject has been discussed in more detail in Heelan (1983) and Ihde (1990).

5. Thus, this notion of abstraction differs from the usual one, which is mostly defined as the inference of a universal concept from its particular instantiations. This kind of abstraction and its role in scientific practice is discussed and assessed in Gooding's chapter.

6. Such broader usages are understandable enough, given the fact that, in ordinary language, experimenting often has the general meaning of trying out something new.

7. His overall position is congenial to Patrick Heelan's view of the anthropological primacy of hyperbolic over Euclidean vision. See Heelan (1983, especially chaps. 14 and 15).

8. In this respect, Van Fraassen's constructive empiricism is typical in that a substantial account of experience and observation is conspicuously absent (see Van Fraassen 1980).

9. Cf. Dehue (1997) on the rise of comparative randomized experiments in the life sciences, psychology, and the social sciences.

10. See, e.g., Feenberg (1995, chap. 5). This chapter, "On Being a Human Subject: AIDS and the Crisis of Experimental Medicine," describes a case of AIDS patients who challenged the established methodological and ethical separation of cure and care.