Do not despair

Do Not Despair: There Is Life after Constructivism

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This article reviews recent work in socio-historical technology studies. Four problems, frequently mentioned in critical debates, are discussed—relativism, reflexivity, theory, and practice. The main body of the article is devoted to a discussion of the latter two problems. Requirements for a theory on socio-technical change are proposed, and one concrete example of a conceptual framework that meets these requirements is discussed. The second point of the article is to argue that present (science and) technology studies are now able to break away from a too academic, internalistic perspective and return to the politically relevant "Science, Technology & Society" issues that informed much of this work more than a decade ago.

Prologue

On Monday 16 October 1989, Trevor Pinch and I were driving on Interstate 880 through Oakland, California. The world in which we were living was self-evident and without ambiguities (at least after we had managed to shift to the right lane and thus avoided being forced over the Bay Bridge into San Francisco). We hardly noticed the road while passing over its Nimitz section. We did not notice the pillars of the Cypress Structure, as the double-deck freeway was locally called; we did not notice the houses down by the freeway; nor were we particularly interested in its history.

The next day, 17 October 1989 at 5:04 p.m., the earth trembled. I was thrown off my feet and onto the bed on a sixth floor hotel room in Berkeley. An earthquake had hit. Interstate 880 and its Cypress Structure collapsed.

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The unambiguous, self-evident world through which we had been cruising the day before was ruptured. Before our eyes, when glued to the TV set and frantically making notes, all of the elements that had made up Interstate 880 were revealed, as indeed they were to the general public. Its technical components were uncovered: Everybody learned that the concrete pillars in that structure were reinforced with vertical steel rods only, without an additional spiral rod. Its political elements were revealed: Washington politicians started to use words like "blame" and "investigation." Its economic elements were uncovered: Some engineers claimed that they had known about the weakness of the structure but that funds had been lacking to carry out the planned reinforcement. Its social elements were revealed: A man stood up from the audience and accused the expert panel in a direct TV broadcast: "I was the first to start helping those people in their cars; I live in those houses, you know. I live in those houses you always drive by, looking down upon us; but nobody came to me and asked how it was, though I was the first there; and you always drive by, looking down upon us; you always drive by, looking down upon us."[1]

The quake did an effective job in revealing the constitutive elements in this sociotechnical world. It did to the Cypress Structure what students of technology are trying to do to bicycles, missile guidance, subway systems, electric power networks, steel, and computer software. Can students of sociotechnical change, although causing less damage, be as effective as the quake?

Introduction

Over the last 10 years, technology studies have experienced a veritable boom. Economic studies of technical change and integrated sociological-historical studies are the most visible bodies of work. In this article, I concentrate on the latter, realizing that the important question of how to relate these two disciplinary contributions is thus left aside for the moment.[2] The aim of the article is primarily to offer an overview of current issues in technology studies, rather than presenting a specific new empirical or theoretical claim.[3]

In a rough and whiggish historical sketch, the integrated field of historical-sociological studies of technology can be depicted as a child of two parents: the (mainly American) history of technology and the (mainly European) sociology of scientific knowledge. An international workshop in 1984 has been mentioned as the birthplace of the child.[4] As most children, at that moment it was promising, but not much more than promising. The main thrust of the workshop papers was programmatic, although the published versions were already more empirically grounded. An informal research program could be distinguished, consisting of three approaches—the systems approach, the actor-network approach, and the social-constructivist approach. From a distance (either geographically, from America, or disciplinary, from philosophy or economics), these three lines within the program were often collapsed onto another and simply labeled *social constructivism.* To answer the question whether this new research program was able to generate fruitful empirical research, a second workshop was held in 1987, and the answer to this question was unambiguously yes.[5] Now the question is raised, Where do we go from here? Toward some kind of postconstructivism? Or perhaps to more constructivism?

In this article, I start with a brief assessment of the present state of the art in sociological-historical studies of technology. Is there "something rotten" in the state of technology studies? I will then specifically address the question of explanations, come briefly to the issue of practice and theory, and conclude by addressing the question, Where do we go from here?

State of the Art—State of Despair?

The sociological-historical studies of technology may be producing an increasing number of case studies, but there are some persistent problems that, some commentators seem to think, threaten to incapacitate the whole endeavor. I will briefly discuss four of these problems: relativism, reflexivity, theory, and practice.

Two problems with the *relativist* elements in recent social studies of technology are often mentioned. The first relates to ontological relativism, the second to normative relativism. As I will discuss in the next section more extensively, the pleas for relativism in technology studies are, however, primarily methodological. I tend to agree with Collins (1985) that epistemological, or ontological, relativism cannot be confirmed or falsified by empirical studies. Thus social-constructivist studies of technology do not imply any ontological position. The normative problem, as formulated by Russell (1986), for example, stems from the idea that the plea for methodological relativism implies a form of political relativism, for instance, with respect to questions of the societal impact of technology, the deskilling of labor by technical innovations, or the democratic control of technology. My reaction to this accusation is similar to Voltaire's when he was accused of letting all norms and values be eroded because he proclaimed that God does not exist. Voltaire reportedly replied that the fact that God is dead did not mean that everything was now allowed—it only meant that things were not allowed for reasons different from the biblical reasons. Similarly, on the basis of relativistic studies of technology, it is possible to argue for political and ethical positions with respect to technological choices.[6]

The problem of *reflexivity* has primarily been formulated with respect to science studies and can be summarized as follows. Modern students of science deconstruct the special character of scientific knowledge. To do so, they need to maintain a privileged stance for the knowledge that their own studies produce, and hence they refute their basic claim. They saw off the branch on which they sit, and they saw it off between their seat and the tree.[7] I must confess that I have no satisfying answer to the reflexivists' critique. Neither the option of restoring scientific knowledge to its old glory, nor the option of being mute for the rest of my scientific life seems acceptable. Probably the solution to the problem is to be found, not in general terms, but in special treatments of the *specific* case at hand.[8] If the reflexivists continue to issue *general* statements about science and technology studies, I propose to elect them to the honorable position of jester at the court of our field: making us laugh and weep and think at the same time, although not committing themselves to dirtying their hands by making necessary decisions.[9]

The problem of *theory* has been on the agenda of recent sociological-historical studies of technology from the beginning. One of the criticisms formulated against the history of technology was that, although historians typically opened the "black box" of technology to investigate the contents of technology (as opposed to, for example, economic and philosophical studies of technology), they almost never got out of that black box again to compare with other case studies and thus form a generalized understanding of processes of technical change. Now that there is a growing body of empirical case studies, the question of how to make theoretical generalizations becomes very pressing indeed. I will devote the central part of my article to this problem.

The problem of *practice* may be particularly Dutch. Science and technology studies in the Netherlands did not so much emerge from the academic disciplines of mainstream sociology, history, or philosophy. Rather, their origin lies in the Dutch "science and society" movement that resulted in the early 1970s in the establishment of critical STS programs in most science and engineering faculties.[10] By the end of the 1970s, an increasing need was felt for a more empirical and theoretical foundation of the critical STS research and teaching. Seen in this perspective, the science and technology studies of the 1980s are an academic detour to collect ammunition for the struggles with political, scientific, and technological authorities. Of course, one may define this academic path, not as a detour, but as the right route; then there is no "problem of practice." But if one still feels bound to the old

STS ideals, as I do, the question becomes pressing whether the detour has not been long enough by now, whether it is not time to start to relate present findings in science and technology studies to political issues of democratic control of science and technology. I briefly discuss this problem at the end of my article.

So, is our state in despair? Are the problems of relativism and reflexivity stifling our movements, albeit in an interesting project? Or is the problem of theory turning our endeavor into mere story telling and thereby into a far less ambitious project? Is, finally, the problem of practice demonstrating that the project is not only unambitious but even completely useless? I think not. The problem of relativism has been dealt with by Bloor (1981) and Collins (1985) years ago. The problem of reflexivity can be lived with and even benefited from. And the problems of theory and practice can be addressed head-on. I now turn to this task, using the social constructivist perspective as the main entrance into the problem.[11] For illustrative purposes I shall draw on three case studies: the bicycle, Bakelite, and fluorescent lighting.[12]

Toward a Theory of Sociotechnical Ensembles

The three steps to attack the problem of theory are the following. First, using the bicycle case, I argue for the need to analyze technical change as a social process. Key concepts are *relevant social group* and *interpretative flexibility*. At a philosophical level, supporting the proposed analysis, the principle of symmetry plays an important role. Second, the case of Bakelite is used to develop the theoretical concept of *technological frame*. I discuss what requirements a theory of technical change should meet and how technological frame does fit those conditions. Third, drawing on the application of the concept of technological frame in the fluorescent lamp case, I argue that we have moved so far now that the original definition of *technical artifacts*, with which I started this work, is too narrow. Instead, I propose to take *sociotechnical ensembles* as the unit of analysis. At the philosophical level, this means a shift from the principle of symmetry alone to also endorsing the principle of generalized symmetry.

A Sociology of Technology Is Feasible—Interpretative Flexibility

The development of the bicycle shows how impossible it is to explain the course of events and the development of designs by referring to intrinsic properties of the artifacts. In the 1870s in England, the high-wheeled bicycle was developed. It seems a patent mistake: Why build this strange machine instead of using the chain, sprocket, and gears that were known since Leonardo da Vinci's times to construct the modern low-wheeled bicycle directly? To find an answer I have sought to trace the meanings that were attributed to the bicycle by different relevant social groups. For women and middle-aged men, the high-wheeled bicycle was indeed a dangerous, non-working machine: a loose stone or hole in the road was enough to make one topple head-over-heels. Additionally, the machine made women move at too conspicuous a level among men's eyes through Victorian streets. Such a bicycle had to lose out in the marketplace, it seems. This is, however, not what happened. The high-wheeled bicycle even became such a commercial success that, for several years, it could be denoted by the term *ordinary*. It evidently was also a machine that worked well. It was such for a specific relevant social group: the "young men of means and nerve," athletic, upper- and upper-middle-class men who used the high-wheeled bicycle to impress their lady-friends in Hyde Park. This relevant social group constituted the "Macho Machine," whereas the group of women and middle-aged men constructed the "Unsafe Machine."

Using relevant social groups as the entrance for the description, it is thus possible to demonstrate the interpretative flexibility of artifacts. This concept of interpretative flexibility is central to the social constructivist project and, indeed, to most of recent social and historical studies of technology. Demonstrating the interpretative flexibility of an artifact amounts to showing that one seemingly unambiguous "thing" (a technical process, or some material contraption of metal, wood, and rubber as in the case of the bicycle) is better understood as several different artifacts. Each of the different artifacts hidden within that seemingly one "thing" can be traced by identifying the meanings attributed by the relevant social groups. The concept of interpretative flexibility is crucial in countering technical determinism. Indeed, to recognize the interpretative flexibility of artifacts is synonymous with refuting technical determinism.[13] Hence the concept's key role in the social studies of technology: Technical development can be subjected to social analysis only when it can be seen as being not autonomous and not driven by purely internal dynamics. The use of the concept of interpretative flexibility is thus the *raison d'être* of the social studies of technology, the justification for its existence.

The concept of interpretative flexibility finds its philosophical and methodological basis in the principle of symmetry. This principle was formulated by Bloor (1973, 1976) for the social studies of science. Bloor argued that, to analyze scientific belief systems, the sociologist of scientific knowledge should be impartial as to the truth or falsity of beliefs. True and false claims were to be analyzed symmetrically, that is, with the same conceptual apparatus. This means that the acceptance of a claim that is now considered to be true should not be explained by its truth content (for example, in terms of a better correspondence with nature), whereas the acceptance of another claim that is currently considered false is explained by referring to, for example, the social circumstance of its conception. "Nature" was not to enter the explanatory endeavor as *explanans*; rather, it should be the *explanandum*. Nature was considered not to be the cause of scientific beliefs but the result.[14] Pinch and Bijker (1984) extended this principle to the analysis of technology by arguing that working and nonworking machines were to be analyzed symmetrically. The working of a machine should not be the *explanans* but should be addressed as the *explanandum*. The working machine was not considered as the cause of its success but as the result of its being accepted in relevant social groups.

Along these lines I have described the history of bicycles and used the case study to extract a general model for describing cases of technical development. To have such a descriptive model is necessary if a set of comparable case studies is to form the basis for generalizations. The descriptive model should allow the analyst to get into the black boxes of the various case studies but also subsequently to get out of the box again to compare one case with the others. Thus the model should strike a fine balance between getting down to the nuts-and-bolts level of technology and staying at enough analytic distance to allow for cross-case-study comparisons.

The social construction of technology (SCOT) model was developed to meet these requirements. I shall briefly summarize its main characteristics, partly introduced in the previous paragraphs. In the SCOT model, *relevant social groups* form the starting point. Artifacts are, so to speak, described through the eyes of the members of relevant social groups. The interactions within and among relevant social groups constitute the different artifacts, some of which may be hidden within the same "thing." In that case, the interpretative flexibility of that "thing" is revealed by tracing the meanings attributed to it by the various relevant social groups. With reference to a general methodological adage—that instability is more revealing about a system's characteristics than stability—it was specified that, in tracing those meanings, the focus should be on the *problems* and associated *solutions* that relevant social groups see with respect to the artifact. Such a description would then result in mapping out increasing or decreasing *degrees of stabilization*. In this descriptive model, an artifact does not suddenly leap into existence as the result of a momentous act by a heroic inventor; rather, it is gradually constructed or deconstructed in the social interactions of relevant social groups.

Toward a Theory of Technological Change—Technological Frame

In a subsequent case study, I used this SCOT model to describe the development of Celluloid and Bakelite. The main purpose of that study was to move one step further than the thick descriptions provided by the descriptive model. Assuming that it is now possible to generate an empirical base of different case studies in terms that enable cross-case comparisons and generalizations, the next task is to develop a conceptual framework for making such generalizations. What can be said about the characteristics that such a conceptual framework requires? I will discuss three such characteristics, related to, respectively, (1) the "seamless" character of the "web of technology and society," (2) the change/continuity dimension, and (3) the actor/ structure dimension.

It is impossible to make a priori distinctions between, for example, the technical, the social, and the scientific. The case of the invention of Bakelite can illustrate this point. Bakelite was claimed to be the first "truly synthetic" plastic material, successor to the "semisynthetic" Celluloid (made from a base of cellulose from paper and textile wastes) and "natural" plastics, such as ivory, horn, and shellac. Baekeland investigated the chemical condensation reaction between formaldehyde and phenol and modified this in such a way that the resulting reaction product could be molded. Did Baekeland's success in controlling the violent condensation reaction produce a scientific fact, as he himself claimed and for which he was decorated (Baekeland 1913)? Or was it the result of successful technical tinkering (as we may now think, knowing that Baekeland's scientific explanation has been superseded by macromolecular theories)? Or was it neither a scientific nor a technical accomplishment but, first of all, a social and economic one—negotiating competitors into partners during patent litigation and building networks of manufacturing companies to use the new material?

This characteristic of modern technical development has been described with the metaphor *seamless web* (Hughes 1986; Bijker, Hughes and Pinch 1987). The web of modern society is not made up of distinct pieces of scientific, technical, social, cultural, and economic cloth; rather, whatever creases can be seen are made by the actors or by the analyst.[15] Another way of expressing the same is to observe the activities of engineers and to recognize that a successful engineer is not purely a technical wizard but an economic, political, and social one as well. A good technologist typically is a "heterogeneous engineer" (Law 1987).

The consequence of the previous observation is that our theoretical concepts are required to be as heterogeneous as the actors' activities and as seamless as the web to which the concepts will be applied. If this would be otherwise, the old distinctions would be led in by the back door of generalization, after having been kicked out through the front door by the descriptive model. Our conceptual framework should thus not compel us to make any a priori choices as to the social or technical or scientific character of the specific patterns it will make visible to us.

The second and third requirements relate to the change/continuity and the actor/structure dimensions. The social-constructivist approach, as advocated above, stresses the contingent character of technical development. Through demonstrating the interpretative flexibility of a technical artifact, it is shown that an artifact can be understood as being constituted by social processes, rather than by purely technical ones. This seems to leave more latitude for alternatives in technical change than when the constraints would be purely technical. Moreover, by breaking down classical distinctions, as argued in the previous paragraphs, the old theoretical vocabulary of discerning fixed patterns of dependent and independent variables has to be discarded. This seems to be a historian's delight, as much as a sociologist's curse: no structuralist explanations for human action, but free reign for the individual actor.[16]

The other side of the coin, however, is that heterogeneous engineers seem to be actors without histories of their own: Because there are no constraints, there are no limits to the spectrum of possibilities; everything is possible, change is all there is, and permanence has disappeared. The social-constructivist analysis may be able to account for technical change, but can it explain constancy in history? Do rupture and revolution have a place in the analysis, whereas flow and evolution do not? Here the approach seems to turn into (some) historians' curse and (some) sociologists' delight.

Let me address the second requirement to be met by a theory of sociotechnical change. The conceptual framework should enable us to explain *change* in history as well as the lack of it—*continuity* in history. The preliminary work for this issue of change/continuity is, in the SCOT descriptive model, provided by the concepts *stabilization* and *closure*. The degree of stabilization was introduced as a measure of the acceptance of an artifact by a relevant social group. The more homogeneous the meanings attributed to the artifact, the higher is the degree of stabilization. The concepts closure and stabilization are closely linked. Originally, closure was introduced in the sociology of scientific knowledge (SSK) to denote the ending of a scientific controversy with the emergence of consensus in the scientific community. SSK studies have shown how, with the closure of a controversy, an immediate rewriting of the controversy's history takes place. As soon as consensus emerges, the interpretative flexibility of scientific claims ceases to exist, and Nature is invoked as the cause of consensus and not as the result.[17]

It is important to recognize that, consequently, this process of closure is almost irreversible—almost, but not completely. Nowadays it is difficult to think of air tires as other than unambiguously normal parts of bicycles. When one has a punctured and flat tire, one is of course reminded of the technical features of "keeping the air on the right side of the rubber," but this does not make one think about solid tires, only about technically better air tires (and about the repair kit, left at home). It is, in other words, hardly possible to envisage the world as it existed before the closure of the controversy. This seems to introduce a static element in social-constructivist accounts of technology. Is the process of closure a flip-flop mechanism, digitizing the continuous flow of time? It is primarily to counter this problem that I introduced the concept of *degrees* of stabilization of an artifact. Following the histories of the various artifacts, growing and diminishing degrees of stabilization can be seen. By using the concept of stabilization in this way, I could argue that the invention of the safety bicycle can be understood not as an isolated event (for example, in 1884) but as an 18-year process (1879-97). This process was traced by noting the dropping of modalities in contemporaneous writings about the safety bicycle.

So, the social-constructivist analysis highlights the contingency of technical development (by demonstrating the interpretative flexibility of an artifact), thus stressing the possibilities for change, but is also able to describe how this freedom of choice is narrowed down by closure and stabilization processes. These stabilization processes have a dual character: They include irreversible processes of closure that impose a steplike character onto technical change, but they are also continuous in-between, as is described by growing and diminishing degrees of stabilization. This is the second requirement to be met by the conceptual framework: to combine the contingent interpretative flexibility and the constraining stabilization or the change and the permanence or the steplike and the continuous. This requirement is difficult to meet. The typical way to tackle such a task is to give a static description and then add the time dimension to it—leaving the concepts intrinsically static. Such a method would try to explain the ability of a bicyclist to ride upright by drawing on a model of the bicycle as a pair of scales that is balanced by the bicyclist by equalizing the left- and right-hand forces.[18] The equilibrium of a rolling bicycle can be understood only by using intrinsically dynamic concepts such as angular momentum. Similarly, theoretical concepts are needed that have this process character built in.

The third requirement, relating to the *actor/structure dimension*, builds on the same aspects in the descriptive SCOT model. The emphasis on the socially constructed character of artifacts, through demonstrating artifacts' interpretative flexibility, stresses the contingent character of technical change.

Does this imply that anything is possible? That each configuration of artifacts and social groups can be built up or broken down at will? That there is no end to interpretative flexibility and to the generation of new alternative artifacts and subsequent different design lines within one material contraption? This, of course, cannot be: A theory of technology proposing such a view of our technological society evidently underestimates the solidity of a society and the stability of technical artifacts. Indeed, this is where the concepts closure and stabilization processes enter the stage again. After having demonstrated the interpretative flexibility of an artifact, the second step in the SCOT model is to investigate how one of the artifacts eventually does stabilize and how others destabilize and disappear from history. By this stabilization process, a new structural environment for further technical development emerges. This should be the third requirement: to combine in a theoretical analysis the contingency of technical development with its being structurally constrained or, in other words, the strategies of actors and the structures by which they are bound, or Free Will and Fate.

The concept of technological frame is proposed as a theoretical concept, meeting all three requirements I have formulated.[19] First, a technological frame is heterogeneous, in the sense that it does not exclusively belong to the cognitive or the social domain.[20] Among the components of a technological frame are exemplary artifacts as well as cultural values, goals as well as scientific theories, test protocols as well as tacit knowledge. Second, technological frames are not fixed entities—they are being built up as part of the stabilization process of an artifact. It is the interactive character of technological frame that makes it an intrinsically dynamic concept. A technological frame does not reside internally in individuals or externally in nature—a technological frame is largely external to any individual, yet wholly internal to the set of interacting individuals in a relevant social group. Thus a technological frame needs continuously to be sustained by interactions, and it would be very surprising if its characteristics remained unchanged. Third, technological frames provide the goals, the thoughts, the tools for action. They enable thinking and action like Wittgenstein's (1953) "form-of-life" does. A technological frame offers both the central problems and the related strategies to solve them, as I showed for the Celluloid frame. But, at the same time, the building up of a technological frame will constrain the freedom of members of the relevant social group. A structure is being created by interactions, which will, in turn, constrain further interactions. Within a technological frame, not everything is possible anymore (the structure-centered aspect), but the remaining possibilities are more clearly and readily available to all members of the relevant social group (the actor-centered aspect).[21]

Beyond a Sociology of Technology—Sociotechnical Ensembles

In the previous section, the requirements for a conceptual framework for the analysis of society and technology were outlined. Let us now assume that such a framework would become available—be it around the concepts of technological frame or translation in actor-networks or whatever. Where would this lead us? It seems inevitable that the analysis will move us outside the boundaries of a sociology of technology. I introduce this issue with a third case—the fluorescent lamp.

The fluorescent lamp was commercially presented in April 1938 by General Electric as a lamp for coloring purposes; amazingly bright colors became available with hitherto impossible efficiencies. A (de-)constructivist analysis of the lamp results in demonstrating its interpretative flexibility: Besides the "color lamp" for General Electric, there was also the "high-efficiency lamp" for the relevant social group of electricity producers. These were afraid that their sales would drop, and a fierce conflict broke out. Closure was reached during a meeting between top executives of General Electric and the utilities. It was reached by constructing, during that conference, a third fluorescent lamp—the "high-intensity lamp." This was the fluorescent lamp that eventually would stabilize. At that moment, April 1939, there was, however, no immediate prospect of having it physically available—the high light intensities upon which participants agreed were then still "technically" impossible. Following the further social construction of this high-intensity fluorescent lamp, we see that inseparable from that process was a variety of "other" elements—a reconstruction of the relationship between lamp producers and utilities, a breakdown of the patent monopoly of General Electric, rules for testing lamps, special auxiliaries, and America's "war effort" in the early 1940s. The sociological study of the fluorescent lamp along the lines set out above thus leads to a study of patent economics, firm organization, state regulation, economics of innovation, and society at war.

The "stuff" of the invention of the fluorescent lamp was economics and politics, as much as electricity and fluorescence. It now seems inevitable that the analyst must transcend the dichotomy between the social and the technical. To work on the basis of this distinction, the analyst found it necessary to argue explicitly against technical determinism, to demonstrate interpretative flexibility, to argue indeed for the nonexistence of seams between the social and the technical in the web of modern society. But having climbed that way, the ladder can be pushed away.

A landscape of sociotechnology unfolds. All relations are both social and technical. Purely social relations are to be found only in the imaginations of sociologists, among baboons, or possibly on nudist beaches; and purely technical relations are to be found only in the sophisticated reaches of science fiction (Lem [1973] 1976). The technical is socially constructed, and the social is technically constructed—all stable ensembles are bound together as much by the technical as by the social. Where there was purity, now there is heterogeneity. Social classes, occupational groups, firms, professions, machines—all are held in place by intimately linked social and technical means. This landscape is different from the one described when I discussed the bicycle case. A principle of general symmetry is substituted for the principle of symmetry; technical artifacts are replaced by sociotechnical ensembles as the unit of analysis; and the sociology of technology seems to move imperialistically into the domain of general sociology.

The sociotechnical is not merely an intimate combination of social and technical factors; it is something sui generis. Sociotechnical ensembles, rather than technical artifacts or social institutions, become our unit of analysis. And sociotechnical processes constitute the patterns discerned by our theoretical concepts. The technical and the natural do not enter through the back door because they do not exist anymore in our vocabulary. Each time *machine* is written as shorthand for *sociotechnical ensemble*, it should, in principle, be possible to sketch the (socially) constructed character of that machine. Each time *social institution* is written as shorthand for *sociotechnical ensemble*, it should be possible to spell out the technical relations that go into making that institution into a stable setup. Society is not determined by technology, nor is technology determined by society. Both emerge as two sides of the sociotechnical coin, during the construction processes of artifacts, facts, *and* relevant social groups.

The principle of general symmetry extends Bloor's (1973, 1976) principle of symmetry, discussed previously. This symmetry principle advocates that true and false beliefs (or, in the case of technology, successful and failing machines) are to be analyzed in the same terms. Callon (1986) extended this principle to another level: The construction of science and technology on one hand and the construction of society on the other hand should be analyzed within the same framework. Neither technical reductionism (explaining society by a reduction to technical development) nor social reductionism (considering the technical to be determined by the social) should be the basis for an analysis of technology-and-society.

The history of science and technology studies can be described as a successive series of new conceptualizations of this "symmetry" idea (Woolgar 1992). Thus Merton's (1973) work was a plea for symmetry between science and other social institutions, and he consequently argued for drawing science into the analysis. Bloor (1973, 1976) argued for drawing the contents of (truthful) science into the analysis. Pinch and Bijker (1984) argued for treating technology and science symmetrically and drew technology into the analysis. The reflexivists (see above) argue for drawing the analyst into the analysis by applying the symmetry principle to the researcher and the researched. Callon (1986) argues for drawing society into the analysis. Collins and Yearley (1992b) observe that this seemingly "progressive" history of science studies should not compel us to accept any next step—and they argue indeed against both the reflexivist program and Callon's general symmetry. As I have tried to show, however, in the case of technology studies there are good reasons for drawing society into the analysis by blurring the boundary between the technical and the social. So far, these reasons have been empirical and theoretical. In the next section, I argue that there are also good reasons related to the practice of technology studies.

Linked to the principle of general symmetry is a plea to treat human and nonhuman actors symmetrically in case descriptions.[22] An illuminating debate of this issue was recently held between Collins and Yearley (1992a, 1992b) and Callon and Latour (1992). The debate potentially divides students of sociotechnology into two camps. For one camp, the debate amounts to a heresy against the best of the Winchian (Winch 1958) tradition in the social sciences by allowing machines as actors into the story. For the other camp, the analyses within Bloor's (1973, 1976) symmetry scheme are hardly more than internal accounts and do not provide insight into such crucial questions as the relation between microevents and macrosocial developments. In the remainder of this section, I want to indicate a specific methodological direction for technology studies to move into, although without suggesting that this will solve the fundamental issues involved in the debate, by briefly discussing three points—the status of the social and the technical within sociotechnical ensembles, reductionism, and the possibility of explanation.

Sociotechnical ensembles, I have argued, are to be the subject matter for technology studies. What remains to be said about the relationship of the social and the technical? Can the *social* construction of the technology be left behind? No—the methods described above are still the best we have to describe sociotechnical ensembles. The sociological deconstruction of technical artifacts is the key to breaking open stabilized technologies. As I claimed in the case of the fluorescent lamp, this will allow for a symmetrical analysis of the technically constructed character of relevant social groups and society.[23] The ways in which the social and technical elements combine into a sociotechnical ensemble is currently a major research topic. One fruitful approach seems to be an analysis of the distribution of tasks and skills within such an ensemble. Latour and others working with the "translation" framework study associations of humans and machines and try to map in symmetrical terms such as skills distributions,[24] whereas Collins and others try to explain specifically why some skills can and others cannot be mimicked by machines.[25]

A second issue is *reductionism*. This term is often used in a derogatory sense; reductionism is something that should be avoided. I argue, however, for its revaluation, albeit in a new, and yet to be developed, form. When the social and the technical were still two different worlds, two forms of reductionism were practiced. Technical reductionism assumed that the developments in the social world could be explained by what happened in the technical, thus resulting in technical determinism. Social reductionism assumed likewise that the technical was completely determined by the social—interest theories in the sociology of scientific knowledge are an example. Both forms of reductionism should indeed be avoided if sociotechnical ensembles are to be the new unit of analysis. However, if the ideal of explanation is not to be given up, some form of reduction is necessary. Without it, research would relapse into an indiscriminate empiricism. The possibilities of lucid story telling as well as of more formal theorizing would then be given up.[26] Much work is currently devoted to finding new forms of reduction within the new realm of sociotechnology.

The ideal of explanation need not be given up. Reduction can and should be accepted. To do this, part of the sociotechnical web is to be taken as a relatively stable backdrop for the events happening in the forefront. Thus, for specific questions, some parts of the sociotechnical world are assumed to be fixed, and the development of other parts can be set against that backdrop. For example, in the case of the fluorescent lamp, I was primarily interested in the construction of the lamp, and not in the (re-)construction of General Electric. This does not mean, however, that General Electric is not as much a sociotechnical ensemble as the fluorescent lamp or that its properties are immanent rather than constructions. With this form of reduction between forefront and backdrop, new explanatory schemes are being worked out.

One example is the work by Latour (1992b) and others, already mentioned, in which "programs" and "antiprograms" are introduced to explain (they say "to map") the development of a sociotechnical ensemble. In their case, the program of the Berliner Homeowner Association is "keep the door shut at night," whereas the antiprogram of the tenants is to "remain free to let friends go in and out without bothering to relock the front door." The sociotechnical ensemble (my term) is the continuously changing association of door, lock, several keys, janitor, verbal notices, written signs, tenants, Homeowner Association, friends, and so on.

A second set of examples is formed by scholars who seek to understand the relationships between technology, society, and power. Pfaffenberger (1992. 294), for example, examines the technological construction of political power and concludes that "artifacts do not have politics"—at least not in any context-independent and intrinsic way. They have politics only when they are discursively regulated by symbolic media that mystify and therefore constitute the political aims; in other words—only if they are considered as technological ensembles. Law (1991) collected several essays aimed at studying the distribution of power in, by, and through sociotechnical ensembles. Various explanatory frameworks, drawing partly on such writers as Barnes (1988), Clegg (1989), and Foucault (1979), are being proposed to make sense of the constitution of power differences in modern society and technology.

A third set of examples, although the difference from the previous two is somewhat artificial, is provided by studies that focus on the development of sociotechnical ensembles. Several of these have been collected by Bijker and Law (1992). Schwarz and Thomson (1990) argued for combining the social constructivist perspective with "cultural theory." To conclude this section, I briefly discuss how the previously introduced concept of technological frame may offer an explanatory reduction, other than in terms of the social-technical dichotomy. As a first-order analysis, three different configurations can be distinguished—when *no* clearly dominant technological frame is guiding the interactions, when *one* technological frame is dominant, and when *more* technological frames are at the same time important for understanding the interactions related to the sociotechnical ensemble that is being studied. In each of these configurations, different processes of technical change are typically found.

The first configuration (and here the case of the early history of the bicycle provides an example) occurs when there is no single dominant group and there is, as a result, no effective set of vested interests. Under such circumstances, if the necessary resources are available to a range of actors, there will be many different innovations. Furthermore, these innovations may be quite radical.[27] More than in the other configurations, the success of an innovation will depend upon the formation of a constituency, a group that comes to adopt the emerging technological frame.[28] Strategies of enrollment are crucially important for actors in this configuration. *In the second configuration*, one dominant group is able to insist upon its definition of both the problems and the appropriate solution of those problems. Under such monopolistic circumstances, innovations tend to be conventional (work in the Celluloid era is illustrative). Problems may arise from functional failure (Constant 1980), and the solutions are judged in terms of their perceived adequacy to solve such failures. *In the third configuration*, when there are two or more entrenched groups with competing divergent technological frames, arguments that carry weight in one of the frames will carry little weight in the other. Under such circumstances, criteria external to the frames in question may become important as appeals are made over the heads of the other social group to third parties. In addition, innovations that allow the amalgamation of the vested interests of both groups will be sought. Such innovations (the construction of the high-intensity fluorescent lamp is an example) are, so to speak, doubly conventional because they have to lodge within both technological frames.

Return from the Academic Detour: The Turn Toward Practice

Let us now turn to the problem of practice, which, I have argued earlier in this article, should be as high on the agenda as the problem of theory. The theme of controlling technology and intervening in its development has yielded very different approaches in the past decades. In the technological determinist view, mentioned previously, technology is conceived as a separate entity that follows a linear path. Technology is like train, with a track that is fixed, although not known in detail. One cannot hope to change the train's direction, only to check its speed and the safety of the crossing. Orthodox "technology assessment," as exemplified since 1972 by the work of the U.S. Office of Technology Assessment, thus seeks to predict technological development and its impact on society and hopes to avoid some of its negative effects by early warning, as it were. Cost-benefit analyses are another example of control and intervention instruments that are based on this image of technology. This approach to technology implies a control dilemma (Collingridge 1980)—either it is too early to foresee the implications of a new technology, or it is too late to intervene because the technology has become so entrenched in society and culture that it cannot be changed anymore. Linked to the more social reductionist views are models of technology assessment developed in Sweden and the Netherlands.[29] In these models, the possibility of continuously shaping and reshaping a technology, during all its stages of development, is recognized. A framework is being developed to encourage a more positive interplay between the formal institutional technology assessments and the more informal technology evaluations by other relevant social groups. Thus the role of actors other than engineers and politicians is also recognized and given some place.

What form can an orientation toward practice take if sociotechnical ensembles are the unit of analysis? Here, Collingridge's (1980) control dilemma disappears. Instead, the seamless web character of technology and its pervasively socially constructed character indicate a multitude of opportunities to influence the development of technology (and society, and . . .).

I will suggest some possible themes for study that may be grouped under the banner of "control and intervention studies."

In this perspective, *ethical studies* of technology could comprise a combination of "ethnographic ethics" and "strategic ethics." In ethnographical studies, the coemergence of values and practices, of ethical vocabularies and technologies, of labor relations and industrial systems is to be investigated. In the day-to-day employment of technology, professional codes and societal values are shaped. Values are, in this view of technology-society-ethics, not pregiven as universal ethical laws but socially constructed together with the technology. *Ethnoaccounting studies* apply the constructivist perspective to an analysis of the economics of firms and projects (MacKenzie 1990b). Investments, costs, and profits are not considered as unambiguously available, objective facts. Instead, they are analyzed as socially constructed in the process of managing a firm and shaping a technology. The role of *nontraditional design constituencies* is important to understand, once the observation has been made that a large variety of relevant social groups contributes to the social construction of technology. Understanding the role of, for example, consumers in shaping a clinical technology will suggest ways of controlling the development of medical technologies through intervening in the hospital rather than directly in the technology-developing firm. *Regulations and norms* are a traditional steering instrument, but they are almost always used with a mechanistic stimulus-and-response perspective on technology. When extending the analysis of the previous point, regulations and norms can be studied as activating and supporting networks of firms and other relevant social groups that are involved in the construction of a technology.[30]

The most obvious role for technology studies in practice, however, may be an analytic one. The deconstructive capacity of recent work can be effectively used to show interpretative flexibility, to suggest alternative technological choices, to debunk the sociotechnical ensembles constructed by the powerful. Not many of our studies have been presented with this explicit aim, but the work by, for example, Ashmore, Mulkay, and Pinch (1989); Latour (1987, 1992a); Collins (1990); MacKenzie (1990b); Mack (1990); and Blume (1991) can be read in this way.

These scholarly works, however, are not the only examples. If this task is taken seriously, we should explicitly pay attention to questions of the public understanding of science and technology and to instruments providing possibilities of control to the general public. Much of Wynne's (1983, 1988) work has been explicitly directed toward such goals. Collins (1987) addressed the problem of the public image of science and technology as it is constructed in the media. Bijker (1989) discussed how science teaching in secondary school could contribute to a public image of science and technology that would be more inviting to a democratic participation in public discussions on issues of technological and scientific controversy than the present image of science is. And we should not be afraid to engage in even more unorthodox and less academic endeavors. One example of such a project is "Technological Culture" in Amsterdam (Schwarz 1990), which builds explicitly on recent studies of science and technology.

Conclusion

This article was meant to give an overview of recent technology studies, to help evaluate the state of the art, and to assess directions for future research. Originally presented in a conference session titled "Post-constructivism," the article has addressed the question, Where do we go from here? Others have argued that technological determinism might be reassessed as "a viable and fruitful perspective on technology and society" and that we might need a "model that allows 'the substance' or 'content' of technology independently to shape subsequent political, economic and social choices." My answer may be clear by now. Technological determinism is too viable a vision to be flirted with (see the Epilogue below). If technological determinism remains as prevalent as it currently is, the image of technology will continue to be dominated by elements of autonomy, internal dynamics, and being beyond control. Such an image of technological change does not stimulate citizens' participation in processes of democratic control of technology. A similar point has been made about the need for the general public to have more a constructivist image of science (Bijker 1986): If scientific facts are dictated by Nature—rather than constructed by humans—any scientific controversy (for example, about the risk of radioactive radiation) will lead to the conclusion that one of the debating parties is right and the other is wrong, the good guys against the bad guys. The reaction "Let them sort that out among themselves; I don't want to have anything to do with that" is then very understandable. Likewise, if a social-constructivist image of technological development is not built up, stressing the possibilities and the constraints of change and choice of technology, a large part of the public is bound to turn away and to let technology get out of control.[31]

I started this article by asking whether the state of technology studies was in despair because of four problems—relativism, reflexivity, theory, and practice. My conclusion now is that the "social-constructivist program" can be pursued and extended in perspective (sociotechnology rather than technology should be the future subject matter), in depth (explanations can now be developed on the basis of the empirical research of the past decade), and with political relevance (the analyses are being directed toward issues of power distribution and reshaping society).

Epilogue

The earthquake of 17 October 1989 seemed to have been effective in revealing the composing elements in the sociotechnical world of Interstate 880. But one week later we could already witness the covering up, the closure of the black box, the camouflage of the socially constructed character of Technology, Nature, and Society. The *New York Times* of 22 October looked back on the quake as a battlefield between Nature, Technology, and Humans. It first described California as the American symbol of opportunity, freedom, and renewal, as a sunny paradise and human dominion where the land was as beautful as it was terrible. Technology played its independent role: Dams and aqueducts brought water into the deserts, where vast cities and farms blossomed. But then, in just 15 seconds on a Tuesday evening, "Nature sought to restore a bit of its equilibrium" (Reinhold 1989).[1] Thus all interpretive flexibility had vanished after one week—natural and technical determinism were the central guiding posts again.

Let us hope that the studies of sociotechnical ensembles, as called for in this article, will have a more lasting effect. If so, there is no reason to despair: There is life after constructivism—constructive STS studies contributing to a better society.

Notes

1. This quote is not transcribed from a recording but reconstructed on the basis of my notes. The social gap revealed here is part of the highway system. The lower-class people, not owning cars, have to live near the city center. The freeways that carry the middle-class citizens between their suburban homes and downtown workplaces cross over the living quarters of the poor.

2. For a comprehensive and daring view of the present state of the art in economic technology studies, see Dosi et al. (1988). Blume (1991) developed a framework that aims at the sociological and economic perspectives.

3. Additionally, the reader may be warned that the tone of the article is, because of the circumstances for which it was prepared originally, at times rather polemical.

4. See Bijker, Hughes, and Pinch (1987) for the papers from this workshop and an account of its history. Woolgar (1991) confused autobiography with historical analysis when he argued that the sociology of technology was merely a "turn towards technology" by sociologists of science who wanted to apply their instruments to other fields. He was also mistaken in interpreting the radical potential of modern technology studies in primarily philosophers' terms: "How many philosophers are going to get upset at the contention that technologies are socially

constructed? Not a lot!" (p. 36). Technology studies are potentially more counterintuitive than science studies: Not many people (besides philosophers) will get upset when they are told that TRF is a social construct. There is more "bite and controversy" associated with the claim that one cannot straightforwardly check whether a bicycle is working or not.

5. See Bijker and Law (1992) for the papers from this workshop.

6. See Pinch and Bijker (1986), Star (1988), and Bijker (1990).

7. See for more sophisticated discussions on reflexivity, see Woolgar (1988a, 1988b), Ashmore (1989); especially related to technology studies are Woolgar (1991) and the reply by Pinch (forthcoming).

8. Ashmore, Mulkay, and Pinch (1989) have investigated the possibility of applying social sciences. They studied two cases. The first was health economics. The second case was—and this constitutes the reflexive turn—their own sociology of knowledge (in studying health economics). This project has convinced me of the possibility of incorporating some elements of the reflexive program in specific projects. See also Pinch, Ashmore, and Mulkay (1992).

9. The reader should note my lack of reflective consciousness in this article (at least until this note): The history of technology studies is presented in a very specific way to lead to the conclusion that social constructivism is new, promising, where the action is and will be. For a fair complaint about such a presentation from the philosophy of technology side, see Winner (1991).

10. I use the acronym *STS* in its old-fashioned meaning of "science, technology and *society*" and not merely "science and technology studies," as was recently done in this journal. See Bijker (1988) for a brief account of the development of STS initiatives into more academic science and technology studies.

11. For a comprehensive summary of the actor-network approach and a discussion of similar issues from this perspective, see Law (1992).

12. For a full account of these case studies, see Bijker (forthcoming). Summaries were published in various articles: For the bicycle, see Pinch and Bijker (1984); for Bakelite, see Bijker (1987); for the fluorescent lamp, see Bijker (1992).

13. See, for an introduction to the issue of technical determinism, the introductory essay by MacKenzie and Wajcman (1985) and, for a comprehensive discussion of various shades of technical determinism, MacKenzie and Spinardi (1988).

14. For a discussion of the principle of symmetry, see Laudan (1981) and Bloor (1981). See also Collins (1985).

15. The metaphor of the seamless web breaks down if we focus on the *actors* instead of the *analysts*. Actors label specific activities differently. It is exactly this process of actors making distinctions that we analysts should study, rather than assuming a priori our own distinctions.

16. See also Hagendijk (1990) and Amsterdamska and Hagendijk (1990).

17. The classic discussion of this phenomenon is given by Latour and Woolgar (1979) in their "splitting and inversion model." Collins (1981) discussed the implications for historical studies of science. Bijker (forthcoming) and Misa (1992) reworked the concept for present purposes. See also Woolgar (1988b), especially chapter 4.

18. This is the model that anybody with secondary school physics as a background is bound to use. To such an observer, the task of keeping a bicycle upright seems strikingly difficult. This explains the amazement of people in the 1860s, seeing bicyclists for the first time.

19. The "systems" concept (Hughes 1983) and the "translation" concept in actor-network theory (Law 1992) have similar aims.

20. This is one of the important differences with "[technological] paradigm" (Kuhn 1970; Gutting 1984) and "frame of meaning" (Collins and Pinch 1982; Carlson 1992).

21. Giddens's (1984) concept of structuration has similar characteristics.

22. The first step in doing that is to speak of *actants* rather than *actors*. The first is the semiotic term for anything that acts (in a text) and does not have the anthropomorphic character of *actor* (Akrich and Latour 1992; Latour 1992b; Callon and Latour 1992).

23. It is possible to mirror the SCOT descriptive model completely for the analysis of society. One would then start with a social group, identify all relevant artifacts, describe how each of these artifacts constitutes one version of the social group (thus demonstrating the interpretative flexibility of the social group) and trace how some of these social groups stabilize. This is, of course, very similar to what archaeologists do. There is no principal reason not to follow this mirror method, but I do not deem it necessary to realize an adequately symmetrical description of the social and the technical in sociotechnical ensembles.

24. See, for example, Akrich (1992); Latour (1992a, 1992b); and Latour, Mauguin, and Teil (1992).

25. See Collins (1990); Collins, De Vries, and Bijker (1990); Bijker, Collins, and De Vries (1990).

26. Latour's (1984, 1988) programmatic plea for "irreductionism" thus seems a gross overstatement, only understandable in the light of the fight against the old forms of reductionism. Also analyzing "how" questions and "mere" story telling imply reduction, although often in a less explicit and unambiguous way than formal theory. See below for an example of the explanatory, and thus reductionist, work in which Latour is engaged himself.

27. See Hughes (1987) for a discussion of radical and conventional inventions.

28. See Staudenmaier's (1985) use of the concept of constituency in the history of technology.

29. Smits and Leyten (1991) present a comparative study of different concepts of technology assessment in, among others, Sweden and The Netherlands. For more information about Sweden, see SFS (1982); for more about the Dutch "constructive technology assessment" approach, see Daey Ouwens et al. (1987) and Schot (1992). Schwarz and Thompson (1990) conclude with "constructive technology assessment" on the basis of their cultural theory, which they developed on the basis of the work of Douglas (e.g., 1970, 1982), an anthropologist.

30. See also Jasanoff (1990), who investigates the regulatory process from a similar perspective.

31. This is, of course, not to say that we should deny the solidity and momentum of technological systems. That might result (via invoking expectations that are too optimistic, thus causing disillusionment) in an equally counterproductive cultural-political climate. It is exactly with this point in mind that I stressed, in the main body of this article, the need for a theoretical framework that pays due respect to both the actor and the structure perspective.

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