An Introduction to Science and Technology Studies

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S&TS is partly responsible for the explosion of talk of social construction. Because scientific knowledge is usually seen as simply reflecting the natural world, and scientists must therefore be relatively passive in the creation of that knowledge, the claim that scientific realities are socially constructed is a very strong one. As a result, S&TS's constructivist claims have been influential. This can be seen in the explicit use of constructivist resources from S&TS in such fields as psychology, geography, environmental studies, education, management, cultural studies, and even accounting.

However, the diversity of claims about the social construction of reality means that constructivism in S&TS cannot be any neat theoretical picture. Instead, constructivism provides reminders of the points with which we began this chapter, that science and technology are social, that they are active, and that they do not take nature as it comes.

Some of these forms of constructivism are controversial on any reading, and all of them are potentially controversial in the details of their application. But given their diversity it is also clear that even the staunchest of realists cannot dismiss constructivist claims out of hand. Constructivism is the study of how scientists and technologists make socially situated knowledges and things. Such studies can even show how scientists build good representations of the material world, in a perfectly ordinary sense. As recognized by some of the above strains of constructivism, science gains power from, among other things, its ability to manipulate nature and measure nature's reactions, and its ability to translate those measurements across time and space to other laboratories and other contexts. Laboratory and other technologies thus contribute to objectivity and objective knowledge. As a result, constructivist S&TS may even *support* a version of realism, though not the idea that there is unmediated knowledge of reality, nor the idea that there is one complete set of truths.

CHAPTER 7

Actor-Network Theory

Actor-Network Theory: Relational Materialism

Actor-network theory (ANT) is the name given to a framework originally developed mostly by Michel Callon (e.g. 1986), Bruno Latour (e.g. 1987), and John Law (e.g. 1987). ANT has its origins in an attempt to understand science and technology – or *technoscience* in Latour's (1987) terminology, since on this account science and technology involve the same processes. It is, though, a general social theory centered on technoscience, rather than just a theory of technoscience.

The theory represents the work of technoscience as the creation of larger and stronger networks. Part of this is in straightforward analogy to traditional analyses of power politics: just as the political actor strives to put together alliances that allow him or her to maintain power, so do scientists and engineers. However, the actors of ANT are heterogeneous in that they include both human and non-human actors, with no important distinction between them. Both humans and non-humans have *interests* that need to be accommodated, and that can be managed and used. Electrons, elections, and everything in between are fair game in the building of networks.

Michel Callon (1987), for example, describes the effort of a group of engineers in Electricité de France (EDF) to introduce an electric car in France. EDF's engineers acted as "engineer-sociologists" in the sense that they simultaneously articulated a vision of fuel cells for these new cars, of French society into which electric cars would later fit, and of much between the two – engineering is never complete if it stops at the obvious boundaries of engineered artifacts. Not only the EDF actors did engineering-sociology; their opponents at Renault, who were committed to internal combustion engines, criticized both the technical details and the social feasibility of EDF's plans. The engineering and the sociology are inseparable, because neither the technical vision nor the social vision will come into being without the other, though with enough concerted effort both may be brought into being together.

The sociology in question need not involve such macro-level thinking, instead focusing on concrete social actors. Latour describes the efforts of the engineer Rudolf Diesel to build an earlier new type of engine: "At the start, Diesel ties the fate of his engine to that of *any* fuel, thinking that they would all ignite at a very high pressure. . . . But then, nothing happened. Not every fuel ignited. This ally, which he had expected to be unproblematic and faithful, betrayed him. Only kerosene ignited, and then only erratically. . . . So what is happening? Diesel has to *shift his system of alliances*" (Latour 1987: 123; italics in the original). Diesel's alliances include entities as diverse as kerosene, pumps, other scientists and engineers, financiers and entrepreneurs, and possibly the consumer market. The technoscientist needs to remain constantly aware of a shifting array of dramatically different actors to succeed. A stable network, and a successful piece of technoscience, is the result of managing all of these actors so that they contribute toward a goal.

Actors build networks. These networks might resemble machines, when their components are made to act together to achieve a consistent effect. Or they might resemble facts, when their components are made to act as if they are in agreement. The work of technoscience is the work of understanding the interests of a variety of actors, and *translating* (both in place and in form) those interests so that the actors work together or in agreement (Callon 1986; Callon and Law 1989).

ANT is a materialist theory. Science and technology work by translating material actions and forces from one form into another. Scientific representations are the result of material manipulations, and they are solid precisely to the extent that they are mechanized. The rigidity of translations is key here. Data, for example, is valued as a form of representation because it is supposed to be the direct result of interactions with the natural world. Visiting an ecological field site in Brazil, Latour (1999) observes researchers creating data on the colors of soil samples. Munsell color charts are held against the samples (just as a painter will hold a color chart against a paint sample) so that the color of the sample can be translated into a uniform code. As Latour jokes, the gap between representation and the world, a way of seeing a standard philosophical problem, is reduced by scientists to a few millimeters. Data-level representations are themselves juxtaposed to form new relationships that are summarized and otherwise manipulated to form higher-level representations, representations that are more general and further from their objects. Again, the translation metaphor is apt, because these operations can be seen as translations of representations into new forms, in which they will be more generally applicable. Ideally, there are no leaps between data and theory – and between theory and application – but only a series of minute steps. Thus there is no "action at a distance," though there may be long-distance control (see Star 1989).

That there is no action at a distance is a methodological as well as an empirical claim (Latour 1983). The working of abstract theories and other general knowledge appears a miracle unless it can be systematically traced back to local interactions, via hands-on manipulation and working machines, via data, and via techniques for summarizing, grouping, and otherwise exploiting information. Therefore, science and technology must work by translating material actions and forces from one form into another. Universal scientific knowledge is the product of the manipulation of local accounts, a product that can be transported to a wide variety of new local circumstances. It is only applicable through a new set of manipulations that adapt it once again to those local circumstances (or adapt those local circumstances to it).

Seen in these terms, laboratories give scientists and engineers power that other people do not have, for "it is in the laboratories that most new sources of power are generated" (Latour 1983: 160). The laboratory contains tools, like microscopes and telescopes, that change the effective sizes of things. Such tools make objects human in scale, and hence easier to study. The laboratory also contains a seemingly endless variety of tools for separating parts of objects, for controlling them, and for subjecting them to tests: objects are tested to find out what they can and cannot do. This process can also be thought of as a series of tests of actors, to find out which alliances can and cannot be built. Simple tools like centrifuges, vacuum pumps, furnaces, and scales have populated laboratories for hundreds of years; these and their modern descendants tease apart, stabilize, and then quantify objects (Carroll-Burke 2001). *Inscription devices*, or machines that "transform pieces of matter into written documents" (Latour and Woolgar 1986: 51), allow the scientist to deal with nature on pieces of paper. Like the representations produced by telescopes and microscopes these are also medium-sized, but perhaps more importantly they are durable, transportable, and relatively easy to compare to each other. Such *immutable mobiles* can be circulated and manipulated independently of the contexts from which they derive. Nature brought to a human scale, teased into components and made stable in the laboratory or other *center of calculation*, and turned into marks on paper or in a computer, is manipulable.

We can see that, while ANT is a general theory, it is one that explains the centrality of science and technology to the idea of modernity (Latour 1993b). Science and technology explicitly engage in crossing back and forth between objects and representations, creating situations in which humans and non-humans affect each other.

Box 7.1 The Pasteurization of France

Louis Pasteur is perhaps the model scientist for Latour. Pasteur's anthrax vaccine is the subject of an early statement of ANT (Latour 1983), and his broader campaign on the microbial theory of disease is the subject of a short book (Latour 1988). In the spirit of Tolstoy's *War and Peace*, Latour asks how Pasteur could be seen as the central cause of a revolution in medicine and public health, even though he, as a single actor, can do almost nothing by himself.

The laboratory is probably the most important starting point. Here is Pasteur, describing the power of the laboratory:

> As soon as the physicist and chemist leave their laboratories, . . . they become incapable of the slightest discovery. The boldest conceptions, the most legitimate speculations, take on body and soul only when they are consecrated by observation and experience. Laboratory and discovery are correlative terms. Eliminate the laboratories and the physical sciences will become the image of sterility and death. . . . Outside the laboratories, the physicists and chemists are unarmed soldiers in the battlefield. (in Latour 1988: 73)

Pasteur uses the strengths of the laboratory to get microbes to do what he wants. Whereas in nature microbes hide, being invisible components of messy constellations, in the laboratory they can be isolated and nurtured, allowing Pasteur and his assistants to deal with visible colonies. These can thus be tested, or subjected to *trials of strength*, to find their properties. In the case of microbes, Pasteur is particularly interested in finding weak versions that can serve as vaccines.

Out of the complex set of symptoms and circumstances that is a disease, Pasteur *defines* a microbe in the laboratory; his manipulations and records specify its boundaries and properties. He then is able to argue, to the wider scientific and medical community, that his microbe is responsible for the disease. This is in part done via public demonstrations that repeat laboratory experiments – breakthroughs like the successful vaccination of sheep against anthrax are carefully staged demonstrations, in which the field is turned into a laboratory, and the public is invited to witness the outcomes of already-performed experiments. Public demonstrations help to convince people of two important things: that microbes are key to their goals, whether those goals are health, the strength of armies, or public order; and that Pasteur has control over those microbes.

Microbes can be seen as not merely entities that Pasteur studies, but agents with whom Pasteur builds an alliance. The alliance is ultimately very successful, creating enormous interest in Pasteur's methods of inquiry, reshaping public health measures, and gaining prestige and power for Pasteur. Thus we might see Pasteur's work as introducing a new element into society, an element of which other people have to take account if they are to achieve their goals.

If he is successful in all of these steps, then it should be easy for Pasteur to convince people to act around his conceptions of disease and health. When doctors, hygienists, regulators, and others put in place measures oriented around his purified microbe, it becomes a taken-for-granted truth that the microbe is the real cause of the disease, and that Pasteur is the cause of a revolution in medicine and public health.

While ANT is thoroughly materialist, it is also built on a relational ontology; it is based on a *relational materiality* (Law 1999). Objects are defined by their places in networks, and their properties appear in the context of tests, not in isolation. Perhaps most prominently, not only technoscientific objects but also social groups are products of network-building. Social interests are not fixed and internal to actors, but are changeable external objects. The French military of 1880 might be interested in recruiting better soldiers, but Pasteur translates that interest, via some simple rhetorical work, into support for his program of research. After Pasteur's work, the military has a new interest in basic research on microbes. Translation in ANT's sense is not neutral, but changes interests.

Whereas the strong programme was "symmetric" in its analysis of truth and falsity and in its application of the same social explanation for, say, both true and false beliefs, ANT is "supersymmetric," treating both the social and material worlds as the products of networks (Callon and Latour 1992; Callon and Law 1995). Representing both human and non-human actors, and treating them in the same relational terms, is one way of prompting full analyses, analyses that do not discriminate against any part of the ecologies of scientific facts and technological objects. It does not privilege any particular set of variables, because every variable (or set of actors) depends upon others. Networks confront each other as wholes, and to understand their successes and failures science and technology studies (S&TS) has to study the wholes of those networks.

Box 7.2 Ecological thinking

Science and technology are done in rich contexts that include material circumstances, social ties, established practices, and bodies of knowledge. Scientific and technological work is performed in complex ecological circumstances; to be successful that work must fit into or reshape its environment.

An ecological approach to the study of science and technology emphasizes that multiple and varying elements contribute to the success of an idea or artifact – and any element in an idea or artifact's environment may be responsible for failure. An idea does not by itself solve a problem, but needs to be combined with time to develop it, skilled work to provide evidence for it, rhetorical work to make it plausible to others, and the support to put all of those in place. If some of the evidential work is empirical, then it will also demand materials, and the tinkering to make the materials behave properly. Solutions to problems, therefore, need nurturing to succeed.

There is no *a priori* ordering of such elements. That is, no one of them is crucial in advance. With enough effort, and with enough willingness to make changes elsewhere in the environment, anything can be changed, moved, or made irrelevant. As a result, there is no *a priori* definition of good and bad ideas, good and bad technologies. Success stories are built out of many distinct elements. They are typically the result of many different innovations, some of which might normally be considered technical, some economic, some social, and some political. The "niche" of a technological artifact or a scientific fact is a multi-dimensional development.

Some Objections to Actor-Network Theory

Actor-network theory, especially in the form articulated by Bruno Latour in his widely read book *Science in Action* (1987), has become a constant touchstone in S&TS, and is increasingly being imported into other domains. The theory is easy to apply to, and productive of insights in, an apparently limitless number of cases. Its insistent focus on the materiality of relations creates research problems that can be solved. And its claims about the relationality of materials mean that its applications are often counter-intuitive. But this success does not mean that S&TS has uncritically accepted actor-network theory. The remainder of this chapter is devoted to criticisms of the theory. This discussion of the problems that ANT faces is not supposed to indicate the theory's failure. Rather, it contributes to an explanation of the theory, and to demonstrating its scope.

1 Practices and cultures

Actor-network theory, and for that matter almost every other approach in S&TS, portrays science as rational in a means–end sense: scientists use the resources that are available – rhetorical resources, established power, facts, and machines – to achieve their goals. Rational choices are not made in a vacuum, or even only in a field of simple material and conceptual resources. They are made in the context of existing cultures and practices of science and technology. Practices can be thought of as the accepted patterns of action and styles of work; cultures define the scope of available resources (Pickering 1992a). Opportunistic science, even science that transforms cultures and practices, is an attempt to appropriately combine and recombine cultural resources to achieve scientists' goals. Practices and cultures provide the context and structure for scientific opportunism. But because ANT treats humans and non-humans on the same footing, and because it adopts an externalized view of actors, it does not pay attention to such distinctively human and apparently subjective factors as cultures and practices.

In his *Constructing Quarks*, for example, Andrew Pickering argues that scientists' judgments about which theories are most likely to be productive depend upon their own skills (Pickering 1984). Researchers will more highly value a theory the exploration of which demands skills, such as mathematical skills, that they already have or can easily obtain. At the same time, judgments about which skills are most likely to be productive will depend upon the theories that prevail, and thus choices about theories can redefine the culture and practices of the field.

Cultural networks do not fit neatly into the network framework offered by ANT. Trust is an essential feature of scientific and technological work, in that researchers rely upon findings and arguments made by people they have never met, and about whom they may know almost nothing. But trust is often established through faith in a common culture. Steven Shapin (1994) argues that the structure of trust in science was laid down by being transferred from the structure of gentlemanly trust in the seventeenth century; gentlemen could trust each other, and could not easily challenge each other's truthfulness. Similarly, trust in technical judgment often resides in cultural affiliations. Engineers educated in the École Polytechnique in France trust each other's judgments (Porter 1995), just as do engineers educated at the Massachusetts Institute of Technology (e.g. MacKenzie 1990).

Therefore, either practices and cultures are themselves actors, which is counter-intuitive at the least, or something has to be added to the culturally flat world of ANT to account for rational choices.

2 Problems of agency

Actor-network theory has been criticized for its distribution of agency. On the one hand, it may encourage analyses centered on key figures; many of Latour's examples are of heroic scientists and engineers, or of failed heroes. Such centering may make the world appear to revolve around these heroes or near-heroes. The stories that result miss work being done by other actors, miss structures that prevent others from participating, and miss non-central perspectives. Marginal, and particularly marginalized, perspectives may provide dramatically different insights; for example, women who are sidelined from scientific or technical work may see the activities of science and technology quite differently (see, e.g., Star 1991). With ANT's focus on agency, positions from which it is difficult to act make for less interesting positions from which to tell stories. So ANT may encourage the following of heroes and would-be heroes.

On the other hand, actor-network analyses can be centered on any perspective, or on multiple perspectives. Michel Callon even famously uses the perspective of the scallops of St. Brieuc Bay for a portion of one statement of ANT (Callon 1986). This positing of non-human agents is one of the more controversial features of the theory, attracting a great deal of criticism (see, e.g., Collins and Yearley 1992).

In principle, ANT is entirely symmetrical around the human/non-human divide. Given its externalized perspective, non-humans can appear to act in exactly the same way as do humans – they can have interests, they can enroll others. (Strictly speaking, all of the actors of ANT are *actants*, or things made to act. Thus agency is an effect of networks, not prior to them. This is a difficult distinction to sustain, and the ends of ANT's analyses seem to rest on the agency of non-humans.) In practice, though, actor-network analyses tend to downplay any agency that non-humans might have (e.g. Miettinen 1998). Humans appear to have richer repertoires of strategies and goals than do non-humans, and so make more interesting subjects of study. The subtitle of Latour's popular *Science in Action* is *How to Follow Scientists and Engineers through Society*, indicating that however symmetric ANT is, of interest are the actions of scientists and engineers.

3 Problems of realism

Running parallel to problems of agency are problems of realism. On the one hand, ANT's relationalism would seem to turn everything into an outcome of network-building. Before their definition and public circulation, through laboratory and rhetorical work, natural objects cannot be said to have any real scientific properties. Before their public circulation and use, artifacts cannot be said to have any real technical properties, to do anything. For this reason, ANT is often seen as a blunt version of constructivism: what is, is constructed by networks of actors. This constructivism flies in the face of strong intuitions that scientists discover, rather than help create, the properties of natural things. It flies in the face of strong intuitions that technological ideas have or lack force of their own accord, whether or not they turn out to be successful. And this constructivism runs against the arguments of realists that (at least some) things have real and intrinsic properties, no matter where in any network they sit.

On the other hand, positing non-human agents appears to commit ANT to realism. Even if ANT assumes that scientists in some sense define or construct the properties of the so-called natural world, it takes their interests seriously. That is, even if an object's interests can be manipulated, they resist that manipulation, and hence push back against the network. This type of picture assumes a reality that is prior to the work of scientists, engineers, and any other actors. Latour says, "A little bit of constructivism takes you far away from realism; a complete constructivism brings you back to it" (Latour 1990: 71).

The implicit realism of ANT has been both criticized, as a step backwards from the successes of methodological relativism (e.g. Collins and Yearley 1992), and praised as a way of integrating the social and natural world into S&TS (Sismondo 1996). For the purposes of this book, whether ANT does make realist assumptions, and whether they might move the discussion forwards or backwards are left as open questions, much as they have been in the field itself.

4 Problems of the stability of objects and actions

The last problem facing ANT to be mentioned here is one that will be made increasingly salient in later chapters. According to ANT, the power of science and technology rests in the arrangement of actors so that they form literal and metaphorical machines, combining and multiplying their powers. That machining is possible because of the power of laboratories and laboratory-like settings (such as field sites that are made to mimic labs; see Latour 1999). And the power of laboratories depends upon relatively formulaic observations and manipulations. Once an object has been defined and characterized, it can be trusted to behave similarly in all similar situations, and actions can be delegated to that object.

Science and technology gain power from the translation of forces from context to context, translations that can only be achieved by formal rules. Colorful language aside, this picture overlaps with the picture put forward by the logical positivists in the 1930s, who also saw the successes of science and technology as only explicable in terms of formal rules. However, rules have to be interpreted, and Wittgenstein's problem of rule-following shows that no statement of a rule can determine its interpretations (box 3.2). As we will see, S&TS has shown how much of the work of science and technology involves tinkering, how difficult the work of making observations and manipulations is, how much expert judgment is involved in routine science and engineering, and how that judgment is not reducible to formulas (chapter 9). ANT, while it recognizes the provisional and challenge-able nature of laboratory work, glides over these issues. It presents science and technology as powerful because of the relative rigidity of their translations, or the objectivity – in the sense that they capture objects – of their procedures. Yet rigidity of translation may be a fiction, hiding many layers of expert judgment.

Conclusions

Since the publication of Latour's *Science in Action* (1987), ANT has dominated theoretical discussions in S&TS, and has served as a framework for an enormous number of studies. Its successes, as a theory of science, technology, and everything else, have been mostly bound up in its relational materialism. As a materialist theory it explains intuitively the successes and failures of facts and artifacts: they are the effects of the successful translation of actions, forces, and interests. As a relationalist theory it suggests novel results and promotes ecological analyses: humans and non-humans are bound up with each other, and features on neither side of that apparent divide can be understood without reference to features on the other. Whether actor-network theorists can answer all the questions people have of it remains to be seen, but it stands as the most successful of S&TS's theoretical achievements so far.

CHAPTER 8

Two Questions Concerning Technology

Is Technology Applied Science?

The idea that technology is applied science is now centuries old. In the early seventeenth century, Francis Bacon and René Descartes both argued for the value of scientific research by claiming that it would produce useful technology. In the twentieth century this view was championed most importantly by Vannevar Bush, one of the architects of the science policy pursued by the United States after the Second World War: "Basic research . . . creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science. . . . Today, it is truer than ever that basic research is the pacemaker of technological progress."

The view that technology is applied science has been challenged from many directions. In particular, accounts of artifacts and technologies show that scientific knowledge plays relatively little direct role in the development even of many state-of-the-art technologies. Historians and other theorists of technology have argued that there are technological knowledge traditions that are independent of scientific knowledge traditions, and that to understand the artifacts one needs to understand those knowledge traditions. At the same time, however, some people working in science and technology studies (S&TS) have argued that science and technology are not sufficiently well defined and distinct for there to be any determinate relationship between them.

Because of its large investment in basic research, in the mid-1960s the US Department of Defense conducted audits to discover how valuable that research was. Project Hindsight was a study of the key events leading to the development of 20 weapons systems. It classified 91 percent of the key events as technological, 8.7 percent as applied science, and 0.3 percent as basic science. Project Hindsight thus suggested that the direct influence