# Reactors, Weapons, X-Rays, and Solar Panels: Using SCOT, Technological Frame, Epistemic Culture, and Actor Network Theory to Investigate Technology

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*Every major technical change reverberates at many levels, economic, political, religious, cultural. Insofar as we continue to see the technical and the social as separate domains, important aspects of these dimensions of our existence will remain beyond our reach.*
–Andrew Feenberg, *Questioning Technology*

## Abstract

The article explores how four different theories have been used to investigate technology. It highlights the worth and limitiations of each theory and argues that an eclectic, ever-evolving approach to the study of technology is warranted.

## Introduction

Traditional approaches to the history of science and technology have been challenged for being too narrow, deterministic, and selective. For instance, before the creation of the Society for the History of Technology (SHOT) and the International Association for Science and Technology Studies (IASTS), historical investigations of scientists and technology tended to focus exclusively on "men and machines" at the expense of larger social, political, and economic circumstances (Hirsh 1983; Nye, 1984). When these approaches did attempt to investigate the context surrounding science and technology, they typically reduced changes to secondary effects of economic and social policy, often subscribing to doctrines of technological and social determinism. When historians and sociologists of science and technology did endeavor to look closer at context and determinism, they tended to be inconsistent and parochial in their selection of case studies, habitually focusing on great technological systems like electricity or military weapons at the expense of topics such as gender, culture, and race.

In contrast, the progressive field of science and technology studies (STS) has adopted as its fundamental concern the "investigation of knowledge societies in all their complexity: their structures and practices, their ideas and material products, and their trajectories of change" (Jasanoff 2004, 2). This perspective views technological knowledge and its material embodiments as at once products of social work and indicative of different forms of social life. A growing number of academic STS programs, the increased technological sophistication of society, and the interdisciplinary nature of its subject matter have coalesced to deepen the significance and application of STS. Correspondingly, the number of scholars subscribing to its views – and the literature and intellectual momentum attached to them – has spawned dozens of different theories, case studies, and analytical tools designed to illuminate the interplay between technology and society.

To help focus on the foundations of the discipline, this paper will investigate four widely used methodological approaches for studying technology. Specifically, it will argue that the social construction of technology, technological frame, epistemic culture, and actor network theory together offer a more varied and dynamic way of differentiating the interconnections between the "black box" of technology and cultural, social, political, and economic structures. The central argument of this paper holds that these concepts are useful in describing (a) the different social groups involved in the production of technological artifacts that might otherwise remain concealed; (b) the relationship such technology has with socio-cultural structures and practices; (c) the tendency for technological artifacts to have meanings that are mediated and negotiated, rather than fixed, and contingent on discourses of conflict, difference, and strategy; and (d) the often invisible role of knowledge, expertise, technical practices and material objects that shape, sustain, and transform relations of authority and institutions of policymaking.

This paper is not intended to provide a comprehensive investigation of these technologies or theories. Rather, it is designed to provide a helpful and concise guide for scholars and educators wishing to sample a variety of STS methods and topic areas. To do so, it focuses on four of the most cited and used theories in the field. The paper begins with a discussion of SCOT and nuclear reactors before examining technological frame and military weapons, epistemic culture and x-ray hair removal, and actor network theory and solar panels.

## The Social Construction of Technology (SCOT) & Nuclear Reactors

Sociologists such as Wiebe Bijker (1992, 1996), Donald MacKenzie (1993, 1999), Trevor Pinch (1999, 2001), and historian Thomas Hughes (2001) have promoted a model called the social construction of technology. This model holds that technological systems commit policymakers to a particular set of technical arrangements and are inherently "socially constructed artifacts" (Hughes 2001, 52; Bijker & Law 1992; Kline & Pinch 1999). These authors propose that large technological systems often involve many distinct agents, subjecting them to an interpretive flexibility that gives the same technological artifact varying meanings for different groups (Kline & Pinch 2001, 113-114). Or, as political theorist Landon Winner (1999) puts it, "artifacts have politics."

The methodological approach called the social construction of technology (SCOT) suggests that technological systems are often organized according to five interrelated themes. First, technological artifacts are viewed as intrinsically complex and, like "the social" or "the economic," contain meaning that is not fixed but emergent (MacKenzie 1998; Bijker & Law 1992). This meaning materializes through what John Law refers to as "heterogeneous engineering," the process by which multiple meanings get manufactured into technological objects. Second, because the development of technology involves competing organizations, consumers, entrepreneurs, and politicians seeking to maintain a particular set of technical arrangements, artifacts are often the product of conflict, difference, and resistance. Third, technologies involve strategy and "are not neutral servants of whatever social or political order chooses to adopt them. Their adoption and operation involves changes to that order – changes that are not automatic consequences of new technology but must themselves be engineered, often in the face of conflict and resistance" (MacKenzie 1998, 14). Fourth, since "technological systems contain messy, complex, problem-solving components," technologies encompass not only physical artifacts but also an entire network of organizations, processes, people, research programs, regulatory laws, and knowledge systems (Hughes 2001; Bijker, Hughes, & Pinch 2001). Fifth, since technologies are "invented and developed by system builders and their associates, the components of technological systems are socially constructed artifacts" with disparate effects on social, economic, and cultural practices (Hughes 2001, 52; Bijker & Law 1992).

Thus, SCOT proposes that both social determinism and technological determinism are flawed because "neither the purely social nor the exclusively technical is a determinant" in constructing technology. Rather, technological designs are shaped both by inescapable physical realities and ambient socio-cultural factors. Approaches to understanding technology, then, must recognize that objects are not universal or independent of context (MacKenzie 1998, p. 216). Rather, SCOT can reveal that apparently stable technologies started with many possible futures and have been shaped by "particular social interests and relevant social groups and interpretations" (Mort 2002, p. 22).

The classic example of a socially constructed technology is Langdon Winner's discussion of the American nuclear reactor. Winner proposes (1986, 1999) that the construction and operation of nuclear reactors in the United States requires an authoritarian, systems-centered, immensely powerful but inherently unstable technological approach. This approach blurs the distinction between social and technological determinism. Nuclear reactors are deeply woven in the conditions of modern politics, and fundamentally change the exercise of power and the experience of citizenship. As one environmentalist lamented in the 1970s:

> The increased deployment of nuclear power facilities must lead society toward authoritarianism. Indeed, safe reliance upon nuclear power as the principle source of energy may be possible only in a totalitarian state. (cited in Winner 1986, p. 19)

Yet social values and norms also exert great influence on the technology of nuclear reactors. Nuclear reactors can be socially constructed in two ways. First, many theorists working in the history and philosophy of technology have noted that the adoption of a given technical system actually requires the creation and maintenance of a particular set of social conditions as the operating environment for that system. Some kinds of technology, like nuclear reactors, require their social environments be structured in a particular way much like an automobile "requires wheels to move" (Winner 1986, p. 32). In this sense, the specific features in the design of nuclear reactors provide a convenient means of establishing patterns of social power and authority.

In addition, normative social values become entrenched into the design process of a nuclear reactor. The average cost of a traditional nuclear power plant ranges between $5-7 billion, not including the expense for storage of spent nuclear fuel, maintenance, and decommissioning; thus, the existence of a reactor requires a society with significant amounts of wealth. It also requires a society that uses electricity and demands extremely large quantities of energy for consumption (Nye 1992, 1999; Hirsh 1999; Melosi 1985). Moreover, the extensive transmission networks designed to distribute the electricity provided from nuclear reactors to millions of customers requires a certain level of democracy, coupled with the intent that citizens should have equal access to electricity. In contrast, nuclear power also requires authoritarian management styles and extremely tight security precautions. It is one of those structures whose hazards and vulnerabilities, in the words of Langdon Winner, require "ourselves to become increasingly well policed" (1986, p. 175). And, finally, the truly gargantuan nature of nuclear power plants reflects the American notion of progress, but progress in a very unique way: a monument to gigantism, science, and the domination of people over nature. Thus, the nuclear reactor is not simply a social or technical artifact. Instead, it is a multifarious technology that fundamentally embraces democratic and authoritarian tendencies at the same time (thus being a product of tension and negotiation) while also embedding social values related to wealth, electricity consumption, and progress.

## Technological Frame & Military Weapons

Similarly, the concept of a technological frame is often mentioned in conjunction with SCOT. In his influential work establishing a theory of socio-technical change, Wiebe Bijker (1995) holds that the idea of a "technological frame" attempts to enclose the interactions that occur between, rather than in or above, the actors. It comprises "all elements that influence the interactions within relevant social groups and lead to the attribution of meanings to technical artifacts – and thus to constituting technology" (Bijker 1995, p. 123). Bijker argues that a technological frame must include three components: (1) the array of values, methods, goals, tacit knowledge, user practices, and testing procedures used by a group of practitioners when developing a particular technology; (2) the individual actors that constitute such a group; and (3) the technological artifact itself. Bijker emphasizes that a "technological frame" is intentionally an abstract concept and is intended for use as an analyst's tool when investigating technology.

For example, when investigating the social construction of Bakelite, the first synthetic plastic, Bijker contrasts two distinct social groups, one involving celluloid chemists and the other electrochemical engineers. The chemists, Bijker documents, were primarily concerned with the production of fancy articles, price of the solvent camphor, flammability of celluloid, shrinkage and distortion of plastic, application of heat and pressure, and the use of presses and preheaters to manufacturing celluloid (Bijker 1995, p. 126). These goals, problems, strategies, theories, and artifacts are significantly different from those of the electrochemical engineers. The engineers were primarily concerned with the flow production of chemicals, corrosion and reaction efficiency of plastic, the design of diaphragms, industrial flow processing, fluid dynamics, and basic inorganic chemistry (Bijker 1995, p. 141).

By focusing on social groups, Bijker demonstrates that artifacts possess interpretive flexibility. That is, different social groups see particular technologies in different ways. These technologies, then, become "heterogeneous" because their meaning, rather than being fixed, are interpreted and negotiated by those social groups connected to it. An emphasis on a particular group of practitioners can reveal the wider social interests invested in technology, other associated groups that might otherwise remain hidden, and the different strategies these actors use in their contest over the negotiation of technology.

Such an approach can be especially useful for studying the social interests attached to the production of military weapons. Ken Adler (1997) uses the notion of technological frame particularly well in *Engineering the Revolution*, where he follows the role of Enlightenment French engineers in their design of gunpowder weapons and cannons. Adler holds that the gun transformed the relationship among officers, soldiers, and the nation-state in the same way that our modern landscape is changed by the presence of computers and nuclear weapons.

Using technological frame, here, reveals three interesting things. First, by tracing the work of engineers working in the French artillery service, Adler demonstrates the importance of Honore Blanc, who invented interchangeable tumblers, locks, plates, frizzens, pans, cocks, sears, bridals, screws, and springs in muskets. Blanc's inventions were viewed by Thomas Jefferson during a visit to France, and convinced Jefferson to promote interchangeable gun parts at the armories in Harpers Ferry and Springfield, a move that ultimately influenced Eli Whitney and modern techniques for mass production of products with moving parts. Consequently, the group-centered approach is useful for tracing the course of a technology as it is transferred among different actors.

Second, by following engineers Adler shows that the role of the French government as the provider of productive order was changing. The French Revolution, in eradicating the monarchy, attempted to establish a new state based on the absolute right to property and free trade. This ideal, however, was deeply influenced by engineers, who presented their own vision of the nation and its technological life in their discussions with citizens and politicians. In short, the engineers expanded their role as benefactors of the state, establishing themselves as important actors in creating a productive French order.

Third, such an emphasis on these engineers reveals that they were most successful, not in their technology, but in their social influence. At the beginning of the 1700's, French military engineers were at the periphery of power, connected to a hodgepodge of eclectic social backgrounds, and answerable to lordly patrons. By the end of the century, the engineers represented a highly specialized, autonomous, and professional elite with a clearly defined workforce backed by social institutions and universities. Their corresponding technical advances in the musket, cannon, and M177, while important, were not nearly as influential. Adler's approach reminds scholars of a profound paradox: the engineer's greatest triumph was the assertion to the right of technocratic rule on the basis of a technical mastery that they did not possess. Yet by connecting their vision to popular French ideals and needs, engineers secured the use of automatic machinery and positioned themselves at the center of French industrialization.

On a more contemporary plane, the concept of technological frame is especially insightful for investigating large technological systems, like electric utility equipment, military weapons, and industrial and manufacturing facilities. For example, when applied to the development of the United States National Missile Defense (NMD) system (formally called the Strategic Defense Initiative and then Theatre Missile Defense), technological frame helps reveal at least three separate groups – engineers, politicians, and security analysts – that might otherwise remain hidden.

The requirements for NMD are incredibly complex, demanding thin margins of error and the most difficult aspects of rocket science. Aerospace, electrical, computer, systems, and civil engineers must work together to create a system with the precision needed to "hit a bullet with a bullet" (Mitchell, 2000). This ability to target and intercept incoming missiles is further complicated when adversaries can attempt to overwhelm the system through the construction of decoys, attempts to Multiple Independently Targetable Reentry Vehicle (MIRV) warheads, missile saturation techniques, and the deployments of cruise missiles and weather balloons to overwhelm computer targeting systems (Eland 2000). For these engineers, an NMD system is about protecting the American homeland from a missile attack, and they must focus on making its technology work.

Politicians, in contrast, emphasize the importance of using an NMD system to protect American allies and provide American aerospace and defense firms with lucrative international contracts. The United States supplies over 51 percent of military technology sold globally, and members of the Department of State and Department of Defense have already signed agreements and memorandums with Israel, India, Taiwan, and South Korea promising to export our NMD technology (Sadowski 1992; Warren & Floodin 2001; Mitchell 2000).

Finally, security analysts, often working in association with large security and defense think tanks and government institutions, are charged with providing the justifications for an NMD system by assessing hostile enemies and "states of concern," such as Iran, Libya, and North Korea, that may want to attack the United States. For these analysts, NMD requires the assessment of rogue nations needed to create popular support for the missile shield, and the psychological assurance that such a system will deter and prevent an attack on the American homeland (Mitchell 2000; Spring & Anderson, 2000).

Technological frame highlights that these different social groups employ disparate production habits, methods, and techniques. For instance, engineers work mostly in aerospace and scientific laboratories, evaluate their findings through research, development, and demonstration, and present their results at academic conferences. In contrast, politicians must report to different committees and panels within Congress and the Federal Government, evaluate the "success" of missile projects only in terms of economic development, the creation of jobs, and establishment of export markets, and present their findings through public deliberation. Security analysts create their knowledge at various think tanks from reading literature and citing similar authors, evaluate their findings through the internal workings of their institution, and present their research directly to the public through reports and statements. Yet while these groups approach NMD differently, they play an indispensable role in designing, selling, and justifying the technology.

In sum, the concept of technological frame can be useful for studying historical and contemporary military technology. In the case of arms manufacturing in Enlightenment France, the concept helps reveal how a particular ensemble of actors transfer their technology, establish their profession, mold the course of society, and use the power of vision and deception to retain political influence. In the case of NMD, the concept reveals that the NMD system is not merely a technical system with military implications. Instead, it emerges through a web of social groups concerned about the technology's feasibility, economic potential, and psychological protection. In this instance, each social group directly relates to the other: a system that cannot work provides no comfort; a system that cannot make money will not appease aerospace contractors; and the lack of public support prevents the system from being built (and thus working), and so on. Technological frame reveals that the technical controversy over making NMD effective also concerns engineers, politicians, and security analysts. Put simply: the development of any large technological project – particularly one such as NMD – is conceived, planned, and designed to achieve a complex set of objectives that will enhance the security and economy of society. In doing so, it necessarily involves many distinct groups with competing and complementary values, goals, and techniques to achieve them. These each get built into such a technological system.

## Epistemic Culture & X-Ray Hair Removal

In her work on the sociology of scientific knowledge, Karin Knorr-Cetina (1999) elucidates the concept of an epistemic culture when describing the operation of scientific laboratories. Knorr-Cetina begins by suggesting that scientific laboratories configure social and natural order, and that these reconfigurations work differently in disparate fields of science. As a result, scientific laboratories develop distinct cultural, social, and technical stances. Experiments within the laboratory, Knorr-Cetina elaborates, reflect this natural and social ordering, culminating in her notion of an "epistemic culture." For Knorr-Cetina, epistemic cultures are "those amalgams of arrangements and mechanisms – bonded through affinity, necessity, and historical coincidence – which, in a given field, make up how we know what we know" (1999, p. 1). Thus, epistemic cultures are individual communities of practitioners that create and warrant knowledge used to structure, mechanize, and configure ideas to a natural, scientific, or social order within the confines of their discipline.

This means that the production of technological knowledge is fundamentally social because it is defined or constituted by practices of work, trust, methods of analysis, methods of interpretation, values, and institutional arrangements within each epistemic culture. Knorr-Cetina refers to these sets of relations as "knowledge machinery" because they represent a complex social network – between agents and instruments – that constrain the production of knowledge. The concept of an "epistemic culture" can expose the ways that the construction of technology becomes an active social process that is constantly negotiated, implemented, superceded, and revised within the confines of corresponding scientific, social, and political epistemologies.

One insidious example concerns x-ray hair removal technology. Finding its roots with Darwin and the American Dermatological Association's emphasis on the ugliness of excess hair, from 1914-1945 the popular media promoted the ideal of the hairless feminine body. This image was connected to newly emerging conceptions of race, class, and gender identity: human hair reflected at once one's ethnicity, masculinity/femininity, and affluence. During the 1920s and 1930s, however, techniques to remove excess hair (such as abrasives, razors, tweezing, and waxes) remained painful, time intensive, and had to be repeated. Similarly, more expensive techniques such as chemical depilatories, diathermy and electrolysis offered permanent solutions, but were meticulous and extremely costly (Herzig 2003). The concept of using x-ray technology to remove hair, despite warnings from the American Medical Association's Bureau of Investigation about potential health effects, was initially promoted by a small group of doctors as a better alternative.

A group of practitioners working in medicine with x-ray technology developed the process of x-ray epilation, or using x-rays to remove excess hair from the face, back, neck, arms, and legs. Even though a team of researchers found that epilation was responsible for more than 35 percent of all radiation-induced cancer in women, the practice continued for three decades from the 1940s through the 1960s (Martin et al. 1970). The concept of an epistemic culture helps explain how the use of such damaging technology became self-sustaining. Practitioners placed faith in epilation not only because it was undeniably effective at removing hair, but because it bypassed the physicality of other techniques. Since they were invisible, x-rays were perceived to be harmless (and the harm from them was attributed to other factors). In addition, the use of x-ray technology was closely associated with notions of modernity, progress, and science. The "mystery" of "science" convinced both users and practitioners of the unquestioned benefit of x-ray technology. Furthermore, the use of x-ray technology established professional and class identity. For practitioners, it offered a well paying and respected profession. For users, it offered a hair removal procedure unequaled in cleanliness and luxury.

Taken together, the technology of the x-ray combined with social values about science, class, and contemporary notions of risk to create an epistemic culture of doctors, nurses, and patients convinced about the benefits of x-ray epilation. Here, the knowledge machinery – the complex network of instruments, people, and values – played a unique role in shaping the acceptance and continuation of x-ray hair removal. As part of this extensive knowledge machinery, the x-ray existed not as a passive object, but an active and interactive vessel that simultaneously stimulated and constrained knowledge practices.

### Actor Network Theory & Solar Panels

Finally, theorists Steve Woolgar, Bruno Latour, and Michel Callon are largely responsible for developing the methodological tool known as Actor Network Theory (ANT) (Latour & Woolgar 1979; Latour 1987; Callon 1986; Callon & Latour 1986; Callon & Latour 1992). ANT suggests that the processes of creating and adopting technology are complex, interactive, and political (Mort 2001, 17). Successful technologies must not only get built; they must be built into society. Technical objects are not things in the usual sense, but "nodes in a network that contains both people and devices in interlocking roles" (Feenberg 2001, 114). ANT suggests that the social alliances in which technology are constructed are bound together by the very artifacts they create. Thus, social groups do not precede and constitute technology but "emerge with it" (Feenberg 2001, 114-115). In this way, it is possible to explore the process by which power relations are configured and rendered fixed, invisible, and logical by viewing power as something that circulates. ANT attempts to investigate the formation of power before it gets distributed, before facts and machines become inexplicably bound to societal perceptions and behaviors. At this level, scholars are able to see the ordering, not just the order (Mort 2001, 8-9). ANT, then, attempts to uncover the facts, machines, people, and bureaucracies that must be aligned, molded, and disciplined to create technological development; these combine to make up the actor world, an "overall environment that provides the conditions for a technology to succeed" (Mort 2001, 17).

In the process of creating this world, a diversity of animate and concealed entities must be enrolled into the network so that their primary function becomes the promotion of that network. This parallels the way that Latour & Woolgar (1979) talk about the scientific laboratory. Latour & Woolgar propose that the scientific laboratory can be understood as a system of literary inscription that uses the process of enrollment to establish "truth." Scientific laboratories must publish in science journals to raise funds for further research, so they often reduce their experiments to a series of graphs or statements in an article (and build their argument in association with other claims being made by similar scientists in different articles). Thus, scientific knowledge is sutured not through objective knowledge practices but a subtle process of indoctrination through literature. The structure of this network gives rise to the factual status of any given claim, rather than any "objective" notion of truth. For Latour (1987) and Callon (1986), when you connect enough actors and networks to a claim, it becomes a fact because such statements appear to be supported by all of the actors (or the weight of the network) behind it. The same is true for the technology: link an invention, like the microcomputer, to so many different projects, goals, actors, and businesses, and its importance becomes a "fact" rather than merely one among many possible historical outcomes. Thus, ANT proposes that the power of scientific knowledge is nothing more than the sheer power of the scientific network.

Three components of ANT – the socially constructed nature of technology, the process of enrollment, and the creation of socio-technic networks – help frame and conceptualize the current status of solar panels, or photovoltaic (PV) sources of energy, in the electric utility industry. Even though PV systems are relatively old (the photovoltaic effect was first discovered by French physicist Antoine-César Becquerel in 1839), cost effective, decentralized, modular, clean, and offer the ability to be implemented into architecture, they are not widely used to generate and produce electricity (Hirsh 1999; Abate 2004; Clayton 2004; Distributed Power News 2001; Renaud 2004; Sheer 2001). ANT is insightful for explaining why, despite these benefits, more consumers and utility companies do not rely on PV systems for electricity.

Put simply, the largest impediment to solar energy remains the traditional socio-technic network already established by electric utilities. Solar panels threaten the traditional way of generating power through large, centralized power plants because they are small and decentralized. Technically, it is more reasonable to build systems in disaggregated and distributed manner which reduces overall stress on the grid, insulates the grid from interruptions, and provides better quality power (Lovins 2002). Politically, the use of smaller on-site systems of electricity accommodate local needs more effectively and are more easily managed, accessible, and comprehensible (Winner 1986; 32-33). Yet, since the choice between conventional and renewable energy systems is really about the power of two competing sociotechnical networks (one consisting on the rapid expansion of centralized fossil fuel energy facilities, the other on decentralized and efficient renewable technologies), traditional systems have greater momentum. Even though solar panels offer many benefits – virtually renewable sources of energy, diversity, flexibility, advantages of scale, and the provision of better quality energy – ANT suggests that these benefits will never be realized as long as the goals, actors, and influence of the network behind fossil fuels is greater than that behind solar panels.

From an ANT perspective, the network predicated on fossil fuel extraction, the creation of new coal and uranium mines, maintenance of oil refineries, and American social attitudes about consumption and efficiency remains more established, understood, used, and accepted within society. Such a path can be understood as having, to borrow from Thomas Hughes (1983), significant momentum (i.e., mass, velocity, and direction involving many powerful industries, politicians, and consumers). In contrast, newer technologies such as photovoltaic systems have not yet achieved the credibility of conventional forms of energy production, making it illogical for consumers to accept them.

Thus, ANT highlights that the reason PV systems fail to gain widespread support is because the network behind them constituted by liberals, environmentalists, and local activists isn't large enough to offset the network created by conservative policymakers, investors, and utility operators. ANT suggests that the debate over PV systems is not just about technology; it is really a struggle involving persuasion and enrollment. Viewed this way, the struggle over PV systems is also a struggle over values, or competing knowledge systems. ANT can be noteworthy, then, for de-centering the technological artifact as the object of inquiry and expanding scholastic focus on "technology" to include the vast social and cultural networks that surround it, as well as focusing on the importance of credibility, communication, and the illusion of objectivity surrounding technological practices. By focusing on the relational aspects among engineers, inventors, analysts, politicians, artifacts, manufacturing techniques, marketing strategies, historical context, economics, and social and cultural factors, ANT highlights that technology emerges through a seamless web of material objects and immaterial epistemologies. This situates energy technologies as neither inevitable nor static. Instead, energy technologies are the product of a complex power play between divergent actors and their interests.

## Conclusion

Using SCOT to investigate nuclear reactors reveals how social values become embedded in technological artifacts. Applying technological frame to French arms manufacturing and American National Missile Defense demonstrates that large technological systems extend across many different social groups. Considering epistemic culture when tracing the history of x-ray hair removal technology suggests that knowledge, expertise, and technical practices can combine to shape, sustain, and transform relations of authority and the institution of medical policy. ANT highlights that solar panels have meanings that are mediated and contingent on communicative or persuasive efforts by proponents and opponents enrolled in a large sociotechnic network.

In addition to equipping scholars and educators interested in technology with more dynamic tools to assess its relationship with society, these four tools are also important for empowering activists and citizens concerned with preserving their autonomy in a more technologically sophisticated society. Concepts like SCOT and ANT help refute the belief in the technological determinism of technological artifacts. They suggest that no technological system is truly self-sustaining, and that there is hope in dismantling even the most pervasive technological systems (like the military industrial complex). In addition, concepts like technological frame and epistemic culture help identify the different actors and interests involved in technology. Such tools suggest who activists should approach to mold sociotechnical change. Similarly, such efforts help re-politicize the usually technical discourse surrounding technology, showing that it is neither objective nor neutral. By identifying the relational aspects among people, artifacts, and knowledge, SCOT and ANT help show that there is no one person or institution masterfully manipulating the course of military technology. Instead, it is a complex amalgam of political, social, economic, and technical interests. Finally, because these approaches view technology as part of a social system, the failure and acceptance of certain technologies can sometimes have nothing to do with technical feasibility, and instead relate to contests over values, power, and interests (Moy 2001; MacKenzie 1993) (See Table 1).

**Table 1. Summary of Four STS Methods and Case Studies**

| Approach | Primary Authors | Central Thesis | Key Concepts | Contribution |
|---|---|---|---|---|
| Social Construction of Technology (SCOT | Wiebe Bijker, Donald MacKenzie, Trevor Pinch, and Thomas Hughes | Technological artifacts are socially constructed. | Interpretive flexibility, heterogeneous engineering | Reveals that both social and technical factors concurrently shape technological artifacts. |
| Technological Frame | Wiebe Bijker | A single technological artifact is seldom worked on by only one group of people. | Relevant social groups | Helps reveal otherwise concealed actors connected to technological systems. |
| Epistemic Culture | Karin Knorr-Cetina | The sciences produce knowledge differently, and are bound by disparate epistemic communities and practices. | Knowledge machinery | Reveals that the way practitioners think about problems simultaneously enables and constrains their work. |
| Actor Network Theory (ANT) | Steve Woolgar, Bruno Latour, and Michel Callon | Technical objects are nodes in a network of people and devices in interlocking roles. | Enrollment, sociotechnical networks | Reveals that knowledge and power can be equally important in why technologies succeed and fail. |

Two conclusions can be drawn from such a discussion. First, none of these theories need be viewed as mutually exclusive. They share many similarities, and can be used to complement each other. Their cumulative power suggests that the sociology of scientific knowledge, history of science, and history of technology have much to offer each other. ANT and epistemic culture widen approaches to studying technology by calling attention to systems of knowledge production, discipline formation, and the relations between actors and technological artifacts. SCOT demonstrates that social values can become constructed into technological systems, and technological frame shows that different social groups working on the same technology employ distinct methods and techniques to achieve differing goals.

Second, these theories highlight that the categories we use to describe, understand, and theorize technology should not be viewed as monolithic, and should always be open to revision. Thus, in the same way that neither social nor technological determinism can fully explain technology, the above theories will likely need to be adapted, revised, and perhaps discarded as our knowledge about science and technology expands. The meaning of technology, because it is intimately attached to social and cultural interests, will continue to change. Policymakers and analysts must recognize these changes, or make visible the social threads weaving the image of technology together, if they will devise truly sustainable and dynamic approaches to designing and understanding technology.

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