

“Scientific Controversies” for International *Encyclopedia of Social and Behavioral Sciences*

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There is a long history of studying scientific controversies within the sociology of science. Different sorts of controversy and different approaches to analyzing them have emerged over the years. Here I summarize the main developments.

Priority Disputes

The first type of controversy to gain attention within the sociology of science was the “priority dispute”. This is a dispute between one or more scientists or groups of scientists who claim “priority” for a scientific discovery. In other words there are claims and counterclaims as to who has first made a particular discovery. The reason scientists care so much about priority was first pointed out by Robert Merton (1957). He argued that the main reward in science is recognition, bestowed in prizes and the naming of discoveries. In other sorts of endeavors, for instance technological invention, rewards take other forms, such as patent rights or money.

Priority disputes in science are frequent occurrences because science as an activity builds upon previous knowledge and techniques which are widely disseminated and

shared amongst the scientific community. This means that scientists, who often work within what Thomas Kuhn (1962) has called a shared paradigm, are solving similar sorts of puzzles and this will lead to disputes as to who first arrived at a particular solution. New instruments and techniques, which enable new discoveries, are also collectively shared. Discoveries are, thus, very much in the air. Often scientists are aware that they are in a race and who their main “competitors” are. During such races the norms of sharing data, techniques, and knowledge may break down, and such races can be accompanied by acrimonious accusations of breaches of correct scientific behavior, such as occurred during the race to discover the structure of DNA, where Watson and Crick were accused of stealing Rosalind Franklin’s X-ray crystallography results (Sayre 1975).

Merton's interest in priority disputes stemmed from his claim that science has a particular normative structure or "institutional ethos" with an accompanying set of rewards and sanctions. Because so much of the reward structure of science is built upon the recognition of new discoveries, scientists are particularly concerned to establish priority for their findings. Priority disputes are legion, such as the famous fight between Newton and Leibnitz over who first discovered the calculus, or the more recent fight between the French, Institute Pasteur group, and the American Researcher, Robert Gallo, over who first established HIV as the cause of AIDS. In

this case there was not only scientific priority at stake, but also the licensing of the lucrative blood test for identifying AIDS. The controversy could only be settled by intervention at the highest political level. The Presidents of America and France, Ronald Reagan and Jacques Chirac, agreed to share the proceeds from the discovery. This case was marked by additional controversy because of allegations of scientific misconduct raised against Gallo which led to Congressional and NIH investigations. It was one of the first times in science that a controversy was settled by politicians. The AIDS priority dispute reminds us that the notion of a “community of scientists” struggling for recognition amongst themselves does not fit science in the latter part of the twentieth century. Scientists in areas such as biotechnology increasingly move between academia and start-ups and seek both reputational and financial recognition (stock options and the like) (Shapin 2008).

Thomas Kuhn (1962) raised a fundamental problem for the analysis of priority disputes. A priority dispute is predicated upon a model of science, known as the "point model" of scientific discovery, which can establish unambiguously *who* discovered *what* and *when*. Asking the question who discovered oxygen, Kuhn showed that the crucial issue is what counts as oxygen. If it is the dephlogisticated air first analyzed by Priestly then the discovery goes to him, but if it is oxygen as understood within the modern meaning of atomic weights then the discovery must

be granted to Lavoisier's later identification. The "point model" requires discovery to be instantaneous, and for discoveries to be recognized and dated. A rival "attributional model" of discovery, first developed by Augustin Brannigan (1981), draws attention to the social processes by which scientific discoveries are recognized and "attributed". This approach seems to make better sense of the fact that what counts as a discovery can vary over time. In short, it questions the Eureka moment of the point model. Woolgar (1976), in a pioneering analysis of the discovery of pulsars, showed that the date of the discovery varies depending on what stage in the process is taken to be the defining point of the discovery. If the discovery is the first appearance of "scruff" on Jocelyn Bell's chart recording of signals from the radio telescope, then it will be dated earlier than when it was realized that the unambiguous source of this "scruff" was a distant star. This case was particularly controversial because it was alleged by the dissonant Cambridge radio astronomer Fred Hoyle that the Nobel prize winners for this discovery should have included Jocelyn Bell, who was then a graduate student. Priority disputes can thus touch on the social fabric of science, such as its gender relationships and hierarchical structure.

The point model of discovery is embedded in the reward system of science. For example most significant rewards accrue to the scientist or group who are "first past

the post". Interestingly with modern discovery claims posted to the internet, the exact date and time when a paper is first posted becomes even more crucial in establishing priority.

Controversy as a Method

Controversies as a form of method became important in the sociology of scientific knowledge (SSK) in the 1970s and 1980s. SSK went on to replace the earlier Mertonian sociology of science with its focus upon the rewards and institutions of science. For SSK researchers and for other strands within the emerging field of Science and Technology Studies (STS), such as feminist science studies (Haraway 1989), it has been important to study moments of contention in science. It is during such moments that the often invisible processes of the working of science become more visible and hence available to analysis.

One metaphor for understanding the methodological importance given to controversies is that of "punching" a system. Scientists on occasion gain insight into natural systems by punching them. For example, one may learn more about the laws of momentum by bouncing one billiard ball off another than by watching a stationary billiard ball. Similarly Rutherford famously used scattering experiments in which gold foil was bombarded with alpha particles to uncover the structure of

the atom and in particular the presence of the nucleus. In sociology a similar methodology was advocated by Harold Garfinkel, for investigating the taken-for-granted features of social life. His breaching experiments involved breaking or breaching some taken-for-granted social convention, say, in routine greetings. The methodological assumption underpinning the study of controversies is similar, only in this case the breach in the normal social operation of science is produced by the scientists themselves. By studying a scientific controversy, or moments of contestation, one learns something about the underlying dynamics of science and its relations with wider society. For instance, during a controversy the normally hidden social dimensions of science (including its gender biases) may become more explicit. Sites of contestation are places to facilitate the investigation of, for instance, the metaphors, assumptions and political struggles embedded within science (or for that matter, technology and medicine).

Three Strands of Controversy Research

One can identify broadly three strands of research on controversies within the sociology of science. The first approach, which dates back to the 1960s, was concerned largely with controversies provoked by contemporary science and technology and what was perceived to be its increasingly deleterious impact on the wider society. The controversies often crystallized around particular technologies

such as nuclear power, pesticides and agribusiness in general, or technologies used in warfare, such as Agent Orange, or the perceived threat of what was then called “genetic engineering”. Often groups of concerned citizens and scientists organized to oppose such technologies – for example Rachel Carson’s warnings about the dire effects of pesticides in her book *Silent Spring*. The source of controversy was the perceived negative impact of science and technology on particular groups and it is the study of these political responses which forms the core of the analysis.

The second strand is the study in the 1970s and 1980s of controversies *within* science. This was briefly mentioned above and emerged as part of SSK and its attempts to study how scientific knowledge is “socially constructed”. By focusing on controversies at the research frontier of science, scholars were able to delineate what was at stake for groups of scientists as they fought over very specific knowledge claims, such as the existence of a new room-temperature form of nuclear fusion known as “cold fusion”, or whether particular experimental results in physics had been replicated or not (Collins [1985] 1992). This approach was also extended into technology by what has been called the study of technoscience (Latour 1987), and by the Social Construction of Technology (Bijker, Hughes and Pinch [1987] 2013).

The third strand of controversy studies can be thought of as a merger of the earlier two strands. Within modern S&TS many researchers follow scientific controversies wherever they ramify. In other words, less of a distinction is made between controversies within science and those that impact the wider society. Modern scientometric tools help analysts to follow or map such controversies and the many different participants who may be scattered globally.

Controversies over the Impact of Science on Society

Many of the controversies over science and society which dominate today – such as global warming, sustainable energy, environmental degradation, and biomedical interventions into life – have their roots in earlier debates in the 1960s. The Vietnam War protests, the emergence of the counter culture, and civil rights, formed part of a wider back drop against which science and technology increasingly came into question. The political protest movements of the 1960s led to recognition that science and technology are neither neutral nor necessarily beneficial and that many developments stemming from modern science and technology, such as nuclear power, the petrochemical industries, and genetic engineering, raise profound and controversial issues for a concerned citizenry.

Dorothy Nelkin, a pioneer in analyzing these types of disputes, identified a range of

different sorts of political, economic and ethical controversies which engaged the public (her research was almost exclusively based in the US (Nelkin 1995)). Early research by Nelkin and her colleagues focused mainly on the interest politics of the groups involved (Nelkin 1992): how and why they got involved in political action over science and technology; their underlying political values; and how effective they were. Participants' positions in controversies were taken to be consistent with their interests, although these interests were not necessarily determinate in bringing about closure. For instance, the demise of nuclear power in the US had as much to do with economics as with political protest.

Since scientists themselves often played an active part in these disputes, part of the analysis touched upon how scientists deployed their science for political aims. By and large this research tradition avoided using the entry of scientists into these disputes as an opportunity to examine the core processes of knowledge construction. In short, the attention was focused upon seeing how scientists became political rather than upon how politics might itself shape scientific knowledge. Political controversies were treated as analytically separable from epistemic controversies and as resolved by distinct processes of closure (Engelhardt and Caplan 1987). Typically epistemic controversies were thought to be closed by application of epistemic and methodological standards, while political controversies were closed

through the intervention of "non-scientific factors", such as economic and political interests.

Controversies at the Research Frontiers of Science

The sociology of scientific knowledge (SSK) which emerged in the late 1970s was concerned to examine how scientific knowledge was socially shaped or constructed. A key tenet of this new sociology of science, as formulated by David Bloor ([1976] 1991) in his "Strong Programme", was that of symmetry. This principle called upon sociologists to use the same explanatory resources to explain both successful and unsuccessful knowledge claims. This was a way to avoid a sociology of error whereby the social would be evoked to explain false knowledge, leaving true knowledge as simply revealed, or generated by some universal epistemological principle, or rule of method. Controversies at the research frontiers over knowledge claims were good places to carry through the principle of "symmetry". With each side in a dispute claiming to have "truth on its side", and disparaging the efforts of the other, and with the very outcome of the controversy still unknown, there was less temptation to carry out a sociology of error. Full-blooded sociological explanations as to how credibility and trust were gained, maintained and lost could be mounted. Unlike the approach to controversies on the impact of society favored by Nelkin, the very scientific claims made by the participants became subject to

analysis.

Bloor and his colleagues in what was known as the “Edinburgh School” pursued their program mainly through theoretical analysis supported by historical case studies (an exception was the work of Andy Pickering who studied contemporaneous controversies). Collins and the "Bath School" by contrast, developed an empirical method for studying the sociology of scientific knowledge in contemporaneous cases -- a method based primarily upon the study of scientific controversies (Collins, 1985, Pinch 1986, Collins and Pinch 1998). Generalizing from several case studies of controversies, Collins (1981) argued that during controversies scientific findings exhibited "interpretative flexibility", with the facts at stake being debated and interpreted in radically different ways by the parties in the controversy. This interpretative flexibility did not last forever. By following a controversy over time researchers could delineate the process of "closure" by which controversy vanished and consensus emerged. Collins defined the group of scientists involved in a controversy as the "core set". Only a very limited set of scientists actively partook in controversies, the rest of the scientific community depended upon the core set for their expert judgment as to what to believe.

Following controversies from their inception to the point of closure, allowed

researchers to better understand “science in the making” (Latour 1987).

Controversies when seen through the sociological lens turned out to be messy things and were very rarely resolved by experiments alone. Collins ([1985] 1992) developed the notion of an "experimenter's regress" to explain the lack of compulsion of experiments during controversies.

Often the losing side in a scientific controversy continues to fight for its position long after the majority consensus has turned against it. Those who continue to fight the good fight meet increasing disapprobation from their colleagues and may be forced to leave science altogether. "Life after death" goes on at the margins and often finally passes away only when the protagonists themselves die or retire (Simon 2002). Opposition *outside* science to particular theories *in* science (e.g. Darwin's theory of evolution, Einstein's theory of relativity) also presents a continuing source of controversy (Wazeck 2013). The uncertain side of science is clearest during moments of controversy and it has been argued that teaching science through controversies is good way to give students a more realistic idea of scientific practice. Most scientists never experience controversies directly, and often it is those further from the research frontier who have a more robust sense of scientific method. This “distance lends enchantment” phenomenon (Collins [1985] 1992) has been expressed by MacKenzie (1990) for technology in terms of an “uncertainty trough”

whereby people closest to a technology and those furthest away from it both experience the most uncertainty about a technology's working. Returning to science: after exposure to a controversy, scientists often become more aware of the social side of science and start to read in science studies and even employ ideas drawn from science studies to understand what has happened to them.

The sociological approach to controversies has also been taken up by historians (e.g. Rudwick 1985). Such studies pose particular methodological challenges because often the losing viewpoint has vanished from history (Dascal 1998). Shapin and Schaffer's (1985) study of the dispute between Robert Boyle and Thomas Hobbes over Boyle's airpump experiments was a landmark in research on scientific controversy, because it showed how the wider political climate, in this case that of Restoration Britain, could shape the outcome of a controversy and at the same time help institutionalize a new way of fact making --experiments-- in the Royal Society. It also drew attention to the literary and technological dimensions of building factual assent in science. By documenting the witnesses to particular experimental performances a culture of "virtual witnessing" was born.

The SSK approach to scientific controversy has also been influential in the study of technology. The social construction of technology (SCOT) framework uses concepts

imported from the study of scientific controversy such as "interpretative" flexibility" and "closure". A variety of competing meanings are found in technological artefacts and scholars study how "closure mechanisms" produce a stable meaning of a technology (Pinch and Bijker 1984, Bijker 1995).

Another influential SSK approach to the study of controversies in sciences and technology has been that developed by Bruno Latour and Michel Callon. Actor – Network Theory, as it has become known, has taken on a life of its own and has gone through several reiterations (Munisea this volume). The seminal work in the 1980s formed an important strand to the SSK approach towards controversies. In Callon's 1986 article on a controversy over a new method of harvesting scallops in France, he argues that the outcome of the controversy cannot be explained by reference to the social realm alone, but the analyst must also take account of the actions of non-human actors, such as scallops (Callon 1986). Subsequently Latour's work on how "trials of strength" are settled in science and technology has become especially influential. Such struggles, according to Latour (1987), involve aligning socio-technical resources into so-called "immutable mobiles" or black boxes - objects which remained fixed when transported along scientific networks and which contain embedded within them sets of social and material relationships.

One of the key ideas in all controversy research carried out within SSK is the notion that science has moments of openness or uncertainty followed by closure. Once a matter of fact is settled or black-boxed it is very hard to reopen the black box (Pinch 1986, Latour 1987). Often these processes of closure are woven into the fabric of scientific practices and one can observe the closure or black boxing processes *in situ*. It is at this point that controversy research meets another very influential tradition within SSK known as Laboratory Studies (Lynch 1993). For instance, Latour and Woolgar (1979) in their now classic study of a molecular biology laboratory observed scientific practices close up but also had access to a controversy in the lab. They were able to show how literary inscriptions play a special role as a marker in settling controversies. Controversies could be analyzed in terms of whether certain modalities are added to or subtracted from scientific statements making them more or less fact-like. This enables the opening and closure of a controversy to be followed and how previous resolved controversies get embedded within taken-for-granted results, theories, and techniques.

A detailed examination of the role of discourse in scientific controversies was carried out by Gilbert and Mulkay (1984). They showed how particular repertoires of discourse were used selectively by scientists in order to bolster their own claims or undermine those of their opponents. Subsequently there has been much work on

how a variety of rhetorical, visual and textual resources operate during controversies (e.g. Lynch and Woolgar 1990, Myers 1990, Pinch 1996). Sometimes the resolution of a controversy is only possible by drawing boundaries around the relevant experts who can play a role in the controversy. Sometimes particular scientific objects cross such boundaries and form a nexus around which a controversy can be resolved. Such "boundary work" (Gieryn 1983) and "boundary objects" (Star and Griesemer 1989) form another important analytical resource for understanding how controversies develop and are brought to closure.

Scientific Controversy in Science and Technology Studies Today

The earlier distinction between controversies in science and those over the impact of science of technology has largely been dissolved in contemporary STS. Another way of putting this is to say that in contemporary work the sites of contestation chosen for analysis have become more heterogeneous. Part of the reason for this heterogeneity is that increasingly the boundaries around expertise have become much harder to delineate (Collins and Evans 2007). There is no longer assumed to be a one-to-one mapping between expertise and expert credentials and this means that lay people and activists can themselves acquire enough expertise to engage scientists on their own terms (Wynne 1989). In one well-known case study it was shown how AIDS activists, for instance, managed to reconfigure some of the

science of clinically controlled trials of AIDS drugs (Epstein 1996).

Also the relationship between analyst and actor in controversy research has increasingly been problematized (Ashmore and Richards 1996). Reflexivity is sometimes embraced by analysts who even on occasions become participants in the controversy. The study of controversies in modern technoscience -- with its porous boundaries between science, technology, politics, the media and the citizenry -- also calls for the analyst to adopt a broader array of analytical tools. With the growing role played by the media there is also more attention upon the role of audiences for specific controversies (e.g. Delbourne 2011).

Although the fundamental insights provided by SSK remain influential, such insights are supplemented by an increased understanding of how macro-political structures such as the state, and the legal system, enable and constrain the outcome of scientific controversies. Within the radical agenda of ANT and its sociology of associations this distinction between macro and micro is itself something which is dissolved (Latour.2005). The tools available to study controversies in contemporary science and technology have also expanded. There are several groups involved in a project initiated by Bruno Latour on “mapping scientific controversies”. In this project controversies are defined in the constructivist sense as

“every bit of science and technology which is not yet stabilized, closed or “black boxed” ...” (Venturini 2010). This project on the cartography of controversies is heavily influenced by ANT and has evolved several web-based scientometric tools for following controversies, although face to face interaction still form an important part of the analysis (Venturini 2012).

The contemporary research into controversies draws upon the lessons of constructivist SSK in not taking for granted that claims are settled by epistemic or methodological fiat. The movement from openness to closure involves deploying a whole range of resources. Such work also pays close attention to how actors themselves describe the situation they face. But with the move to study sociotechnical controversies in wider society the sorts of actors dealt with are likely to be much more heterogeneous. The “core set” idea of a bounded community of scientists amongst which the controversy takes place still works for the study of controversies within science, but analysts these days are more likely to embrace the key ANT idea that controversies ramify endlessly, especially when the wider socio-technical assemblage is studied.

Controversies involving science and technology are today examined in the courtroom, in the media, in quasi-governmental policy organizations, in the state

and its security apparatus, and amongst citizens' action groups. A controversy or hot spot may be sparked by almost anything, such as for instance the testing of a new drug, or a claim made about a new smart phone, or a natural calamity such as the collapse of the honey bee population (Suryanarayanan and Kleinman 2013). There has been particular interest in controversies involving health and medicine, such as contentious new disease categories (Murphy 2006), and patient activist groups (Silverman 2013). The strong feminist tradition in science studies has continued with, for instance, research on male contraceptives (Oudshoorn 2003). Anywhere where there are socio-technical disputes – such as for instance in mapping the state (Carroll 2006, Leuenberger and Schnell 2010) - one can study the movement between openness and closure as powerful social choices get embedded within material structures and procedures. In a way controversy research is today a taken-for-granted part of STS - and that is testament to its success as a method.

BIBLIOGRAPHY

Ashmore M and Richards E 1996 The politics of SSK: neutrality, commitment and beyond, *Special Issue of Social Studies of Science*, 26:219-445

Bijker W E 1995 *Of bicycles, bakelites, and bulbs: towards a theory of sociotechnical change*, MIT Press, Cambridge, Ma

Bijker W E, Hughes TS, and Pinch T J (eds) [1987] 2013 *The social construction of technological systems: new directions in the sociology and history of technology*, Anniversary Edition, MIT Press, Cambridge, Ma

Bloor D [1976] 1991 Knowledge and social imagery, 2nd edition, University of Chicago Press, Chicago

Brannigan A 1981 The social basis of scientific discoveries, Cambridge University Press, Cambridge

Callon M 1986 Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St Brieux Bay. In J Law (ed.) Power, action and belief: A new sociology of knowledge?, Sociological Review Monograph, 196-229, Routledge, London

Carrol, P. 2006 Science, Culture and Modern State Formation, University of California Press, Berkeley

Collins H M 1981(ed.) Knowledge and Controversy: studies in modern natural science, Special Issue of Social Studies of Science, 11:1-

Collins H M [1985] 1992 Changing Order, 2nd edition, University of Chicago Press, Chicago

Collins H M and Evans R 2007 Rethinking Expertise, University of Chicago Press, Chicago

Collins H M and Pinch T J 1998 The Golem: What You Should Know About Science, Canto, Cambridge

Dascal M 1998 The Study of Controversies and the Theory and History of Science, Science in Context, 11:147-155.

Delborne J 2011 Constructing Audiences in Scientific Controversy, Social Epistemology, 25 (1): 67-95.

Engelhardt T H and Caplan A L Scientific Controversies: Case studies in the resolution and closure of disputes in science and technology, Cambridge University Press, Cambridge

Epstein S 1996 Impure Science: AIDS, Activism and the Politics of Knowledge, University of California Press, Berkeley, Los Angeles and London

- Gieryn T 1983 Boundary work and the demarcation of science from non-science: Strains and interests in professional ideologies of scientists, *American Sociological Review*, 48: 781-795.
- Gilbert N G and Mulkay M K 1984 *Opening Pandora's Box*, Cambridge University Press, Cambridge
- Haraway D 1989 *Primate Visions: Gender, Race and Nature in the World of Modern Science*, Routledge London
- Kuhn T S 1962 *The Structure of Scientific Revolutions*, The University of Chicago Press, Chicago
- Latour B 1987 *Science in Action*, Harvard University Press, Cambridge Ma
- Latour B 2005 *Reassembling the social: an introduction to Actor-Network-Theory*, Oxford University Press, Oxford and New York
- Latour B and Woolgar SW 1979 *Laboratory Life*, Sage, London and Beverly Hills
- Leuenberger C and Schnell I 2010 The politics of maps: constructing national territories in Israel, *Social Studies of Science* 40:6 803-842
- Lynch M 1993 *Scientific practice and ordinary action: ethnomethodology and social studies of science*, Cambridge University Press, Cambridge
- Lynch M and Woolgar S 1990 (eds) *Representation in scientific practice*, MIT Press, Cambridge, Ma
- Merton R K 1957 Priorities in scientific discoveries: a chapter in the sociology of science, *American Sociological Review* 22:635-659
- Munisea F 2014 *Actor-Network Theory*, this volume
- Murphy, M 2006 *Sick Building Syndrome and the problem of uncertainty*, Duke University Press, Durham , NC
- Myers G 1990 *Writing Biology: Texts and the social construction of scientific knowledge*, University of Wisconsin Press, Madison

Nelkin D (ed) 1992 *Controversies: politics of technical decisions*, 3rd edition, Sage, Newbury Park, Ca

Nelkin D 1995 *Science Controversies: The dynamics of public disputes in the United States*. In S Jasanoff, G E Markle, J C Petersen and T Pinch (eds) *Handbook of science and technology studies*, Sage, Thousand Oaks, Ca

Pinch TJ 1986 *Confronting nature: the sociology of solar-neutrino detection*, Reidel, Dordrecht

Pinch TJ 1996 *Rhetoric and the Cold Fusion Controversy*. In H. Krips, J.E. McGuire and T. Melia (eds.) *Science, Reason, and Rhetoric*, Pittsburgh: University of Pittsburgh Press, 1996, 153-176.

Pinch T J and Bijker W E 1984 *The social construction of facts and artifacts. Or how the sociology of science and the sociology of technology might benefit each other*. *Social Studies of Science* 14, 339-441.

Rudwick M 1985 *The Great Devonian Controversy: The shaping of scientific knowledge among gentlemanly specialists*, University of Chicago Press, Chicago

Sayre A 1975 *Rosalind Franklin and DNA*, Norton, New York

Shapin S 2008 *The scientific life*, University of Chicago Press, Chicago

Shapin S and Schaffer S 1985 *Leviathan and the air-pump: Hobbes, Boyle and the experimental life*, Princeton University Press, Princeton, NJ

Silverman C 2013 *Understanding Autism: parents doctors and the history of a disorder*, Princeton University Press, Princeton, NJ

Simon B 2002 *Undead science: Science studies and the afterlife of cold fusion*, Rutgers University Press, New Brunswick

Star S L and Griesemer J 1989 *Institutional Ecology, "translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-1939*, *Social Studies of Science*, 19: 387-420

Suryanayaranan S and Kleinman DL 2013 Be(e)coming experts: the controversy over insecticides in the honey bee colony collapse disorder, *Social Studies of Science*, 43:2 215-240

Venturini T 2010 Diving in magma: how to explore controversies with Actor-Network Theory, *Public Understanding of Science*, 19:3 258-73

Venturini T 2012 Building on faults: how to represent controversies with digital methods, *Public Understanding of Science*, 21:7 796-812

Warzeck M 2013 Marginalization processes in science: the controversy about the theory of relativity in the 1930s, *Social Studies of Science*, 43:2 163-190

Woolgar S 1976 Writing an intellectual history of scientific development: the use of discovery accounts, *Social Studies of Science*, 6: 395-422

Wynne B 1989 Sheepfarming after Chernobyl: a case study in communicating scientific information *Environment* 31 10-15, 33-39