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Boundary Objects, Social Meanings and the Success of New Technologies

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Abstract
Boundary objects are entities that enhance the capacity of an idea, theory or practice to translate across culturally-defined boundaries, for example, between communities of knowledge or practice. This concept thus has potential to both explain and predict technology adoption; however, it remains sociologically under-theorised. This paper assesses, by recourse to a historical case study of innovations in surgical sterility, how boundary objects work and their relationship to social meanings within communities of practice. It is concluded that not only are there both positive and negative boundary objects, but that technological devices or processes may themselves act as facilitative or inhibitory boundary objects during innovation. The approach set out here has potential as a sociologically-informed model of improving adoption of technologies and policies by managing the positive and negative social meanings of technology objects.

Keywords
Boundary object; community of practice; innovation; medicine; technology

Technologies, Innovation and Boundary Objects

In this paper I want to develop and enhance a sociological understanding of the concept of the 'boundary object'; a construct that has potential to improve the uptake transfer and innovation of research findings, technology and other intellectual property across the fields of social policy, organisation and management and commercial and public services. First introduced to explore scientific communities and organisations (Star 1989, Star and Griesemer 1989), the notion of the 'boundary object' has been applied extensively in studies of innovation in fields as disparate as educational practices (Dirkinck-Holmfeld 2006), social relations (Berg 2002), government (Guston 1999), software engineering (Walenstein 2003) and organisation science (Carlile 2002). Boundary objects are entities that enhance the capacity of an idea, theory or practice to translate across culturally-defined boundaries, for instance between communities of knowledge or practice (Brown and Duguid 1991, Wenger 1998).

Gieryn (1983) regarded *boundary work* as critical to the demarcation of bodies of knowledge, for example, between science and literature, or between science and 'pseudo-science' (Popper 1962). Such demarcations may affect many enterprises in which conflicting cultures between 'communities of practice' or 'communities of knowledge' (Brown and Duguid 1991, Wenger 1998) arise in daily social activities. Thus for example, there may be boundaries between 'lay' and 'professional' knowledge communities, or between producers and consumers, or even between adherents to different political, social or cultural figures or creeds.

These boundaries play a role in adoption or innovation of ideas, practices or technologies within and across organisations. Here boundaries may depend upon practical orientation (for example, research and development versus sales personnel), professional commitments (technology designers versus clinical staff), levels of technical knowledge and so forth. While these barriers may serve the interests of those within these contrasting fields, they can lead to problems of communication and knowledge transfer. Unsurprisingly, therefore, a substantial literature on organisations and technologies has documented the barriers to that occur when a technology is introduced, and how these may be countered. For example, in a study of novel communication technology, Bird and Zarum (2001) concluded that successful innovation matched work tasks and satisfied user demands. Rosen and Gabbay (1999) found that managers were unimpressed by technical advantages, and evaluated a new technology in terms of its impact on the organisation. Operational staff need to understand what a technology aims to do (Williamson 1992), perceive an innovation as capable of improving outcomes or processes (Haines and Jones 1994), and recognise its relevance and validity within a specific setting (Shaugnessy et al 1994). Wood et al's (1998) study of four innovative health technologies found that innovation was 'neither natural nor inevitable, but constantly negotiated and aligned … within an assemblage of scientific and organisational and behavioural factors' (1998: 1734-5). Grimshaw and Russell (1993) argued that a bottom-up approach would improve adoption of technologies, while Greenhalgh et al (2004) similarly concluded that increasing motivation among operational staff could aid adoption. Several writers argue that technologies are most likely to be adopted by practitioners if the evidence is first 'digested', replacing specific findings (the usual outcome of a research project), with a big picture (Brown and Duguid 1991, Haynes 1993). [1]

This brief review suggests that the success or failure of technology adoption may depend as much upon how a technology 'plays' with the actors involved, as with the inherent advantages of the technology itself. This can be particularly true where innovation is driven from outside the knowledge or practice community (for example, by management or from a research and development organisation. As such, 'boundary objects' may be relevant to technological innovation. In some ways the antithesis of Gieryn's (1983) boundary work, the notion of a 'boundary object' was originally developed to explain collaborations within scientific communities (Star 1989) and a natural history museum (Star and Griesemer 1989). Star and Griesemer (1989) described a boundary object as any element that has the capacity to be understood by actors in more than one setting, for example, between different departments in an organisation during product development (Carlile 2002, Miller 2005); between designers and engineers (John et al 2004) or politicians and scientists (Guston 1999). They are 'plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites' (Star and Griesemer 1989: 393).

Boundary objects can be representations, abstractions or metaphors that have the power to 'speak' to different communities of practice (ibid: 412-3, Arias and Fischer 2000: 3). In Carlile's (2002) ethnography of an engineering company, he found that an up-to-date assembly drawing enabled designers, sales and manufacturing teams to engage around new products, while a two-dimensional design drawing or outdated assembly drawing did not. The boundary object allowed the different groups to share meaning, but also to learn about each other's perspectives. Miller (2005) described how he helped different groups within industrial organisations to work together to generate 'maps' that enabled all concerned to understand the entire production process. In a study of product development and marketing, John et al (2004) found that a storyboard served as an effective boundary object between designers, usability analysts and engineers. Walenstein (2003) described a cognitive support theory that could bridge the perspectives of software engineering and human-computer interaction science.

In Star and Griesemer's original (1989: 410-11) typology, boundary objects were categorised into:

a) repositories indexed in a standard fashion, enabling access by people from differing communities of knowledge or practice (for example, a library catalogue);
b) an ideal type, representation or abstraction that is 'good enough' to serve different communities (for example, a blueprint or circuit diagram) even though it lacks detail;
c) an object whose boundaries are the same for different communities, although the content that is bounded differs (for example, a map that summarises political or natural features of a landscape);
d) a standardised form that can be completed by actors within differing knowledge communities.

Reflecting on this typology, Carlile (2002) suggests that boundary objects establish 'a shared syntax or language' within which individuals in different communities can represent their knowledge (Carlile 2002: 451); provide a means for these individuals to communicate across boundaries their concerns or questions about a practice or idea (ibid: 452); and empower members of different communities to transform their own knowledge in the light of the innovation or idea (ibid). These aspects of boundary objects effectively enable communities of practice or knowledge that are normally separated by their perspectives to establish a working relationship around a particular issue, idea or innovative practice.

Boundary objects thus have the potential to both analyse and facilitate adoption of an innovative idea, product or technique. If potential success of technology adoption, embedding or roll-out across organisations depends upon the presence of a boundary object (for example a metaphor, model or perhaps even a job title that is comprehensible to both scientist and practitioner), then those promoting a technology can enhance its adoption by seeking out or developing such an object. Similarly, failing technologies might be reinvigorated by the establishment of one or more successful boundary objects. Consequently, it could be considered a key role of an innovator to identify boundary objects, and to actively engage with users during development of technologies to ensure such objects can be generated, established and sustained during the process of innovation or translation.

However, the literature on boundary objects raises some intriguing questions about which objects might perform such functions. Might we generalise from Star and Griesemer's work to conclude that all museums serve multiple communities, or from Carlile's (2002) study that assembly drawings should always be used when rolling out a new vehicle model? Or are there context factors that preclude such generalisations? If boundary objects are to be mobilised as recruitment-sergeants for new innovations, more needs to be known about how they function and what makes them effective: we need to move from the descriptive to the analytical. While identifying various categories of plastic objects (for example, repositories, maps or forms) is valuable, a more general provenance of this plasticity is also needed. Must we constrain the search for an effective boundary object to those within Star and Griesemer's original typology, or be more catholic in our search? To address this question, I will devote the rest of this paper to delve further into the sociology of the boundary object. I start by unearthing some further examples of objects that perform the functions of boundary objects.

Facilitative and Inhibitory Boundary Objects

In a brief review of actor network theory literature, Hassard (1999) recalled various objects that appeared to fulfil some functions of a boundary object (to transmit meanings between groups), from desks in a classroom which defined the power relations of educational encounters, to a key fob whose unwieldiness encouraged guests to deposit it when leaving a hotel. By contrast, we might also discern a lack of effective boundary objects in cases of failed translation, such as Callon's (1986) description of efforts to re-seed scallop beds, or resistance to innovating the health technologies described in Wood et al's (1998) study. Rogers (1995) offers the failed case of a campaign to persuade Peruvian villagers to boil drinking water, and his brief account is suggestive of how an effective boundary object might have reversed this outcome.

Is it also possible that some objects may act negatively, to inhibit uptake or translation of a technology or other change? Prout's (1996) study of the metered-dose inhaler (MDI) for patient control of asthma suggests such a negative boundary object. Although now widely used as a first-line treatment of chronic asthma, the MDI's acceptance by the medical profession teetered on the brink due to doubts over its safety and efficacy when unsupervised, and assertions that doctors themselves required thorough and extensive training in how to instruct patients to use the device (ibid: 211-12). Only when the device was re-designed to ensure it no longer depended on patient expertise was it broadly accepted as safe and effective.

One interpretation of this history is that the MDI was itself a boundary object, but a negative one. While intended to embed the medical expertise required to administer a safe but effective dose of bronchodilator without direct professional engagement with a patient, the device did not satisfactorily allay doctors' doubts that patients could use it to successfully treat an asthma attack. Instead it acted as an inhibitor to adoption, or a boundary roadblock, in Carlile's (2002) terminology. If, as Carlile has argued, a successful boundary object must provide a shared language, allow concerns to be expressed, and enhance knowledge, then the early MDI failed on all counts. By burying medical expertise in asthma therapy within a standardised device, doctors were denied opportunities to address the uncertainty that could arise in treating a specific asthma attack. Once the device had been refined by technical fixes to address these concerns (for example, by breath-actuation to ensure a correct dose of nebulised drug was inhaled into the lungs efficiently), the device was accepted as an appropriate and adequate tool for administering asthma therapy. At this point, it could be argued that the re-designed device became a positive boundary object in relation to the underlying concept of patient-administered bronchodilation, as it now incorporated the very doubts physician had earlier expressed over patient expertise.

This interpretation of Prout's study raises the fascinating possibility, not explicit in the boundary object literature, that technologies may themselves be positive or negative boundary objects for underlying theories. They may embed precisely those characteristics that enable them to 'speak' to other communities, without the need for other representational work. Indeed, one might argue that the most successful technologies (for instance, cellular mobile phones or prophylactic statins), have been embraced by their users because of their perceived overarching advantage, without any need for knowledge of underpinning theory or technical principles.

However, this proposition makes more urgent a sociologically-satisfying understanding of boundary objects, how they work and how objects can be developed to aid uptake of technology. Explanations of how boundary objects work might logically be divided into the following:

- explanations that assert some intrinsic or essential property of the object, which may or may not be generalisable across the class or sub-category of boundary objects;
- explanations that recognise that the object performs in a specific context (for example two contiguous communities of practice), as a consequence of characteristics of that context.

Reading Star and Griesemer's (1989: 404) paper, it is evident that they did not adhere to an essentialist explanatory model, but considered that it was the active work of participants in the differing communities that made a boundary object effective. Thus, for example, an object might 'satisfy the minimal demands' of each community; incorporate properties that a community could 'mould to its purposes', or that communities could 'extract', 'configure', 'abstract' or 'simplify' properties for local needs (ibid). Carlile's (2002) three boundary object functions (noted earlier) also emphasise the active sense-making work by participants rather than intrinsic capacities of the object. Sociologically, a non-essentialist explanation returns attention to the communities of practice, rather than attempting to divine some inherent property of a boundary object.

The dynamics of innovation within a community of practice is inevitably an extended and complex process, requiring analysis of the values and beliefs of the community, something not undertaken in the boundary object literature. A historical example may thus supply a longer-term understanding of how theory translates across boundaries. In line with my earlier proposition that technologies can themselves have explicit features of a negative or a positive boundary object, I shall draw on an analysis of the innovation of antiseptic and aseptic surgical techniques (Fox 1988), as a case study of innovation of theory and associated practice from a scientific to a practical community. My intent is to explain both resistance and support of new technologies, considering the boundary objects themselves and the underlying social meanings they supply.

Innovating Surgical Sterility

The accoutrements of today's surgical operating theatres/rooms: shiny metals, sterile drapes, masks, gloves, caps and gowns, sets it apart as a space defined by the principles of surgical asepsis (the protection of a wound from microbial infection during and after surgery), and the germ theory of infection first proposed by scientists such as Pasteur and Simmelweiss in the late 19th century. The transformation of surgery from an activity conducted in non-sterile (often filthy) spaces to the regulated sterility of today is emblematic of surgery's emergence as a high-status modern medical specialty.

Traditions have it that a surgeon, Joseph, Lord Lister, is responsible for this transformation (Bland Sutton 1927, Fisher 1977, Medical Research Council 1968, Stern 1941, Truax 1944, Watson Cheyne 1925). Lister endeavoured to translate the findings of microbiological science into the surgical community of practice, bedevilled as it was by high rates of post-operative morbidity and mortality. In a series of papers from 1867 to 1870, he described how a range of antiseptic technologies (which destroyed microbes on surfaces and in the air), including catgut sutures and airtight dressings treated with carbolic acid, and eventually a carbolic acid spray that drenched the surgical field during an operation, had dramatically reduced mortality from infection.

On closer inspection, this history is more problematic than supposed (Fox 1988, Toledo-Pereyra and Toledo 1979). Lister's technical innovations of carbolic dips and spray were rejected by most of his contemporaries (see for example, Anonymous 1879, Nunneley 1869) apart from family members and his immediate colleagues and students, and never caught on widely. In fact, a rival innovative regime of sterile surgical garb and aseptic techniques such as heat sterilisation of instruments and drapes (that sought entirely and pre-emptively to exclude microbes from the operating space) was adopted in its place, despite Lister's criticism of what he saw as 'needlessly protracted and complicated measures' (Lister 1908: 1558). Although the honours and accolades that Lister gained were undoubtedly deserved for a lifetime's advocacy of safer surgery, his antiseptic technologies were wholly eclipsed by aseptic practice. However, the rejection of his antiseptic technologies and the comparatively smooth adoption of asepsis illuminate the discontinuous innovation of germ theory into surgery and the role that boundary objects played. I shall argue that Lister's antiseptic technologies were inhibitory boundary objects for the adoption of surgical sterility, while aseptic technologies were facilitative boundary objects. Unpacking this will expose the mechanism of boundary object function.

Lister, Antiseptic Technologies and Germ Theory

In 1867, Lister published a series of papers in the surgical house-journal, the *Lancet* (Lister 1867a, 1867b, 1867c), describing the use of carbolic acid on surgical dressings. He reported impressive recovery statistics for compound fracture, a malady with a mortality rate of around 60 per cent. However, in these and later papers, Lister not only described his techniques, but situated and justified them within a radical theory of infection: germ theory. Derived from Pasteur's work on fermentation, this explicitly identified bacteria and other microbes as the causes of post-operative infection.

Historians have documented strong opposition to germ theory in the last third of the nineteenth century (Gaw 1999, Toledo-Pereyra and Toledo 1979). A long paper in the *Edinburgh Journal of Medicine* denied the theory as a basis for infection, explaining the microscopic appearance of bacteria as evidence for spontaneous generation (Hughes Bennett 1868: 832). The following year, the address in surgery to the British Medical Association argued that

> ... the theory and reasoning by which the antiseptic treatment of wounds is supported appear to overlook facts open to all the world, to disregard observations familiar to every person through all ages.... We may probably with safety deny the existence of germs in the number and universality maintained by Pasteur and Lister (Nunneley 1869: 152).

The vehemence of such assertions reflects the context of this opposition. By advocating germ theory, Lister challenged the dominant humoral theory of infection that dated back almost 2000 years to the semi-legendary Roman physician and philosopher Galen, and underpinned the practices and beliefs of contemporary medicine. Humoralism asserted that health depended on a balance between four humours; with disease-epidemics resulting from dangerous environmental imbalances. The emerging public health of the 19th century was based in humoral theory, believing that diseases or all sorts, including wound infections were the result of foul emanations or *miasmata*, possibly caused by earthquakes or volcanoes (Thompson 1827). A lecture by the surgeon Hudson (1869) emphasised miasmata as the cause of post-partum infection

> Women were delivered in the same room where other women recovered from or awaited childbirth. Their bloody discharge filled the air with noxious smells, an animal miasmata [sic] which doctors likened to the foul vapours emanating from the debris-filled streets — civic miasmata (Hudson 1869: 49)

Followers of miasmatic doctrine considered ventilation and the prevention of overcrowding as paramount measures against infection. James Paget's (1862) address in surgery to the British Medical Association concluded that 'personal cleanliness, ... abundant fresh air, and a sufficient or a liberal mixed diet' were required for safe recovery (Paget 1862: 155). In 1874, the Lancet Sanitary Commission Report upon the wards of St Bartholomew's Hospital advocated

> ventilation of the wards and of the wounds, cleanliness, and the removal of all offensive and decomposing matters, the 'preparation' of patients for operation, the non-aggregation of a large number of wounds in a given space, isolation, personal attention to personal hygiene — in fact, the strict observance of the well-known rules of surgery are the chief factors in the successful treatment of surgical cases (Lancet Sanitary Commission 1874: 247)

In humoral theory, disease is the consequence of the dialectic between an *initial cause* such as heat, cold or trauma; and an *antecedent cause,* which was a bodily predisposition. These combined to create the *cohesive cause* of disease, which prevented an organ from functioning properly (for example: an excess of phlegm on the stomach) (Nutton 1983: 4). In the case of infections, the initial cause was atmospheric corruption acting on a body already predisposed to disease by a physical weakness, or a social deprivation such as ignorance or poverty (ibid). While initial causes were implicated in disease, the antecedent causes were also key, and the susceptibility of people through bad diet, poverty and bad habits made these factors targets for a reforming medicine, both within the burgeoning public health movement, and by political reformers such as Edwin Chadwick and Freidrich Engels. Florence Nightingale's emphasis on 'hygiene' in hospitals was also grounded in this philosophy (Rosenberg 1979).

Lister thus faced a surgical establishment firmly grounded in the Galenic tradition of humoral theory; and Toledo-Pareyra and Toledo (1979) have documented how the surgical establishment rallied against germ theory. A seminar in 1883 had only one of seven speakers supporting antiseptic techniques (Anonymous 1883), while many surgeons refused to adopt antisepsis in the 1890s (Smith 1979: 271-5). Lister belatedly realised the pervasiveness of humoral theory, and in a despairing tone, implored his peers to accept antiseptic technologies, even if they were not receptive to germ theory:

> You need not believe in the germ theory at all. All you have to believe is that there are such things as putrefaction and other septic agencies, and that our wounds are liable to these, and that they are very pernicious, and that these things come from without, and that we have the means of preventing them by various chemical agencies.... And then as to practice, it is not a very difficult thing to wash your hands in a carbolic solution, and have your instruments in their carbolic solution for a quarter of an hour before you operate. It is not a very difficult thing to wrap around the limbs a suitable envelope of antiseptic material (Lister 1883: 859).

However, even in this plea, Lister's focus remained upon destroying germs (initial cause), while disregarding the susceptibility of the patient (antecedent cause) as a factor. It was this focus that was so unpalatable to his contemporaries. As Lister pointed out in his paper on the carbolic spray, the purpose of the spray was not only to destroy airborne germs, but also to continually disinfect the surgeon's hands, a process that pre-operative washing in carbolic acid had initiated (Lister 1871: 32). In 1874, one of Lister's followers stated that *pyaemia* (hospital fever) was spread 'in the articles of dress, the hospital appliances, the nurses, the students and the surgeon himself' (Barnes 1874: 179). The message transmitted to the surgical community was 'infection is caused by germs, you introduce germs into a wound when you operate, but use the carbolic technologies and you can minimise the effects of your infective agency'. Accepting antiseptic technology was tantamount to admitting that the surgeon was himself a corrupter of sterility rather than a healer of disease.

The Emergence of Aseptic Technologies

While Lister was struggling against professional resistance to antisepsis in the 1870s, William MacEwen -- Lister's junior surgical colleague at the Glasgow Royal Infirmary -- emerged as the first aseptic innovator. MacEwen discarded his frock-coat (the contemporary surgical uniform), in favour of a sterilisable white apron, and sterilised surgical instruments in boiling water rather than immersing them in carbolic acid (Bowman 1942: 61).

The subsequent adoption of aseptic technologies such as sterile clothing and instruments was gradual, but - in contrast to that elicited by Lister's antisepsis - the contemporary literature suggests little controversy, despite the inconvenience of the processes. The German surgeon Von Neuber used a gown rendered aseptic by boiling in 1883 (Fisher 1977: 275). Surgeons operating in all-encompassing suits 'of some light material' were illustrated in Beck (1895) *Manual of Surgical Asepsis*. Eye-witness accounts of surgeons' practices in the *British Journal of Surgery* (1913, 1914) remarked on the use of sterilised gowns by surgeons and visitors. Bloodgood was the first to use gloves while operating, in 1893, at the Johns Hopkins University Hospital (Mitchell 1945: 902). Castenada (1961) notes that masks were mentioned in passing by the Polish surgeon Mikuliez-Radecki in 1897. The *British Journal of Surgery* (Anonymous 1914: 696) commented that Professor Garre's operating room techniques 'are mainly on the orthodox aseptic plan', while at Watson Cheyne's clinic

> Masks for the nose and mouth are worn by all in the immediate vicinity of the operating table, but long before their introduction into surgery Sir Watson had imposed an 'area of silence' around the patient, and had established a code of grunts by which his needs were communicated to his assistants (Anonymous 1915: 325)

Unlike Lister's antiseptic technologies, aseptic practices were inconvenient and required specialised operating spaces to be fully effective. Despite this, there was an inexorable elaboration of aseptic procedures over this period. Beck's (1895) *Manual of Surgical Asepsis* described at length the technologies, which at that time included the use of sunlight, electricity, heat, steam, mechanical cleaning, dryness, and boiling water, and aseptic garbing such as operating suits, caps, and trimmed beards (Beck 1895: 61). One critic of the aseptic ritual (a pejorative term used by Lister and his supporters) was a surgical associate of Lister's

> Precautions are taken as regards architectural and mechanical arrangements, the amount of skilled assistance required, and the use of masks, gloves and other accessories, all of which are in their entirety quite incompatible with ordinary practice (Cameron 1907: 62).

The new techniques of sterility and garbing may have been inconvenient, but as Bland Sutton recalled in his (1927) comparison of antiseptic and aseptic environments:

> Operating theatres which resembled a shambles in 1860 are replaced by rooms of spotless purity containing scintillating metal furniture and ingenious electric lights. All concerned in the operation are clothed from nose-tip to toe-tip in sterilised linen gowns, and their hands covered with sterilised rubber gloves (Bland Sutton 1927: 781)

Analysis of the literature suggests that asepsis went with the grain of the emerging public health movement, with its emphasis on moral as well as physical cleanliness. Around that time, Benjamin Richardson's polemical *Hygeia: A City of Health* campaigned to sweep away the slum dwellings, public houses and squalid hospitals of the time, to create a model living environment in which the conquest of disease and mortality would be achieved not by science but by 'pure air, proper nourishment, a regulated temperature, bodily exercise, cleanliness, mental education, good morals' (Richardson 1875). A few years later, the surgeon MacCormack (1880), in a text ironically entitled *Antiseptic Surgery*, argued that with

> … care and watchfulness and scrupulous cleanliness in well-managed hospitals and private houses, there is little left for the complete antiseptic treatment to do.... I hope there will be no attempt to prove that antiseptics are self-sufficient when there are neither good sanitary arrangements nor skilled nurses nor very watchful surgeons (MacCormack 1880: 86)

Textbooks on aseptic surgery made the link between sterility and cleanliness explicit. Lockwood's (1896) *Aseptic Surgery* noted that 'standards of cleanliness in Britain being so high, it is unnecessary for me to go into specific directions for preparation for operating' (Lockwood 1896: 166). Bland-Sutton's (1927: 781) opposition of the shambolic character of an 1860 operating theatre and the 'spotless purity' of an aseptic one, articulates those notions of dirt and cleanliness, purity and pollution, which reflected the Victorian world-view on matters moral as well as medical. The personnel in Bland Sutton's aseptic theatre, sterile from nose to toe, were firmly on the side of purity. This role for the aseptic surgeon was explicitly contrasted with the antiseptic techniques in Beck's *Manual of Surgical Asepsis*

> Instead of trying to kill microbes brought into contact with a wound, the endeavour is now to keep the wound free of microbes without employing so-called 'germicidal' agents (Beck 1895: 61).

Aseptic method, he continued, is by its nature prophylactic, and the surgeon's task was to assure the continuing cleanliness of the patient despite the threat from a harmful Nature. Vallack's (1905) *Principles and Practice of Asepsis* set this out explicitly

> It cannot be too strongly insisted upon that the healing of every wound and the recovery of every sick person are due to the reparative power of the tissues alone. The surgeon and the physician are not the agencies whereby recovery is brought about; their function is to aid, when able, the tissues in their struggle. The vast majority of micro-organisms are quite unable to attack living tissue ... [but] a multitude of organisms can overcome tissue when resistance is low (Vallack 1905: 4)

Vallack's re-statement of a Galenic dialectic between initial cause (infective agent) and antecedent cause (susceptibility), suggests why aseptic technology was accepted by Victorian surgeons. Asepsis is not just a theory of infection: rather it is a theory of the relationship between patient, Nature and the surgeon, with the latter as proxy for the patient's safety from infection (be the cause a germ or a *miasma*). Whereas in Lister's schema, the surgeon was the cause of disease, and the carbolic technologies the antagonists of this danger, in asepsis, the surgeon is protector, the assurer of safe surgery. It follows that aseptic technologies (clothing, sterilised instruments and so forth) are metonymic for the surgeon as protector. They are, in a nutshell, boundary objects for a theory of surgical healing that works regardless of whether germs or *miasmata* are the initial causes of disease. Of paramount importance is the underlying message that the surgeon is not the agent of disease, but the procurer of safety.

In summary, this case study has examined an episode in the innovation of surgical sterility. First, I documented Lister's endeavours to introduce technologies explicitly based in a germ theory of infection that ignored the susceptibility of the patient, and by focusing on initial cause alone inevitably associated the surgeon with the agency of infection. The antiseptic technologies were imbued with negative connotations; they were in effect inhibitory boundary objects for promoting surgical sterility. Second, we saw a range of aseptic technologies that were implicitly supportive of a humoral theory of the patient as susceptible to infection, and that linked common-sense notions of cleanliness with sterility. Now the surgeon, as the agent whereby an operating field was rendered free from microbes, became the opponent of infection. Consequently, the technologies of asepsis became facilitative boundary objects for adopting surgical sterility.

Discussion: boundary objects and social meanings

Modern society depends upon inter-disciplinary working: we live in the co-dependent society that Durkheim typified (1933) as 'organic', and functional teams in science, industry and the public sector frequently include members drawn from a range of knowledge, practice and skills backgrounds. While professional closure may insulate a community of practice, members still need to engage with clients and suppliers, as well as with other communities of practice. In such a context, the concept of a boundary object is attractive. It offers the promise of communication across barriers, to facilitate the growth of knowledge or the success of a policy or other innovation. An effective boundary object might even succeed in bringing harmony to a dissensus, or peace to a conflicted situation.

However, boundary object literature has not delivered on this promise, for a number of reasons. First, the approach has been taxonomic and descriptive: from Star and Griesemer's paper onwards, what has been provided has been a classification of types of boundary object. Second, the concept has remained under-theorised: little has been written on how boundary objects work, and what role human agency plays in this function. Finally, the range of possible boundary objects is narrow: limited to abstractions or representations of other objects constructed within communities of knowledge or practice.

In this paper I have sought to address these shortcomings: to broaden the range of what might count as a boundary object, and to explicate the mechanism whereby they work. My historical case study has provided my data source: its detailed analysis of social meanings has suggested that technological objects (a spray, a gown, a mask and so on) can themselves perform a function as a boundary object in relation to knowledge transfer between two communities (in this case, nascent microbiologists and the surgical profession); that this function may be either facilitative or inhibitory of cross-boundary communication and innovation; and most significantly, that the mode of function depends upon the meanings that these objects encapsulate for the recipient community. I wish to focus on the last of these findings, as it subsumes the others within it, and provides the basis for a sociologically-informed theory of boundary objects.

The history of the innovation of surgical sterility is a fascinating example of irrationality, inertia and resistance to change among a professional grouping. Toledo-Peyrera and Toledo (1979) offer a comprehensive account of resistance to Lister's work, documenting opposition both in the UK and US to his ideas and practices. Their paper shows that antiseptic technology was never accepted in either setting, while my research (Fox 1988) has shown that the more inconvenient asepsis became accepted with little dissent. Toledo-Peyrera and Toledo fail however to offer any explanation: their paper concludes that eventually, with the acceptance of germ theory, both antisepsis and asepsis could be adopted. Neither in their paper nor in my own research is there evidence that asepsis was facilitated by the kinds of boundary object in Star and Griesemer's typology. However, the role of other objects should not be underestimated in this tale of innovation.

I have argued that in the case of Lister's technologies, not only was he trying to overturn a theory of the relationship between the human and the environment that was rooted in two millenia of medical scholarship, and was currently gaining a renewed lease-of-life in the emergent public health reforms of the Victorian era, but also that his techniques had the unintentional consequences of equating the surgeon with pollution. The meanings associated with the technologies were thus both alien and deeply offensive to a healing professional. On the other hand, asepsis not only worked equally well regardless of whether infection were caused by germ or miasma, but had the opposite meaning: now it was the surgeon who was the agent of purity, acting on behalf of a susceptible patient to guard them from a dangerous environment. Sterile clothes, masks, heat-sterilised instruments were boundary objects because they had the secondary function of assigning surgeons the role of healer, both within their own community and perhaps in a wider lay community also.

It is this analysis that leads to an understanding of how boundary objects work. Carlile (2002) suggested that boundary objects provide ways for individuals in different knowledge or practice communities to represent, question and transform their knowledge (Carlile 2002: 451-2). My analysis details the positive or negative meanings that an idea or theory can have for a community of practice, with consequences for the transformation of knowledge within that community. Antiseptic and aseptic technologies were recognised by microbiologists such as Louis Pasteur as appropriate efforts to eliminate microbes from a surgical field (Pasteur 1996). However, Lister failed to grasp that his technologies communicated the unfortunate additional message that a surgeon's physical intervention during an operation established her/him as part of the problem of, not the solution to, post-operative morbidity. Had his 1883 partial repudiation of germ theory (quoted earlier) gone on to acknowledge the importance of patient, and made links to general hygiene and cleanliness, perhaps antisepsis might have fared better. Yet by that time, his approach already had an opponent in asepsis that pressed all the right buttons, linking hygiene, a concern for the material and spiritual comfort of the patient, and a set of ritualised hygienic practices that survive to the present (Fox 1992), with a semiotics that established the surgeon as an agency of purification that could cocoon the patient against the threats from the environment. With asepsis, the humoral/germ theory debate was irrelevant: what was important was that the surgeon was now on the side of right, not an agency of disease and putrefaction. Clean clothes, spotless operating furniture and instruments and a reverential atmosphere around the operation all served not only to protect the patient, but also to elevate the surgeon to the status of high priest of sterility. [2]

With this analytic framework, in which the meanings of objects and technologies for key actors are fully examined, boundary object theory is reinvigorated. Boundary objects are not limited to the categories outlined by Star and Griesemer (1989: 410-11), but may manifest in the technological innovation itself. Such objects may embed a message that is particularly appealing to the target community (an insight that is hardly novel to those who work in marketing or politics). This reminds us that technology is not neutral, but imbued with ideological content (for example, medical expertise or a social engineering agenda). More explicitly, what is re-introduced to the boundary object conceptualisation -- by recognising the significance of an object's meaning -- is an acknowledgement of the social and power relations that a technology or a technological object mediates. The success or failure of an innovation depends on the reception of this meaning and these social relations.

With this missing component instated, we acquire a more sophisticated basis for a sociological approach to innovation and boundary objects that is predictive as well as retrospective. This theory of boundary objects is attractive because it suggests a way to improve technology adoption: a valuable contribution to scientific or medical advances that depend on buy-in from a range of stakeholder groups. Positive and negative boundary objects are not simply passive vehicles that allow communication between communities of practice or knowledge, but elements that encapsulate the broader social meaning of a concept, theory, technology or practice, and the underlying relations that surround its development and adoption. [3] This formulation offers a new opportunity to apply a theory of social meanings to problems of technology innovation and adoption.

There is a task here that can be the bread-and-butter of a jobbing sociologist; to identify the beliefs, values and significances of a target community of practice, prior to efforts to innovate a technology, policy or other development. The approach set out here diverges from two major theories of innovation, the diffusion theory developed by Everett Rogers (1995) which focuses on the individual characteristics of adopters, and technology acceptance theory (Davis et al 1989), in which potential adoptees evaluate the utility of an innovation. Unlike these theories, what is argued here is that collective social meanings within communities of knowledge or practice can underpin the success of adoption. Recognising the semantic role that technological or policy objects perform within this recipient community may enhance the rate or depth of adoption, and also predict or avoid blockages that may occur during innovation. Sociologists can play a role in unblocking stalled innovation, strategically altering the meanings that an object has for a recipient community, by working with its members to manage adoption. Sometimes the kinds of meta-objects that Star and Griesemer (1989) identified may play a critical role in this adoption process, but on other occasions, it may be the technological object itself, with the social meanings it encapsulates, that will be key to successful innovation.

Notes

1. Much of this literature reflects the dominant theories of innovation: the diffusion theory developed by Everett Rogers (1995), which focuses on the processes by which individuals mediate adoption, or technology acceptance theory (Davis et al 1989), in which adopters rationally evaluate innovations in terms of usefulness and effort.

2. Inevitably efforts to assert the sentiments of historical actors must remain as plausible speculation. Fortunately, sociologies of current technological innovations will have recourse to data sources that should allow greater certainty concerning actors' beliefs and social meanings.

3. This approach diverges markedly from the original conception of a boundary object. Some readers may feel that the original, narrower definition should be retained, in which case the kinds of objects I have described here may be regarded simply as 'innovation objects', or some such.

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