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REVIEW ARTICLE

New concepts of science and medicine in science and technology studies and their relevance to science education

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Abstract Science education often adopts a narrow view of science that assumes the lay public is ignorant, which seemingly justifies a science education limited to a promotional narrative of progress in the form of scientific knowledge void of meaningful social context. We propose that to prepare students as future concerned citizens of a technoscientific society, science education should be informed by science, technology, and society (STS) perspectives. An STS-informed science education, in our view, will include the following curricular elements: science controversy education, gender issues, historical perspective, and a move away from a Eurocentric view by looking into the distinctive patterns of other regional (in this case of Taiwan, East Asian) approaches to science, technology, and medicine. This article outlines the significance of some major STS studies as a means of illustrating the ways in which STS perspectives can, if incorporated into science education, enhance our understanding of science and technology and their relationships with society.
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Introduction

Since the 1970s, science, technology, and society (STS) has been a vibrant and productive field of study, bringing new insights to issues concerning science and technology that have been of critical importance in technoscientific societies. These new insights have helped us to break away from the conventional version of science and technology under

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which we have labored since the Enlightenment. As a consequence, as we illustrate below, it has become possible to see well-known scientific discoveries and inventions in a new light. The conventional version of science, however, is still the major paradigm in many fields, including science education.

Science education has been carried out, more often than not, as a science popularization project, and the key term has been science literacy. The assumption is that the lay public needs to be able to comprehend and appreciate the content of the ever-changing progress in science. The knowledge—power differential between scientific experts and the lay public is one of the major defining elements of what Brian Wynne has termed a deficit model, with the lay public being in a perpetual state of inadequacy or even irrational fear, and in need of further education, patient enlightenment, and careful management by the science and engineering elite. However, as Steven Yearley has pointed out, the lay public is never in a position to learn science simply for the knowledge itself. Rather, issues such as health risks and environmental hazards are usually of critical importance in popular conceptions of science [1].

STS seeks to offer alternative views of scientific enterprise in terms of its epistemological foundations and its relationships with society across gender, age, ethnicity, and social status. STS research has disabused us of the notion that the relationships between science, technology, and society should be seen in a romantic light; even though science and technology can be beneficial, their relation to society is far more complex than advocates of science have claimed. In this paper, we propose that a science education informed by STS, particularly in Taiwan, where conventional views of science prevail, will prepare students to become future concerned citizens in a technoscientific and democratic society. Science and technology issues require an input from citizens, whether at the level of discussion or decision-making.

We propose that future science education will benefit greatly from STS studies if the following elements are integrated into the curriculum. First, science education should be oriented toward "science controversy education" (originally formulated by Professor Chunghsi Lin of Yun-Lin Science and Technology University), as it is essential that concerned citizens in a 21st-century technoscientific society learn how to debate the pressing science issues of the day. The controversies can be those between experts or those between experts and lay people as informed citizens. It is important for students to learn about the social context of science controversies so they can also understand the risks and problems that often accompany scientific enterprise. Second, science education needs to address gender issues, since gender is a constitutive element of scientific enterprise. Third, historical perspective is critical to our understanding of science; we need to take history more seriously than we have up to now. Finally, an STS-informed science education should move away from a Eurocentric position and look into the distinctive patterns, unique possibilities, and specific orientations of East Asian science, technology, and medicine.

To substantiate our position, we review several major works on STS research. The contribution of these studies ranges from revision of epistemological assumptions of science, demonstrating that the practice of science is often socially engaged, and pointing out gender as an active ingredient of science, to shedding new light on the relationship between lay citizens and experts in the production of scientific knowledge and bringing new perspectives from beyond the West.

Revision of established stories

We begin with a revision of a well-established assumption of modern science, namely the notion that is taken for granted that experimentation is the method to produce science and that science is neutral and free from sociopolitical issues. The study by Steven Shapin and Simon Schaffer of Robert Boyle's air pump is a case in point. The established version tells of Boyle's arrival at scientific truth by means of experiments, and from then on experimentation has been the accepted method for producing scientific knowledge. This faith in experiments as the method for producing scientific knowledge relies on the belief that experiments can be replicated and therefore tested. However, this was not self-evident for many in 17th-century England, including Boyle's major rival, Thomas Hobbes, whose method of producing knowledge was natural philosophy and deductive rationality. As Shapin and Schaffer have shown, Boyle's air pump experiments were never successfully replicated by his peers, and his instruments were difficult to build and operate. Situating Boyle's experiments within the social and political concerns of the English Civil War and the Restoration, the authors also refute the notion that hard sciences (such as physical chemistry) were free from social concerns, for "solutions to the problem of knowledge are solutions to the problem of social order" [2].

Looking at another iconic figure of science, a thorough study by Thomas Hughes of Thomas Edison in the history of electrification of the West has complicated the popular image of Thomas Edison the genius. According to Hughes, Edison was not merely an inventor, but also an entrepreneur and system builder; he incorporated various seemingly unlikely elements (such as costs, potential competitors, geography of New York city, scientific knowledge, and experiments) into an integrated system to invent his famous high-resistance incandescent light bulb. In addition, we are surprised to learn that Edison was good at promoting his new system by effectively bringing attention to his creations through the media [3]. This emphasis by Hughes on Edison's system building is a move away from a narrowly focused understanding of technology because it points to the societal import of multidimensional changes brought by the new technology of electrification.

Among STS approaches, actor network theory (ANT) takes this multi-sited approach even further. The advocates of ANT see science as a process of "heterogeneous engineering" in which the social, technical, conceptual, and textual are combined and transformed. This theoretical position has revised some of the standard heroes and their times. According to one of the most notable ANT practitioners, Bruno Latour, one of the main figures of germ theory, Louis Pasteur, succeeded in capturing the attention of the French public through the use of human and nonhuman (artifacts and germs) actors in his laboratory work

on anthrax in the construction of an actors' network. Not only did Pasteur colonize microbes (anthrax bacteria) in the laboratory, he also extended his laboratory boundary (and hence laboratory results) to the world outside the conventional laboratory. What is most surprising in this process of what Latour terms the "pasteurization of France" is the historical abolition of the divide between the laboratory and society. One of the most distinguished theoretical features of ANT is the questioning of several conventional divides, including humans—non-humans, inner—outer, nature—society, and knowledge—objects [4].

The aforementioned divide between the lay public and experts in the politics of knowledge is also under revision. Brian Wynne's study on the unhappy case of sheep farming in Britain after the accident at the Chernobyl nuclear power plant is a case in point. Immediately after the disaster, the British government and scientific experts announced that "the effects of the cloud have already been assessed and none represents a risk to health in the United Kingdom" [5]. Unfortunately, this prediction proved to be too optimistic and premature. Within a month of the accident, the Minister of Agriculture announced a ban on the movement and slaughter of sheep in some parts of Cumbria and North Wales (primarily because of heavy rain associated with the nuclear cloud over the Cumbria area); moreover, approximately 800 farms and over one million sheep were still under restriction 2 years after the original accident. As Collins and Pinch point out, these farmers, "some of the last groups in Britain to experience industrialization, suddenly came under the jurisdiction of a distant scientific bureaucracy" [5]. The scientists' arrogance and "vacillating pronouncements" vexed them, and farmers subsequently lost faith in scientific expertise. The scientists underestimated two aspects of rain-borne radiation, according to Collins and Pinch. Their knowledge of rainwater was inadequate and their assumption that radiocesium would not be retained by plants after contaminated grass was eaten by sheep turned out to be problematic. Witnessing scientists while they monitored farms, the sheep farmers became aware of the open-ended nature of science, whereas scientists presented science with certainty. The sheep farmers resented the fact that officials refused to acknowledge both the complexity of farming and the practical expertise of farmers, which led some farmers to see the official response as a political conspiracy perpetrated by insensible and arrogant scientific elites [5,6]. Although Wynne points out that science is not all about certainty, he also notes that it is not necessarily a political conspiracy. Instead, he suggests that the scientists and sheep farmers could have learned to value each others' contribution and seen the limitations of their own claims.

Addressing the issue of expertise in a similar but more positive manner is Steven Epstein's fascinating case study of AIDS cures and lay expertise. Epstein shows how the gay community in the USA and elsewhere actively participated in the search for cures for AIDS. Most impressively, they challenged the standard scientific practice in drug trials by arguing that giving placebos to patients was unethical when their lives were at stake and timing was critical. In the process, activist groups such as ACT UP (Aids Coalition To Unleash Power) representing people with AIDS negotiated the doctor—patient relationship to yield a more equal partnership. Even the golden rule of randomized controlled drug trials was modified through those negotiations. Some of the self-taught gay activists eventually became a new type of lay expert whose consultation was sought by both lay people and experts [7].

Regarding technological changes, one conventional notion is that new technologies inevitably result in improved efficiency. However, as Ruth Cowen has shown in her classic book on the history of household technology in the USA in the late 19th century, *More Work for Mother*, women's work was not reduced as a result. Rather, new technologies brought less work for men, elimination of servants from middle-class homes, and new standards of cleanliness. For example, the wood-burning stove, which burned less wood than a hearth, reduced men's contributions to the labor involved in preparing a meal, and at the same time allowed women to make more elaborate, multi-dish meals, making women's work more complicated and time-consuming. The stove, according to Cowen, "augured the death of one-pot cooking … and in so doing, probably increased the amount of time that women spent in preparing foodstuffs for cooking" [8]. In short, "Modern labor-saving devices eliminated drudgery, not labor" [8].

STS scholars have revealed the gender politics operating at the practical level of technology use and in the production of scientific knowledge. Much of the epistemological authority of science has been based on the notion that science is value-neutral and free from ideology; it is often assumed that, unlike literature, the language of science is void of metaphors and analogies. Emily Martin's classic essay on the representations of sperm and eggs in science textbooks shows how sperm have been portrayed as aggressive male suitors and eggs as shy girls waiting passively, as if taking part in a human melodrama [9]. This serves as a powerful example of how gender stereotypes are written into biology textbooks, become part of "nature", and in turn come to reconfirm the very gender stereotypes that set a particular view of biology into motion in the first place. In other words, scientific knowledge serves to naturalize gender politics. Writing on analogies in 19th-century science, Nancy Stepan reached a similar conclusion by showing how gender and race analogies mutually supported each other—women being like "negroes" and "negroes" like women, and both were deemed irrational, emotional, and less intelligent than the white man [10].

Finally, we address the problematic area of geopolitics and colonialism. In the past, science was seen as one of the major achievements of Western civilization. However, just as issues of gender and racial politics are central to the understanding of scientific enterprise, an understanding of geopolitics and a move away from Eurocentric perspectives are necessary for an adequate understanding of science. Recent STS research has turned towards an understanding of science in contexts outside of Western metropolitan society. Since this article is written by Taiwan scholars, an interesting Taiwanese example of the recent past is given here.

George Mackay's early Christian male modernity in Taiwan

Gender and racial politics merge with geopolitics in the figure of George Leslie Mackay, D.D. (Doctor of Divinity),

a Canadian Presbyterian missionary who landed on the shores of northern Taiwan in 1872. What was a Westerner, a "white barbarian", able to do in Taiwan over the last quarter of the 19th century? Surely, this story must reek of colonialism. As the first Canadian missionary to settle in Taiwan, Mackay in 30 years built more than 60 local chapels around northern Taiwan, with Danshui area as the headquarters [11]. Each chapel was equipped with a native preacher, a dispensary, often a native Bible woman, and many native communicants with good and regular standing. As a strong-willed and methodical missionary, Mackay was later respected by all local authorities there: Qing China, French, British, and Japanese. Many local elite families associated with him have prosperous descendants down to the present. A few years ago, many Taiwanese and local Presbyterians celebrated his centenary, promoting his works as an important part of Taiwanese modernity.

The aspect of Mackay's legacy that concerns us here first is his legendary tooth-extraction records, a peculiar practice of the time that can be characterized as a type of "religio-medical" practice. With no training as a dentist, Mackay began extracting teeth for Taiwanese early in his career. It started off as a clever innovation on an urgent occasion in which a sharpened wooden stick was used to extract teeth. But the need for such measures in the population at large proved so great that it quickly developed into one of Mackay's signature services in his countryside preaching tours. He carefully noted tooth-extraction numbers, dates, and places in his diary, with entries comparable in their detail only to his records of souls saved through conversion and baptism. Equipped with a few simple modern extraction tools, Mackay's tooth-extracting team was so effective that often three preacher-dentists could extract approximately 100 teeth within an hour from a group of standing patients, lined up in rows in the village public field (Fig. 1).

Although modern antiseptics and anesthesia were developed in the West around the time Mackay was practicing (1872—1900), it is not clear whether his practice was up to date, or whether he was actually financially capable of taking advantage of those modern breakthroughs. Mackay did mention that he purchased his modern extraction tools in New York city. Although Mackay praised Chinese people for having "considerable nerve" (they "endure the pain of an operation wonderfully well"), how exactly did he extract teeth [12]?

Figure 1. Mackay pulling teeth. Note that all three preacher-dentists, including Mackay, and the native technician showing the extraction tools, are male [12].

In fact, Mackay was not practicing dentistry in today's sense of the word. On closer analysis, we can say that Mackay and his male preacher-dentists were actually engaging in a religio-medical practice with no clear line separating the medical from the religious-congregational. He explained, often proudly, the basic steps in his standard procedure:

(1) He visited a village, probably one he and his team had visited before.
(2) He called for a crowd to gather in a public field, accompanied by singing, praising, and preaching.
(3) He distributed medicine (quinine in particular) and extracted teeth.
(4) He managed village family records, performed catechism drills, and "children, young men and women, were examined in presence of all on subjects previously assigned".
(5) There was "Singing practised for an hour by the people in divisions, such as old men, women, young men, girls, and children."
(6) "We preached in turn, short addresses being most profitable, and I immediately questioned them on what was spoken."
(7) He "Observed the Lord's Supper, having not a few refreshing communions." [12]

Like most other colonists in the late 19th century, Mackay used quinine as an effective means for his preaching activities. But again, as with tooth extraction (and the crude antiseptics—but probably no proper anesthesia—they may have administered), these "means" were completely incorporated into the religious activities, which must have made it difficult for ordinary local people to distinguish between the two.

It is clear from this religio-medical procedure that the familiar one-on-one, semi-private dental operations practiced today are quite different from Mackay's practice in Taiwan, where tooth extraction was closely involved in a public, congregational, and ritual process. Mackay's impression that Chinese have "considerable nerve" seems explainable by the fact that the pain in tooth extraction was much suppressed under this public, disciplining gaze and also much relieved within the mesmerizing religious rituals. (Doctor Ying-qiang Yeh suggested this possibility to Daiwie Fu by noting the difference in pain experienced by children receiving injections in a private clinic room compared to children in a public gathering. Doctor Lin Yu-Rong also agreed that this explanation is plausible) [11].

What we have seen in Mackay's activities so far, from religio-medical practices to congregational photography (Mackay was one of the first to bring modern photography into Taiwan), are some of the complex processes by which modern medicine was introduced and would-be modern bodies were trained methodically, observed under public gaze, and identified and confirmed in photographic images. Furthermore, these processes were integrated with and converged into a strong Presbyterian evangelical movement in northern Taiwan, with Mackay the authoritarian figure in the center, backed up by various local and colonial

authorities. The local people knew Mackay as the great old teacher, *Lao Fuzi*, the priest, *Mu-shi*, the great man, *Da-Ren*, and sometimes the divine, *Shen*, yet, revealingly, rarely as "the doctor". These monikers were often posted on large Chinese banners sent to Mackay by local people to show their gratitude or respect. Many of the banners are extant and still exhibited on special occasions. One interesting banner comprised four large, bold words: Claiming "the Divine" in China (*Zhongguo Tseng Shen*). His diary frequently mentions visits by Western councils, navy captains, soldiers and sailors, and other illustrious figures to his Danshui chapel or his headquarters for Sunday services. When MacKay's people encountered hostility against their preaching efforts, his team would often be rescued in time by local Qing officials and Western councils. If this was an early Christian modernity in northern Taiwan, it was also an authoritarian one backed up ultimately by colonial powers.

It is, moreover, a gendered modernity [11,13]. As already noted, the preacher-dentists were all men, and the modern knowledge and techniques promoted by Mackay's church were, basically, controlled and taught by men. But this was not generally the case in late 19th-century Taiwan. If we compare Mackay's evangelical movement with southern Taiwan's British Presbyterian mission, the situation there seems to have been less male-centered. There were outstanding female missionary doctors and trained midwives and nurses working together with male doctors in Tainan's Christian hospital, Hsin-lou. Taiwan's first woman obstetrician—gynecologist, Elizabeth Christie, practiced there for about 9 years before becoming ill and dying at Hsin-lou hospital in 1901. She was so popular and loved by Taiwanese women that a women's hospital under her directorship was proposed to British Presbyterian leaders [11].

Conclusion: a new turning to East Asia for STS

Having proposed the need for a new type of science education in Taiwan, and having then reviewed and discussed new concepts of science and medicine in STS through examples from the West and Taiwan, as well as their colonial past, we would like to introduce another institutional STS development in East Asia. In the last couple of years, working with STS scholars from Japan, South Korea, Singapore and China, as well as a significant group of STS scholars from outside East Asia, we have established a new international journal outside the usual western STS centers: *East Asian Science, Technology, and Society* (EASTS; Fig. 2). Aiming to promote STS studies in East Asian societies, EASTS is a quarterly interdisciplinary journal featuring research and commentary on the development and dynamics of science, technology,

Figure 2. Front covers for the first two issues of *East Asian Science, Technology and Society: An International Journal*.

and medicine, including their involvement in policy, politics, gender, culture, and their recent colonial past.

We believe that EASTS will offer fresh STS perspectives useful to science educators, students, and the general public, as well as scholars from diverse disciplines. From summer 2007 to the present, EASTS has published 17 issues, with twelve special-subject issues ranging from "Public participation in science and technology" to "Biotechnology in East Asia Societies: Controversies and Governance" and "Specialized Knowledge in Traditional East Asian Contexts" [14].

As we have tried to show in this article, STS perspectives offer diverse, complex, and contextualized interpretations of science and technology. Questioning the epistemological foundations of scientific enterprise and looking closely at the social relations of science and technology across gender, social status, ethnicity, age, and region, STS perspectives move us away from Eurocentric and Enlightenment points of view towards a broader yet more fine-grained appreciation of local and global histories and social relations. Highlighting science controversy in our science education is a useful means of enlivening people's understanding of science and technology, while it also serves, most importantly, to further the goal of engaging people in democratic discussion and in mutually shaping the technoscientific societies in which we live.

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