Science-Technology-Society or Technology-Society-Science? Insights from an

ancient technology

Abstract: Current approaches to Science-Technology-Society education (STS) focus primarily on the controversial socio-scientific issues that arise from the application of science in modern technology. This paper argues for an interdisciplinary approach to STS education that embraces science, technology, history, and social and cultural studies. By employing a case study of traditional papermaking technology, it investigates how the interactions between technology and science can be explored in an authentic societal and cultural context across a historical time span. The term Technology-Society-Science (TSS) is used to represent an alternative approach to linking technology, society and science that aims to redress the imbalance between science and technology, and to resolve the tension between two diverging goals of STS education. The educational implications of this alternative approach to STS education are discussed.

Introduction

The movement towards Science-Technology-Society (STS) constitutes both a paradigm shift (Hart & Robottom, 1990) and a megatrend (Yager, 1993) in science

1

education that contributes to the goal of scientific literacy for all (NSTA, 1990; Yager, 1996). However, the nature of STS education is diffuse and complex (Ziman, 1994), and has given rise to diverse emphases when translated into curriculum goals and pedagogical approaches (Aikenhead, 1994; Bybee, 1987; Hodson, 2003; NSTA, 1990). There have also been criticisms that many STS materials lack a theoretical framework (Hodson, 2003; Jenkins, 2002), thus resulting in the marginalisation of STS education in practice and the underdevelopment of STS as a teaching strategy (Zeidler, Sadler, Simmons, & Howes, 2005).

This paper revisits the conceptualisation of STS and its portrayal in science curricula, followed by a brief critique of its current status, in recognition of the tension between the divergent urges to change the status quo. It employs traditional papermaking technology to exemplify the subtle relationships among science, technology and society, and the way that STS education could be developed to give students a more holistic understanding of the interactions amongst the three. The paper concludes with a discussion of the educational implications of the findings of the case study presented herein.

Meaning of STS revisited

In general terms, STS is an approach that integrates 'science contents into social

and technological contexts meaningful to students' (Aikenhead, 1994, p. 59), although the literature includes diverse interpretations of this basic conceptualisation. Ziman (1980, p. 111) argued that teaching science in its social context aims to give students a more balanced view of science and technology to 'oppose scientism and technocracy', implying a need to promote a critical and realistic understanding of the nature of the two disciplines and their place in society. There is a strong tendency to view STS as a vehicle for scientific and technological literacy (National Research Council [NRC], 1996; National Science Teachers Association [NSTA], 1990). The NSTA (1990) outlines 17 attributes of a scientifically and technologically literate person that can be enhanced through STS efforts. Hurd (1986) viewed STS as equipping students with the ability to think critically about socio-scientific issues in preparation for participation in democratic decision making. Solomon (1993, 1994) concurred by characterising STS as a type of science for citizenship. More recently, research has focused on developing students' ability to resolve problems and make informed decision about socio-scientific issues, which involves the reconciliation of multiple viewpoints (Yager, 1996). In pursuit of this goal, a socio-scientific issue (SSI) movement has been advanced as a way to integrate the nature of science, argumentation, values and moral judgements (Zeidler et al., 2005; Zeidler, Sadler, Applebaum, & Callahan, 2009).

There is an equal diversity of conceptualisations of what constitutes an STS curriculum. Aikenhead (1994, p. 52) adopted a broad and flexible design for STS content, which may consist of any combination of the following.

- *A technological artefact, process or expertise*

- *The interactions between technology and society*

- *A societal issue related to science and technology*

- *Social science content that sheds light on a societal issue related to science and technology*

- *A philosophical, historical, or social issue within the scientific or technological community.*

Bybee (1987) suggested an equally broad but more organized conceptual framework for STS programmes, emphasising three dimensions: unifying science and technology concepts, scientific and technological enquiry skills, and science-technology-society interactions that are seen as multidimensional. Ziman (1994) suggested a multiplicity of complementary approaches, including the relevance, transdisciplinary, historical, philosophical, sociological and problematic approaches. A recent STS model, the STS(E), proposed by Hodson (2003, p. 658) incorporates environment (E) and comprises four elements: 'Learning science and technology, learning about science and technology, doing science and technology, and engaging in

socio-political action'. Hodson's framework aims to engender in students a commitment to making responsible decisions with regard to socio-scientific issues.

Critique of existing STS representations in science curricula

The criticisms of STS education in schools follow two main lines. The first is that many STS courses were tilted towards science (Cheek, 2000; Layton, 1988; Roy, 2000). This bias stemmed largely from the historical development of STS science education, which was originally conceived of when traditional science education failed to cater for the needs of the majority, a conception that has legitimised the widely acclaimed goal of preparing students as future consumers of science (Aikenhead, 1980; Millar, 2006), and hence reaffirming science as the bedrock of modern technology and society. Another factor is that many science teachers do not have sufficient knowledge or self-confidence to deal with the interactions amongst science, technology and society (Fensham 1988; Rubba, 1991; Yager, 1993, 1996).

Recent reforms continue to place science at the centre of the STS trilogy, thus relegating technology, albeit unintentionally, to the application of science. Paradoxically, equating technology with 'applied science' is widely regarded as a misconception (Cheek, 2000; Friedel, 2007; Jarvis and Rennie, 1996; Layton, 1994; Macaskill and Ogborn, 1996; Pacey, 1983). There is no shortage of examples to

illustrate this paradox. For instance, in Millar and Osborne's (1998) influential report, "Beyond 2000: Science education for the future", the dominance of science is evidenced by such goal statements as 'their [students'] understanding of science should come from . . . considering a range of current issues involving the application of science and scientific ideas' (p. 5). In a similar vein, the UK national curriculum includes an Applications and Implications of Science category (Qualifications and Curriculum Authority, 2007, p. 223). The country's recently developed science curriculum (Twenty First Century Science) also aims to enable students to recognise 'the benefits of science-based technology, and also . . . the possibility of unwanted consequences' as one of the important 'ideas about science' to be acquired (Millar, 2006, p. 1508).   Despite the relatively greater emphasis of the US National Science Standards (NRC, 1996) on technology, critics (Cheek, 2000; McGee & Wicklein, 1997) have argued that the treatment of technology, particularly its history, remains superficial in most state science frameworks.

The argument that the 'T' in STS should be granted equal status to the 'S' is based on three grounds. First, science and technology are intricately related and influence each other. There are well-documented instances of modern technology arising from science, of technological practices existing before their scientific explanations, of science gaining inspiration from technology, and of the two being

mutually interactive or entirely independent (AAAS, 1990; Friedel, 2007; Hodson, 2003; Volti, 2001, Ziman, 1976). Second, treating technology as subservient to science is problematic, as the two disciplines are different in nature (AAAS, 1990; Cajas, 1999; Layton, 1994; Ziman, 1980). As Van Eijck and Claxton (2008) argue, too much emphasis on the role played by science in technology may overshadow the unique epistemology of the latter and privilege a Eurocentric 'scientific world view in education' (p. 218). Third, the relationship between technology and society is much more complex than the linear relationship implied by the conception of technology as a mediator between science and society. Technology charts the course of societal development (technological determinism) (Heilbroner, 1994), but is also a social construction (Bijker, Hughes, & Pinch, 1987; Mackay, 1991). Pacey (1983) gave technology a wider meaning that embraces both a cultural and organizational aspect in addition to a technical one, and saw innovation as the outcome of mutual adjustments amongst social, cultural and technical factors (p. 25). The foregoing discussion implies the necessity of situating the 'T' in STS in its wider historical and social context, particularly in light of the temporal and spatial 'constraints' imposed by science, which has a much shorter history than technology and was confined mainly to Europe in the early stages of its development.

The second line of criticism of STS in practice lies with its failure to distinguish

between knowledge and action. Jenkins (2002) sees a lack of engagement between STS knowledge and 'commitment to action' (p. 28), noting that when such engagement does exist, it is 'vicarious rather than personal (pp. 20-21). Despite the 'science for democratic decision making' rhetoric preached by science educators and curriculum planners (Hodson, 2003; NRC, 1996; NSTA, 1990; Solomon, 1993), STS education in practice points only to 'ethical dilemmas or controversies, but does not necessarily exploit the inherent pedagogical power of discourse, reasoned argumentation, explicit NOS considerations, emotive, developmental, cultural or epistemological connections within the issues themselves' (Zeidler et al., 2005, p. 359). Thus, critics call for science education to be linked more explicitly with socio-political decisions and actions (Hodson, 2003; Holbrook & Rannikmae, 2007; Irwin, 1995; Jenkins, 2002; Pedretti & Hodson, 1995; Solomon, 1993; Wildson, 2009; Zeidler et al., 2005). Zeidler, Walker, Ackett, and Simmons (2002) went further to suggest that STS should be subsumed in an SSI approach that addresses not only the interconnections amongst science, technology and society, but also the ethical dimensions of science, and targets individual students' own 'moral and ethical development' (Zeidler et al., 2005, pp. 360).

This issue-driven and action-orientated approach to STS education is echoed by the advancement of 'science and technology studies', an interdisciplinary subject

8

informed by increased awareness of socio-scientific issues that have negative implications for the environment, society and mankind (Ankiewicz & De Swardt, 2006). Both STS science education and STS studies share the aim of enabling us 'to understand our new selves and to act with intelligence as democratic citizens in the technoscientific world that surrounds, nurtures and enlivens us' (Mitcham, 1999, p. 130). The two main foci of STS studies within a liberal education are the exploration of the discipline's moral and ethical implications (Kowal, 1991; Spittgerber, 1991) and the development of a critical perspective (Edge, 1995).

Whilst the SSI approach has merits, it also has potential limitations and presents formidable challenges. First, its discourse is necessarily restricted to the contemporary societal context, and thus is highly dependent on the current SSIs regarded as worthy of discussion. Second, it is akin to the 'problematic' approach, which Ziman (1994) suggested can raise important STS issues, but does little to inform students 'how science and technology actually work' (p. 31). Third, the SSI approach may run the risk of reinforcing the perennial misconception that technology is an applied science, as it is often the products, artefacts and applications of science (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006, p. 354) that define the issues addressed. Fourth, as Layton (1994) argued, schools alone may not be well-equipped to discharge their responsibilities for improving citizen participation in socio-scientific issues,

particularly as citizen participation itself is a diffuse concept with many meanings. Fifth, the values taken for granted about such participation in Western democratic societies may not be in congruence with non-Western societies. Hence, cultural and political sensitivity must be emphasised when contemplating an action-orientated STS approach outside the Western world (Layton, 1994; Lee, 2008).

Expanding the study of technology to inform STS

Whilst the two main criticisms of current STS provision are not necessarily in opposition, they do reflect a certain degree of tension in goal prioritisation and have prompted debate over whether STS education is for scholarship or activism (Layton, 1994). The former goal promotes a more holistic understanding of technology by emphasising how science and technology work in societal and cultural contexts, whilst the latter concerns mainly with value development by teaching students to make informed decisions and behave responsibly with regard to science-driven technological issues. If both goals are considered equally important, then it is desirable for science educators to put forward curricular approaches that connect them and develop relevant pedagogical strategies that put theory into practice. A possible way forward is to integrate Ziman's (1994) 'historical' and 'problematic' approaches, which would involve viewing the science-technology-society interface in a historical

continuum that connects past and present.

Most of the examples used to illustrate the interactions between science and technology are drawn from the past few centuries and the Western cultural context, with evidence from ancient civilizations that existed long before the dominance of Europe relatively scarce. Macaskill and Ogborn (1996, p. 57) reminded us that 'there are important stories to tell about how technology has grown and changed, has altered human history, and has bred science as well as being given birth to by science'. The use of familiar examples of technology employed in our daily lives promotes appreciation of the subtle relationship between the two. Some researchers (George, 1992; Gilbert, 1992; Holbrook, Craven, & Lutz, 1996; Jagede, 1994) have proposed the use of examples of indigenous technologies to provide students with STS education that is interesting and relevant to their own cultural experience. It is imperative to note that many of these traditional technologies went through a long period of development and transformation both before and after they met up with science. The study of the technologies developed in ancient non-Western cultures thus has the potential to explicate the cultural factors that influenced the interaction between technology and society before and after the emergence of modern science, an area grossly neglected in current STS education.

The case study reported herein revisited the STS link from the perspective of a

non-Western culture by exploring the historical development of papermaking technology in the Chinese socio-cultural context. Inspiration was sought from its findings to connect the two STS education perspectives identified in the foregoing literature review. The study was guided by the following questions.

1. What insights can be drawn from the evolution of papermaking technology for the interactions amongst science, technology and society? To what extent can the manifestations of STS reflected in this case study reinforce and broaden our existing understanding of this triadic relationship?

2. What implications do the study's findings have for addressing the diverging aims of STS education?

A historical case study approach was employed, as it has proved fruitful for obtaining valuable insights into the role and nature of science (Cross and Price, 1999; Lee, 2008; Solomon, Duveen, & Scott, 1992; Van Eijck & Claxton, 2008) and the socio-historical aspects of technology (Bijker, 1995; Hilgartner, 1995). The AAAS (1990) maintained that without historical examples, generalisations about scientific enterprise are reduced to rhetoric, noting that certain historical episodes are significant to our cultural heritage. Despite the difficulty of generalising from a single case, Stake (1994) argued that case studies enrich our understanding and facilitate the

construction of knowledge: 'a single case as [a] negative example can establish limits

to grand generalization' (p. 245). The case of the steam engine, which led to the study

of thermodynamics, is an oft-cited example used to rebut the common belief that

technology is an applied science (Layton, 1994). As in all historical research,

corroborative data are necessary (Tuchman, 1994). Thus, the study reported here drew

on a wide range of Chinese and Western literature, including the seminal series

Science and Civilization in China, which was edited by Joseph Needham, a

world-renowned expert in the study of Chinese science and technology.

RESULTS AND DISCUSSION

This section provides a concise description of the historical development of

papermaking to provide the necessary background for our discussion. In-depth

analysis of the key STS themes illuminated by this case study follows.

History of papermaking

Paper is regarded as one of China's four great inventions, along with printing,

gunpowder and the magnetic compass. The word 'paper' was derived from 'papyrus',

which was invented in Egypt 5000 years ago and consisted of laminated layers of the

inner bark of *Cyperus papyrus*. Paper comprises matted or felted sheets of fibres made

from macerated plant materials and left to dry on a screen. It is not entirely clear how

paper was first invented. Some evidence suggests that it was the accidental result of

rag fibres left on a mat from which the water was drained away (Tsien, 1985). Song

(1933) suggested that it resulted from beating silk cocoons in water, leaving behind a

thin sheet of 'paper' after drying. The latter theory is supported by the presence of the

radical of 'silk' on the left-hand side of the Chinese character for 'paper' (Xu, 1987).

Technology of ancient papermaking

The development of the technology of paper in China was a continuous process

rather than a one-off event, and involved changes in the use of raw materials and

improved techniques. The earliest paper specimens excavated, which date from

around 100 BC, were made of thick and coarse hemp fibres. A number of other plant

fibres were subsequently used, namely, paper mulberry, rattan, bamboo and straw in

chronological order (Temple, 1998). This succession of raw materials resulted from a

number of factors, including material quality, the depletion of old material, the

availability of new material, the need for greater production and the transference of

materials previously used for other purposes. For example, paper mulberry, which is

native to China, was already used to make cloth by beating its bark (Tsien, 1985).

This cloth was produced and traded by native tribes in the southern part of the country,

and the cloth-making technology involved was probably the catalyst for the replacement of hemp with paper mulberry in the papermaking process.

Making paper from its raw materials involves the maceration of plant fibres by both chemical and mechanical means. Song's (1933) detailed account of the manufacture of bamboo paper can be used to illustrate the ancient technology of papermaking. Bamboo shoots were first cut into pieces and then soaked in a pool near the site of their harvesting for 100 days, after which the pieces were pounded to remove their bark and leave the fibres. These fibres were then mixed with lime, boiled in a large pot for eight days and nights, and then washed in water. After being soaked in a solution of wood ashes, the fibres were placed back in the pot and covered with a layer of rice straw ashes before being taken out and repeatedly strained with a hot wood ash solution. After 10 days of such treatment, the bamboo had become a decayed pulp. This pulp was then pounded in a mortar until it became clay-like in appearance and was then put into a vat so that the fibres were suspended in water. A screen made of fine bamboo strips was dipped into this pulp solution and then mounted on a frame. As the screen was lifted, the matted fibres were picked up, and the water drained away. When the screen was inverted on a wooden board, the matted fibres, or paper, dropped off. They were then allowed to dry, and the process was repeated until a pile of paper had been created. After squeezing out any excess water,

each piece of paper was dried on a specially built double-brick wall with a fire between the walls.

Before the invention of detachable screens, the paper had to be left to dry on the screen. This new type of screens thus speeded up the process. Different treatments for the pulp and the finished paper were later developed, thus improving the quality of the finished product. According to the Hong Kong Museum of History (1999), in the third century, special materials were used to coat the paper to make it less absorbent to ink, a process known as 'sizing'. Gypsum, gum or glue made of lichen were first used as sizing agents, followed by starch flour, which also toughened the paper and made it more resistant to moisture. Later, alum and certain adhesive substances derived from animals or plants were added to the pulp to ensure the more uniform suspension of the fibres. Soya bean starch was also used when loading the fibres to improve the opacity and texture of the finished paper. Mineral powders such as talcum or kaolin were added to the surface of the paper to make it smoother and whiter in appearance. In addition, a type of 'paper solution' made from plant materials was added to the bamboo pulp to bleach it. Paper was also dyed with different kinds of plant extracts, and a plant substance containing an alkali was used to repel insects. Techniques borrowed from lacquer and silk craftsmen were later developed to make paper with gold or silver ornamentations, watermarks and concealed designs (Hong Kong

Museum of History, 1999).

Uses of paper

Historical records show that the earliest paper was used as clothing, curtains, wrapping, and even sanitary or toilet paper. It was only later that paper was widely used for writing, calligraphy and painting. Over time, it was also put to various other uses, including paper armour, wallpaper, lanterns, kites, fans, umbrellas and money, and for such aesthetic purposes as paper folding and cutting, as well as for ceremonial purposes. Paper also contributed to the development of firearms, as it was used to wrap gunpowder in rockets and fire-lances (Hong Kong Museum of History, 1999).

As bamboo was less available in the northern parts of China, people there started the practice of recycling bamboo paper around the 10th century. This recycled paper was called 'reincarnated' paper, meaning literally the 'returning of the soul' (Hong Kong Museum of History, 1999; Song, 1933).

The development of papermaking and the invention of printing were mutually reinforcing in China. The latter made possible the extensive production and wide distribution of paper, which provided printing with its essential raw material. Paper was thus one of the contributory factors to the early use of printing, along with the use of seals and rubbings for duplication, the need for an aid in copying texts written in

the complex ideographic script of Chinese, the standardisation of Confucian texts for

examinations and the demand for copies of Buddhist scriptures (Tsien, 1985).

Transfer of papermaking technology from China to Europe

Papermaking technology first spread to neighbouring Asian countries, and then

to Arabs in the 7th century. Arab traders then transmitted it to Europe in the 12th

century (Hong Kong Museum of History, 1999; Temple, 1998; Tsien, 1985). The first

European paper was made from linen rags, as neither paper mulberry nor bamboo was

available. It has been reported that Europeans also tested a number of raw materials,

including moss, asbestos, potato, wood and various other plants, for use in

papermaking (Tsien, 1985). After its introduction to Europe, many improvements

were made to papermaking technology, including the extensive use of water power in

the pulping process (Hunter, 1978). The increased availability of mechanical grinders

meant pulp could be produced from wood under high temperature and pressure,

although the resulting paper was of poorer quality. Lime and ashes were replaced by

acidic chemical reagents such as acid sulphites or by alkaline reagents such as sodium

hydroxide, greatly enhancing the maceration process. These agents also facilitated the

removal of lignin, which makes paper brittle and turns it yellow through oxidation.

Such chemicals as polyacrylamides were used as sizing agents, instead of starch and

vegetable gums, and chlorine-based agents were used for bleaching purposes.

Discussion

Further conceptualisation of STS

Although it is not appropriate to generalise from the findings of a single case study, five themes that have implications for our understanding of the interactions amongst technology, science and society emerge from the study presented herein. Although these themes are inevitably intertwined, they are presented here individually for the sake of clarity.

Theme 1: What can be said about the nature of technology by considering its ancient manifestations?

The foregoing case study demonstrates that the development of even an ancient or traditional technology such as papermaking can be exceedingly complex. It existed long before modern science came into being, thus reaffirming our existing understanding that technology is by no means an applied science. The technology of papermaking has become interwoven with science only in the past few centuries.

Ancient technology was based primarily on practical and tacit knowledge distilled from everyday living and working experiences. It appears to have involved

rational thinking intermingled with trial and error. It is also possible that processes akin to careful experimentation were involved in arriving at precise procedures, thus casting doubt on the belief that technology borrowed from science the method of systematic experimentation (Layton, 1994). Although the invention of paper is very likely to have come about by accident rather than prompted by a social need, the desire to overcome problems and to adapt the technology to meet new social needs seem to have been the chief driving forces behind its continuous development.

It is imperative to recognise that different technologies interact with one another to produce synergistic effects. For instance, ancient papermaking in China was influenced by cloth making from bark and, in turn, contributed to the development of printing and explosives manufacture. In Europe the manufacture of linen was instrumental to the development of papermaking (Friedel, 2007). A few centuries ago, mechanical engineering was used for the large-scale production of wood pulp, and chemical technology was employed to enhance the delignification of wood fibres. Recently, a new research area has sprung up: the use of biotechnology to reduce the environmental problems caused by papermaking effluents.

In sum, the development of technology follows a very circuitous path rather than the linear path commonly represented as a simple causal relationship between societal needs and technological innovations. This path is criss-crossed by accidents, chance,

human creativity, cultural factors, the availability of resources, the transfer of knowledge from other technologies, and, of ever-increasing importance, the birth of modern science. The impact of modern science is further elaborated in Theme 2. The metaphor of a sponge may be useful for describing technology, that is, it is capable of absorbing and utilising whatever practical knowledge is deemed useful in its seemingly endless drive to solve problems and achieve perfection.

Theme 2: What is the status of ancient technology, and how does it differ from

science?

Can an ancient technology such as papermaking be regarded as a primitive manifestation of science, or as embodying the seeds of modern science? How did the practitioners of ancient technology interpret the phenomena they observed or encountered in the making of artefacts? Did they ever generate scientific concepts in the process? One may wonder how the ancients knew about the seemingly complicated processes involved in papermaking, which are highly related to science, for instance, fermentation and the chemical disintegration of plant tissues, the stabilisation of the pulp, bleaching, sizing, preserving, dyeing and the like. Amazingly, the basic technological framework is largely similar to that practised today. Can the development of papermaking in ancient times thus be explained solely by ancient

wisdom, practical experience, knowledge of crafts and human creativity?

It is likely that these early 'technologists' developed tacit knowledge of their craft from observed data and their own inferences. For example, ancient craftsmen would have possessed some knowledge of the properties of the fibres of the individual plants used to make pulp, the properties of the different additives used for the further treatment of the pulp or finished product, and the unique physical characteristics of paper, including the remarkable change in its tensile strength as water was pressed out of it. The processes of problem solving and improvement necessarily involved rational thought, as in science (Aikenhead & Ogawa, 2007; Ogawa, 1995; Voti, 2001). As previously noted, the meticulous and highly specific procedure used in the production process implies extensive trial and error and, most probably, reasoning akin to controlled experimentation. However, we lack evidence of the formulation of theoretical hypotheses to account for the observed data and inferences, which characterises modern science. For instance, starching effectively prevents the penetration of ink into paper. However, there seems to have been a lack of interest in discovering how or why it does so through investigation of capillarity, nor were attempts made to explore why cooking plant materials with lime helps to loosen fibres. As Bhaduri (2003) argued, the lack of an 'explanatory model' or theory that connects the 'empirical evidence' within a 'cause and effect' framework distinguishes

technology from science (p. 304). His point can be further illustrated using the space paper experiment designed by a high school student in the US state of Wisconsin (Robert C. Williams Paper Museum, 2009a). This student investigated the effects of microgravity on the formation of paper. The experiment he designed was carried out on the space shuttle Columbia during its 1986 flight, and the results showed that paper made in the absence of gravitational forces is better than paper made on earth. Scriven (as cited in Fensham [1988, p. 349]) argued that, although the processes of both science and technology involve experimentation, the testing or improvement of artefacts is fundamentally different from the testing of ideas or hypotheses. The space paper experiment can thus be contrasted with the traditional process of adding mucilage to paper pulp. Both enhance the uniform suspension of plant fibres, but the former was based on an explicit theoretical explanatory model to account for cause and effect, a model the latter apparently lacked. Even if ancient technology contains an element of primitive science in the form of tacit knowledge and rational thought, it remains different from modern science, which goes beyond physical phenomena and a practical understanding of nature to the development of universal theories (Layton 1988).

Theme 3: What role has science played in the development of ancient technology into

its modern form?

The present case study clearly demonstrates the instrumental role played by science in the evolution of ancient technology. Scientific knowledge was increasingly applied to enhance the paper production process, either directly through the application of knowledge gleaned from chemistry, biology and physics or indirectly through the mediation of other technologies, e.g. electrically powered machines or computer-controlled systems. The utilisation of modern chemistry in modern papermaking is particularly wide ranging, involving carbohydrate chemistry, the chemistry of inorganic pigments, organic and polymeric additives, colloid and surface chemistry, polymer chemistry, and environmental and analytical chemistry (Roberts, 1996). Modern biotechnology, which mainly arose from biochemistry and molecular genetics, is also applied in papermaking, for example, in the use of enzymes in biopulping, a pre-treatment process designed to save energy (Bajpai, Bajpai, & Kondo, 1999).

Although science provides a huge library of resources upon which technology draws to solve its problems, to characterise technology as a passive recipient of scientific knowledge is to grossly simplify the real picture. Technology has in many instances been instrumental in stimulating research, as illustrated by two examples in relation to the removal of lignin from wood pulp. First, environmental challenges

prompted research into the use of naturally occurring enzymes in white rot fungus to degrade lignin into a soluble form, thus allowing its effective removal and reducing demand for chemical bleach to remove its undesirable colour (Bajpai et al., 1999; Eriksson, 1998; Kondo, Hirai, Harazono, and Sakai, 1998). Second, the currently used acidic or alkaline delignification method inevitably leads to the degradation of the cellulose fibres, which reduces the quality of the paper. This has stimulated research into organic solvents that can take advantage of the structural differences between cellulose and lignin to protect the former during the delignification process (Roberts, 1996).

Modern papermaking has also contributed to the emergence of paper science (Roberts, 1996), an applied science that has grown into an interdisciplinary subject area and a large enterprise. There are now university faculties specialising in paper science, and specialised journals that disseminate frontline research in the field. Paper science has thus enabled the industry to fulfil the needs of contemporary society. However, four factors must be borne in mind when considering the science-technology interaction. First, the application of science to improve technology is not straightforward, and many practical problems require resolution before viable, improved products can be produced. For example, the use of organic solvents for delignification remains restricted due to recovery problems (Roberts 1996). The

conversion of scientific into technological knowledge is thus highly complex (Tiles and Oberdiek, 1995), and requires considerable reformulation and adaptation. Second, the application of science to papermaking has been primarily designed to improve the efficiency of the process rather than changing the technological frame of papermaking itself. A similar situation is observed in the development of other science-enhanced traditional technologies such as cheese and wine making. Third, science can help to resolve technical problems, but may create other problems in so doing. For instance, since the pulp industry began to use more chemicals, it has produced more potentially hazardous effluents, thus further threatening environmental stability. Ironically, the resolution of this problem also hinges upon science. Fourth, as a corollary to the second and third factor, the application of science in technology is to a great degree a value-laden process. For the foreseeable future, paper science will continue to delve into research to meet two contrasting, value-laden goals – increasing productivity at low cost and improving environmental stability.

In sum, scientific knowledge has taken over from practical tacit knowledge as the dominant driving force behind the continuous evolution of papermaking in the modern era, and paper science represents the integration of theoretical science and the practical aspects of papermaking. The 'technology sponge' has become bathed in a nutritious 'science solution', which has allowed it to gain a tremendous amount of

weight within a short period of time relative to its long history. However, acknowledging this trend does not imply that technology as a way of knowing must be, as Van Eijck and Claxton (2009, p. 230) strongly contested, 'inextricably bound up with particular worldviews such as the scientific'. The difference in nature between the two disciplines still holds; it is only that the increased input from scientific knowledge has greatly increased the vibrancy of technology.

In light of the important interactions between technology and science over time, there may be a need to revisit Pacey's (1983) model of technology, which posits that the 'technical' aspect of knowledge may not be sufficient to represent the role played by science in technology, or the subtle interactions between the two. It is thus desirable to differentiate between the 'scientific' and 'technological' aspects of knowledge, while acknowledging their increasing interdependence. Science is increasingly looked upon as a source of knowledge or stimulation either for improving traditional technologies or stimulating the birth of new technologies.

Theme 4: How have technology and society interacted throughout history? What were the driving or impeding forces behind their interaction?

The results of the case study presented here show that both the invention and initial development of papermaking in China, and its later adoption in Europe, were

very much contextual and rooted in a distinctive culture. The variety of uses that paper was put to in ancient China is remarkable, and the material contributed significantly to the development of Chinese civilization. The transfer of papermaking technology to Europe demonstrates another effect operating in society, that is, cultural differences have served as social filters for technological change (Bulliet, 1994). Papermaking was transferred to Europe by Arabs, but European hostility towards Arabian or Muslim culture at that time considerably delayed its adoption on the continent. Holy Roman Emperor Frederick II even declared the invalidity of all official documents written on paper in 1221 (Robert C. Williams Paper Museum, 2009b).

Such cultural resistance seems to have been exacerbated by economic considerations. Tsien (1985) argued that, in Europe, paper was not perceived to be highly advantageous compared with parchment, which was then plentiful, easy to prepare, relatively cheap and convenient to use. In China, in contrast, the need to replace bamboo probably influenced the adoption of paper technology (Tsien, 1985). The vested interests of European landowners in sheep and cattle for parchment may also have contributed to the resistance to use paper (Robert C. Williams Paper Museum, 2009b). However, these social and economic filters were gradually removed by changing needs, particularly those resulting from the invention of printing, which

increased demand for paper (Hunter, 1978).

Other examples testify to extreme adaptability of technological development to societal needs and constraints. In China, new raw materials were actively sought as existing ones were depleted, and used paper was recycled to produce 'reincarnated' paper, thus conserving precious raw materials. Even today, the availability of raw materials has had a remarkable influence on paper recycling technology. Roberts (1996) reported that recycled paper fibres account for more than half of the total fibrous raw materials used in Europe, whereas recycling is much less common in North America, where the wood supply is relatively abundant.

The need to meet new social demands is exemplified by the environmental challenge to papermaking today. This challenge has been transformed into political and consumer demands, thus leading to the changes in the technology and science of papermaking detailed in previous sections. Society thus imposes 'contextual' values on technology (Layton, 1988, p. 374). Even in the recycling of used paper, there is pressure to replace chemical methods of ink removal with more environmentally friendly means such as enzymatic de-inking (Bajpai, 1999; Moerkbak & Zimmermann, 1998). Thus, it seems justified to conclude that the development of technology and society interacts with each other, leading to the co-evolution of both technology and society (Ankiewicz & De Swardt, 2006), and that modern science has

played a catalytic role in this evolutionary process.

Theme 5: Why did modern science not develop in China despite its ancient technological advances?

In his seminal book *The Structure of Scientific Revolution*, Kuhn (1996) asserted that a paradigm, or at least a candidate for a paradigm, must be present for science to emerge; otherwise, fact gathering is a random activity, and 'technology has often played a vital role in the emergence of new sciences' (p. 16), as it provides a readily accessible source of facts for experimentation. As both Volti (2001) and Kranzberg (1991) argued, many technological developments reach a plateau due to a lack of scientific knowledge, thereby generating a clearly perceived need for fundamental scientific research. In China, however, technology failed to stimulate the emergence of any significant scientific theories that Kuhn (1996) would have classified as a scientific paradigm. Joseph Needham (1954, 1956, 2004) has continued to consider this puzzle over the years. If the steam engine led to the study of thermodynamics (AAAS, 1989; Layton, 1988), then why didn't papermaking or alchemy lead to the generation of chemical knowledge? Why didn't the Chinese develop the science to perfect their technology?

Solving the 'Needham puzzle' requires deeper cultural analysis of China and

Europe. Different causes have been put forward to explain the rise of modern science in Europe, but not in other regions of the world, amongst them the rise to power of the bourgeoisie and merchant classes; the spread of technocratic ideas in government and trade, facilitated by the rise of efficient nation-states (Bodde, 1991; Fichman, 1993; Needham, 1956); the growth of cities, which increased receptivity to industrial innovations; voyages of discovery that broadened European horizons; and the utilitarianism and empiricism embedded in Protestantism (Gieryn, 1988).

Whilst these developments may explain why Europe became the spawning ground of science, some of them also occurred in China. The growth of cities in China has an even longer history than in European nations, for example. China also made impressive sea excursions as early as the 15th century. Two issues are worthy of further deliberation. First, Bodde (1991) noted the 'growing authoritarianism and intellectual orthodoxy of the Chinese bureaucratic state' as a major factor influencing the development of Chinese science unfavourably (p. 367). This is consistent with Seitz's (1992) view that 'the pursuit of science and technology must be free from dogmatic pressures which impede their freedom of speculation and experimentation' (p. 18). Chinese intellectuals were dominated by the Confucian idea of *li*, which prescribes good customs, ethics and harmonious social relationships, thus making rational thought about non-human Nature impossible (Needham, 1956). T.Y. Wu,

former president of Taiwan's Academia Sinica argued that the pursuit of science appeared to be 'traumatically evolutionary but destabilizing' in Chinese society, which was guided by Confucianism as the traditional basis of proper conduct (Seitz, 1992, p. 38). An exemplification of this intellectual orthodoxy was the Chinese civil service examinations, which emphasised literacy rather than science (Bodde, 1991, Needham, 2004). These examinations began in 605 and were abolished only in 1905, when the Chinese realised that they were lagging far behind their Western counterparts in science and technology. Such orthodoxy affected technology less than science because most artisans were illiterate and concerned with the practical rather than the theoretical (Bodde, 1991).

Another issue is the agricultural economy that characterised ancient Chinese society. Huang (1992) argued that this kind of economy was basically self-contained. As long as the existing technology and science could fulfil its fundamental needs, there was no great desire to strive for further developments. Moreover, the economic advantage of technological innovation was perceived as limited because of the abundant supply of low-cost, high-quality labour (Chow, 2004). Jacques Ellul (as cited in Mitcham [1999, p. 129]) characterises three successive human milieu – the prehistoric or natural, the social, and the technological. It appears that China, despite its early technological advances, failed to transcend the social milieu, which is

dominated by large-scale cultivation and hierarchical social organization, and move on to the technological milieu in which society is shaped collectively by science and technology. This discussion leads us to the conclusion that the most fundamental influence on the development of science and technology is embedded in the culture of a society.

Educational Implications

The findings of this study testify to the richness of history in furthering our understanding of the nature of technology, and its interactions with science. There is great potential to further substantiate this understanding, as there are vast sources of traditional technology in China and elsewhere that remain to be tapped. This type of historical case study approach can serve as an anchor to which the otherwise fragmented pieces of information about the interactions amongst technology, science and society, as well as the issues deeply embedded in culture and society, can be connected. The findings of this study imply that the STS approach practised in many existing STS-embedded science curricula need not be restricted to the 'S(Science)-T(Technology as applied science)-S(Societal implications)' model, or rather stereotype. They can also explicate the socio-cultural contexts that chart the course of their historical development of science and technology, thus leading to an

appreciation of the place of both in the evolution of human civilization. In short, such education should address the questions of where we are from and where we are heading. Only from this perspective can students appreciate the nature of technology, understand how technology and science met and worked together to contribute to the progress of human civilization, and determine the promises that the two together hold for the future of mankind.

It is therefore worthwhile to differentiate between two approaches to STS education. The first, which is commonly practised in many existing programmes, focuses on scientific advancement and its impact on society through applications in new technologies, for example, genetic engineering and stem cell technology, and their ethical or environmental implications. The main aim is to develop responsible citizenship. This approach could be referred to as 'S-T-S'. The second approach focuses on the development of technology in history, and traces how it evolved before and after the emergence of modern science. Many technological developments other than papermaking could be discussed in this context, including the production of such fermented food products as cheese (Friedel, 2007), wine and soy sauce, alchemy (Song, 1933), the making of gunpowder (Needham, 1986), sugar cane production (Daniels & Menzies, 1996), the production of silk (Kuhn, 1988), the manufacture of various engineering devices (Friedel, 2007), and other ancient or indigenous

technologies. To distinguish it from the first approach, this approach can be coined as 'Technology-Society-Science', or T-S-S.

In the T-S-S approach, any ancient or indigenous technology could serve as the point of departure for the study of technology's long-term interaction with society and its later 'marriage' to science. As students learn more about the evolution of these traditional technologies, they would realize that science has played an important supportive role in facilitating their breakthrough to increase productivity, but it has also generated undesirable side-effects such as environmental pollution, health hazards and ethical concerns. At this juncture, the distinction between T-S-S and S-T-S becomes blurred. The two will converge if a particular socio-scientific issue arising from technology gains prominence, thus garnering public attention and necessitating personal decision making and action. For instance, the effluents of the papermaking industry have aroused concerns about environmental pollution, and the excessive use of paper has triggered worries about large-scale deforestation, which would further aggravate global warming. T-S-S and S-T-S are analogous to the two sides of the same coin. They merge to form an integrated whole when the past is connected with the present and when the new issues that arise from science-enhanced 'old' technologies must be tackled not only by scientific and technological expertise, but also by the sensible judgement and actions of the citizenry. Table 1 summarises

the difference emphases of the S-T-S and T-S-S approaches with respect to several important dimensions.

[Insert Table 1 about here]

The delineation of these two STS approaches helps to resolve the aforementioned tension in the goals of STS education, that is, the tension between education that aims to produce a more holistic understanding of the interactions amongst technology, society and science and that which targets political citizenship and emphasises personal decision making and responsible behaviour. Whilst the latter goal can be fulfilled through the S-T-S approach, the T-S-S approach provides an avenue for achieving the former. As previously discussed, the intent is not to dichotomise STS into two oppositional approaches. Rather, these two approaches aim to engage students in understanding the role of science and technology in a contextualised way. These approaches are not mutually exclusive, and nor do they preclude the use of additional alternative approaches.

Curricular and pedagogical implications

To bridge theory and practice, the conceptualisation of the T-S-S approach must be translated into concrete pedagogy. A typical T-S-S lesson could start off with enquiry into the development of a traditional or indigenous technology in its historical

and societal context, particularly in relation to its mutual interactions with society, the resolution of technological problems and the overcoming of social barriers. This could then be followed by an exploration of the scientific principles underlying traditional technological processes and a discussion of the contribution made by science to their continuous evolution, thus emphasising how society has been transformed by the synergy between the two knowledge systems.

Layton (1990) suggested that in bridging science and technology education, scientific concepts that improve a technology by enhancing its performance and extending the range of its use and application be identified. In a T-S-S class, before students are introduced to the modern form of an ancient technology, they could be encouraged to revisit and suggest ideas for improving the old technology, such as improvements for papermaking based on their understanding of modern chemistry. There are plentiful opportunities to engage students in hands-on activities, such as asking them to simulate the work of ancient craftsmen or testing their knowledge of scientific principles by asking them to improve old technology. For instance, students could be guided to tread old paths in papermaking by using a pestle and mortar to pound plant fibres and lime as a maceration agent, and then asked to compare the quality of the resulting paper with that produced using modern methods. Such activities allow students to experience the interactions between science and

technology in an authentic context. Through this, T-S-S would not only consolidate students' scientific concepts but also extend their technological capability. T-S-S should be distinguished from the teaching and learning of science through indigenous technology, such as the method proposed by Jegede (1994) and from the technology-determined STS curriculum materials categorised by Fensham (1988). In the T-S-S approach, technology should not be treated solely as a context for learning scientific principles, but also as a vehicle for capturing the dynamic and intricate interactions amongst science, technology and society in a unique cultural context.

In the context of promoting technological education, Gilbert (1992) asked the question: What knowledge base, including content knowledge and pedagogical content knowledge (Shulman, 1987), do science teachers need? For teachers to be able to fully utilise the T-S-S approach, it seems reasonable that they should possess sufficient knowledge, skills and confidence to address the following questions that arise from the five themes identified in this case study.

- What existing technologies originated in ancient times, and what technological principles underpin their operation?

- How did these technologies develop in the unique socio-cultural contexts in which they arose in the pre-science era?

- What is the nature of technology that distinguishes it from science?

- Why do some technologies fail to lead to the development of scientific descriptions and explanations to improve their processes and outcomes?

- How can the operation of ancient technologies be explained by modern scientific principles?

- How was ancient technology enhanced by modern science?

- How will relevant fields of applied science continue to make an impact on the modern forms of ancient technologies, e.g. paper science in the case of papermaking?

- How can ethical, societal and environmental concerns be addressed while developing and using science-enhanced technologies?

- What types of hands-on experience can be provided to students to enhance their technological capabilities and help them to appreciate technology as an essential part of human civilization, as well as the relatively recent contribution of science to its development?

- How can students be engaged in project work for greater in-depth study of a particular technology to reveal the interrelationship amongst science, technology and society?

Ziman (1980, p. 111) has rightly pointed out that 'one of the virtues of STS education is that it offers occasions to practice some of the "humanistic" skills that are

largely excluded from the hard sciences'. The opportunity to integrate science and technology education with the humanities, including such history and social and cultural studies, in the form of T-S-S is a feasible way of achieving this. However, this is easier said than done for at least two reasons. First, the T-S-S approach entails an interdisciplinary form of study that may not be familiar to science teachers. Second, although a historical approach can provide very rich information about the nuances of science-technology-society interactions, Ziman (1980) cautioned that the use of such an approach involves the immense complexity of the history of science, its remoteness from everyday life and the inevitable emphasis on individual achievement over the collective scientific enterprise. The first concern is particularly noteworthy, as the T-S-S approach entails a shift away from the current conceptualisation of STS education to the inclusion of the study of technology in its socio-cultural and socio-historical contexts. The second concern may not be as overwhelming as it first appears. This is because, in the T-S-S approach, it is not the history of theoretical science that is the prime focus, but rather the history of technology and the applied aspects of science, which should be less demanding intellectually for school students. This approach could easily engender in students an appreciation of technology as the collective and sustained effort of society. Furthermore, a historical T-S-S case study can be made more interesting by situating it within students' own cultural context, and

allowing them to engage in a variety of hands-on scientific and technological activities. Researchers have reminded us of the need to acknowledge the existence of the cultural divide among science, technology and the humanities (Bhaduri, 2003; Snow, 1993; Zuga, 1996). However, this caveat should not prevent teachers from adding more interdisciplinary flavour to their current STS content to put science and technology in perspective, and redress the imbalance between these two equally important facets of human culture.

References

Aikenhead, G. (1980). *Science in social issues: Implications for teaching*. Ottawa, Science Council of Canada.

Aikenhead, G. (1994). What is STS science teaching? In J. Solomon & G. Aikenhead (Eds.), *STS education: International perspectives on reform* (pp. 47-59). New York, Teachers College Press.

Aikenhead, G., & Ogawa, M. (2007). Indigenous knowledge and science revisited. *Cultural Studies of Science Education*, 2, 539-620.

American Association for the Advancement of Science (AAAS). (1990). *Science for all Americans*. New York, Oxford University Press.

Ankiewicz, P., & De Swardt, E. (2006). Some implications of the philosophy of

technology for science, technology and society (STS) studies. *International Journal of*

Technology and Design Education, 16, 117-141.

Bajpai, P., Bajpai, P. K., & Kondo, R. (1999). *Biotechnology for environmental*

protection in the pulp and paper industry. Berlin, Springer-Verlag Berlin Heidelberg.

Bhaduri, S. (2003). Science, society, and technology – Three cultures and multiple

visions. *Journal of Science Education and Technology*, 12(3), 303-308.

Bijker, W. E. (1995). Sociohistorical technological studies. In S. Jasanoff, G. E.

Markle, J. C. Petersen, & T. Pinch (Eds.), *Handbook of science and technology*

studies (pp. 229-256). Thousand Oaks, CA, SAGE Publications.

Bijker, W. E., Hughes, T. P. & Pinch, T. F. (1987). *The social construction of*

technological systems: New directions in the sociology and history of technology.

Cambridge, MA, MIT Press.

Bodde, D. (1991). *Chinese thought, society, and science*. Honolulu, University of

Hawaii Press.

Bulliet, R. W. (1994). Determinism and pre-industrial technology. In M. R. Smith & L.

Marx (Eds.), *Does technology drive history?* (pp. 201-216). Cambridge, MA, MIT

Press.

Bybee, R. W. (1987). Science education and the science-technology-society (STS)

theme. *Science Education,* 71(5), 667-683.

Cajas, F. (1999). Public understanding of science: Using technology to enhance school science in everyday life. *International Journal of Science Education*, 21(7), 765-773.

Cheek, D. W. (2000). Marginalization of technology within the STS movement in American K-12 education. In D. D. Kumar & D. E. Chubin (Eds.), *Science, technology, and society: A sourcebook on research and practice* (pp. 167-192). New York, Kluwer Academic/Plenum Publishers.

Chow, G. C. (2004). *Knowing China*. River Edge, NJ, World Scientific Publishing Co.

Cross, R. T., & Price, R. F. (1999). The social responsibility of science and the public understanding of science. *International Journal of Science Education*, 21(7), 775-785.

Daniels, C. & Menzies, N. K. (1996). Vol. 6 (Part III): Agro-industries and forestry; Agro-industries: Sugar cane technology. In J. Needham (Ed.), *Science and civilization in China*. London, Cambridge University Press.

Edge, D. (1995). Reinventing the wheel. In S. Jasanoff, G. E. Markle, J. C. Petersen & T. Pinch (Eds.), *Handbook of science and technology studies* (pp. 3-24). Thousand Oaks, CA, SAGE Publications.

Eriksson, K-E. L. (1998). Biotechnology in the pulp and paper industry: An overview. In K-E. L. Eriksson & A. Cavaco-Paulo (Eds.), Enzyme applications in fiber processing (pp. 2-14). Washington, DC, American Chemical Society.

Fensham, P. (1988). Approaches to the teaching of STS in science education. *International Journal of Science Education*, 10(4), 346-356.

Fichman, M. (1993). *Science, technology and society: A historical perspective*. Dubuque, IA: Kendall/Hunt Publishing Co.

Friedel, R. (2007). *A culture of improvement: Technology and the Western millennium*. Cambridge, MA, MIT Press.

George, J. M. (1992). Helping teachers to incorporate knowledge of indigenous technologies with their science teaching. In D. Layton (Ed.), *Innovations in science and technology education*, Vol. IV (pp. 87-95). Paris, UNESCO.

Gieryn, T. F. (1988). Distancing science from religion in seventeenth-century England. *Isis*, 79(4), 582-593.

Gilbert, J. K. (1992). The interface between science education and technology education. *International Journal of Science Education*, 14(5), 563-578.

Hart, E. P., & Robottom, I. M. (1990). The science-technology-society movement in science education: A critique of the reform process. *Journal of Research in Science Teaching*, 27(6), 575-588.

Heilbroner, R. L. (1994). Technological determinism revisited. In M. R. Smith and L. Marx (Eds.), *Does technology drive history?* (pp. 53-66). Cambridge, MA, MIT Press.

Hilgartner (1995). The human genome project. In S. Jasanoff, G. E. Markle, J. C.

Petersen, & T. Pinch (Eds.), *Handbook of science and technology studies* (pp.

302-315). Thousand Oaks, CA: SAGE Publications.

Hodson, D. (2003). Time for action: Science education for an alternative future.

International Journal of Science Education, 25(6), 645-670.

Holbrook, J., Craven, J, & Lutz, M. (1996). In R. E. Yager (Ed.)

Science/technology/society as reform in science education (pp. 227-238). Albany, NY,

State University of New York Press.

Holbrook, J., & Rannikmae, M. (2007). The nature of science education for enhancing

scientific literacy. *International Journal of Science Education, 29*(11), 1347-1362.

Hong Kong Museum of History (1999). *Heavenly creations: Gems of ancient Chinese

inventions*. Hong Kong, Hong Kong Museum of History.

Huang, S. (1992). *Ke Ji Cai Ying*. Hong Kong, Chung Hwa Book Co.

Hunter, D. (1978). *Papermaking: The history and technique of an ancient craft*. New

York, Dover Publications.

Hurd, P. D. (1986). Perspectives for the reform of science education. *Phi Delta

Kappan, 67*(5), 353-358.

Irwin, A. R. (1995). *Citizen science: A study of people, expertise and sustainable

development*. New York, Routledge.

Jarvis, T., & Rennie, L. J. (1996). Perceptions about technology held by primary

teachers in England. *Research in Science and Technological Education,* 14(1), 43-54.

Jegede, O. (1994). African cultural perspective and the teaching of science. In J.

Solomon & G. Aikenhead (Eds.), *STS education: International perspectives on reform*

(pp. 120-130). New York, NY: Teachers College Press.

Jenkins, E. W. (2002). Linking school science education with action. In W-M. Roth &

J. Desautels (Eds.), *Science education as/for sociopolitical action* (pp. 17-34). New

York: Peter Lang.

Kondo, R., Hirai, H., Harazono, K., & Sakai, K. (1998). Characterization of

oxidoreductases, ferrireductase, and manganese peroxidase, from white-rot fungi. In

K-E. L. Eriksson & A. Cavaco-Paulo (Eds.), *Enzyme applications in fiber processing*

(pp. 142-154). Washington, DC: American Chemical Society.

Kowal, J. (1991). Science, technology, and human values: A curricular approach.

Theory Into Practice, 30(4), 267-272.

Kranzberg, M. (1991). Science-technology-society: It's as simple as XYZ! *Theory*

Into Practice, 30(4), 234-241.

Kuhn, D. (1988). Volume 5 (Part IX): Textile technology – Spinning and reeling. In J.

Needham (Ed.), *Science and civilization in China*. London, Cambridge University

Press.

Kuhn, T. S. (1996). *The structure of scientific revolutions* (3rd edition). Chicago, The

University of Chicago Press.

Layton, D. (1988). Revaluing the T in STS. *International Journal of Science Education,* 10(4), 367-378.

Layton, D. (1990). *Inarticulate science*. Liverpool, School of Education, University of Liverpool.

Layton, D. (1994). STS in the school curriculum: A movement overtaken by history? In J. Solomon & G. Aikenhead (Eds.), *STS education: International perspectives on reform* (pp. 33-44). New York, Teachers College Press.

Lee, Y. C. (2008). Exploring the roles and nature of science: The case of SARS. *International Journal of Science Education,* 30(4), 515-541.

Macaskill, C., & Ogborn, J. (1996). *Science and technology*. School Science Review, 77(281), 55-61.

Mackay, H. (1991). Technology as an educational issue: Social and political perspectives. In H. Mackay, M. Young & J. Beynon (Eds.), *Understanding technology in education* (pp. 1-12). London, Falmer Press.

McGee, L., & Wicklein, R. C. (1997). Technology education in perspective: Clearer visions necessary. *The Technology Teacher*, October, 17-20.

Millar, R. (2006). Twenty first century science: Insights from the design and implementation of a scientific literacy approach in school science. *International*

Journal of Science Education, 28(13), 1499-1521.

Millar, R., & Osborne, J. (Eds.) (1998). *Beyond 2000: Science education for the future*.

London, King's College.

Mitcham, C. (1999). Why science, technology, and society studies? *Bulletin of*

Science, Technology & Society, 19(2), 128-134.

Moerkbak, A. L., & Zimmermann, W. (1998). Applications of enzymes in paper

deinking processes. In K-E. L. Eriksson & A. Cavaco-Paulo (Eds.), *Enzyme*

applications in fiber processing (pp. 133-141). Washington, DC, American Chemical

Society.

National Research Council (NRC). (1996). *National science education standards*.

Washington, DC, National Academy Press.

National Science Teachers Association (NSTA). (1990). Science/technology/society:

A new effort for providing appropriate science for all (The NSTA position statement).

Bulletin of Science, Technology & Society, 20, 249-250.

Needham, J. (1954). Volume 1: Introductory orientations. In J. Needham (Ed.),

Science and civilization in China. Cambridge, Cambridge University Press.

Needham, J. (1956). Volume 2: History of scientific thought. In J. Needham (Ed.),

Science and civilization in China. Cambridge, Cambridge University Press.

Needham, J. (1986). Volume 5 (Part 7): Military technology – The gunpowder epic. In

J. Needham (Ed.), *Science and civilization in China*. Cambridge, Cambridge

University Press.

Needham, J. (2004). Volume 7 (Part II): General conclusions and reflections. In J.

Needham (Ed.), *Science and civilization in China*. Cambridge, Cambridge University

Press.

Ogawa, M. (1995). Science education in a multi-science perspective. *Science

Education,* 79, 583-593.

Pacey, A. (1983). *The culture of technology*. Oxford, Basil Blackwell Publisher.

Pedretti, E., & Hodson, D. (1995). From rhetoric to action: Implementing STS

education through action research. *Journal of Research in Science Teaching*, 32(5),

463-485.

Qualifications and Curriculum Authority. (2007). *The national curriculum 2007*.

(visited at

http://curriculum.qca.org.uk/uploads/QCA-07-3345-p_Science_KS4_tcm8-1799.pdf?r

eturn=/key-stages-3-and-4/subjects/science/keystage4/index.aspx%3Freturn%3D/key-

stages-3-and-4/subjects/index.aspx).

Robert C. Williams Paper Museum. (2009a). *The world of paper.* (visited at

http://ipst.gatech.edu/amp/exhibits/museum_travel_exhibit_world_paper.htm).

Robert C. Williams Paper Museum. (2009b). *The spread of papermaking in Europe.*

(visited at http://ipst.gatech.edu/amp/collection/museum_pm_euro.htm)

Roberts, J. C. (1996). The Chemistry of paper. Cambridge: the Royal Society of

Chemistry.

Roy, R. (2000). Real science education: Replacing "PCB" with S(cience)

through-STS throughout all levels of K-12: "Materials" as one approach. In D. D.

Kumar & D. E. Chubin (Eds.), *Science, technology, and society: A sourcebook on*

research and practice (pp. 9-20). New York, Kluwer Academic/Plenum Publishers.

Rubba, P. A. (1991). Integrating STS into school science and teacher education:

Beyond awareness. *Theory into Practice*, 30(4), 303-308.

Sadler, T. D., Amirshokoohi, A., Kazempour, M., & Allspaw, K. M. (2006).

Socioscience and ethics in science classrooms: Teacher perspectives and strategies.

Journal of Research in Science Teaching, 43(4), 353-376.

Seitz, F. (1992). *The science matrix: The journey, travails, triumphs*. New York,

Springer-Verlag.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform.

Harvard Educational Review, 57(1), 1-22.

Solomon, J. (1993). *Teaching science, technology and society*. Buckingham: Open

University Press.

Solomon, J. (1994). Conflict between mainstream science and STS in science

education. In J. Solomon & G. Aikenhead (Eds.), *STS education: International*

perspectives on reform (pp. 3-10). New York, Teachers College Press.

Solomon, J., Duveen, J., Scot, L., & McCarthy, S. (1992). Teaching about the nature

of science through history: Action research in the classroom. *Journal of Research in*

Science Teaching, 29(4), 409-421.

Song, Y. X. (1933). *Tian gong kai wu*. Shanghai, Commercial Press.

Splittgerber, F. (1991). Science-technology-society themes in social studies: Historical

perspectives. *Theory Into Practice,* 30(4), 242-250.

Stake, R. (1994). Case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of*

qualitative research (pp. 236-247). Thousand Oaks, CA: Sage Publications.

Temple, R. (1998). *The genius of China: 3,000 years of science, discovery, and*

invention. London: Prion Books.

Tiles, M., & Oberdiek, H. (1995). *Living in a technological culture: Human tools and*

human values. London & New York: Routledge.

Tsien, T. H. (1985). Paper and printing. In J. Needham (Ed.), *Science and civilization*

in China, Volume 5, Part I (pp. 1-485). Cambridge, Cambridge University Press.

Tuchman, G. (1994). Historical social science: Methodologies, methods, and

meanings. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research*

(pp. 306-323). Thousand Oaks, CA, Sage Publications.

Van Eijck, M., & Claxton, N. X. (2008). Rethinking the notion of technology in education: Techno-epistemology as a feature inherent to human praxis. *Science Education,* 93, 218-232.

Volti, R. (2001). *Society and technological change*. New York, Worth Publishers.

Yager, R. E. (1993). Science-technology-society as reform. *School Science and Mathematics*, 93(3), 145-151.

Wildson, L. P. D. S. (2009). Scientific literacy: A Freirean perspective as a radical view of humanistic science education. *Science Education,* 93(2), 361-382.

Xu, S. (1987). *Shuo wen jie zi*. Shanghai, Shanghai Ancient Books Press

Yager, R. E. (1996). History of science/technology/society as reform in the United States. In R. E. Yager (Ed.), *Science/technology/society as reform in science education* (pp. 3-15). Albany, NY, State University of New York Press.

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, 86(3), 343-367.

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education,* 89, 357-377.

Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing

reflective judgement through socioscientific issues. *Journal of Research in Science*

Teaching, 46(1), 74-101.

Ziman, J. (1976). *The force of knowledge: The scientific dimension of society*.

Cambridge, Cambridge University Press.

Ziman, J. (1980). Teaching and learning about science and society. Cambridge:

Cambridge University Press.

Ziman, J. (1994). The rationale of STS education is in the approach. In J. Solomon &

G. Aikenhead (Eds.), *STS education: International perspectives on reform* (pp. 47-59).

New York, Teachers College Press.

Zuga, K. F. (1996). STS promotes the rejoining of technology and science. In R. E.

Yager (Ed.), *Science/technology/society as reform in science education* (pp. 227-238).

Albany, NY, State University of New York Press.

Table 1. Summary of the S-T-S and T-S-S approaches

Dimension	Focus of STS education	
	S-T-S approach	T-S-S approach
Perspective	Contemporary, forward looking	Historical, retrospective
Nature of technology	Application of scientific knowledge in technology is emphasized.	Technology is seen as part of human culture that existed long before science.
Role of science	Instrumental for the development of new technologies that exert a profound impact on society	Impact on technology and society only in the past few centuries; instrumental for the evolution of ancient technology into its modern form
Role of technology	Mediates the impact of modern science on society, i.e. acting as a connector between science and society	Instrumental for the development of human civilization, particularly in the pre-science era; interacts dynamically with society and science to create outputs that are highly contextual and value-laden.
Role of Society	Reactionary to science-stimulated technology; tends to be science- and technology-determined	Society shapes technology through societal needs and social filters; society itself is shaped by technology; development co-determined by technology and society
Application to education	Focus on scientific concepts and relevant SSIs at the interface between science, technology and society (SSIs).	Focus on technology and technology-society interface in the beginning, then shifting the focus to the technology-science-society interface as technology evolved to its modern form; emphasise a holistic understanding of technology as it interacts with science and society
Relationship with other disciplines	Dominated by science	Interdisciplinary, integrating science, technology, history and social studies