RESEARCH INTO STS SCIENCE EDUCATION

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Science and technology education in schools has traditionally served an elite group of students (Driver et al., 1996; Fensham, 1992). Traditional school science attempts to socialize students into a scientific way of thinking and believing. Although only a small minority of students succeeds at developing a scientific worldview (Costa, 1995), educators are rewarded for having identified this academic elite group of students for the purpose of supplying university science and engineering programs. The other students who do not see themselves as future scientists and engineers are screened out. Generally, they do not embrace a scientific worldview. They do not think like a scientist. They do not *want to* think like a scientist. They experience school science as a foreign culture. They are outsiders to the school's pre-professional training in science.

This large majority of high school students responds well to science courses that promote practical utility, human values, and a connectedness with personal and societal issues, taught from a student-centered orientation (rather than the scientist-centered orientation found in traditional science courses). As future citizens, these students will experience science and technology in their everyday world as outsiders to professional science and technology. The goal for science education is to develop students' capacities to function as responsible savvy citizens in a world increasingly affected by science and technology. Thus students will need to understand the interactions between science-technology and their society.

This social need gave rise to the science-technology-society (STS) movement in science education (Solomon & Aikenhead, 1994; Yager, 1996; Ziman, 1980). Originally inspired by environmentalism and the sociology of science, STS school science first focused on values and social responsibility. Then a conceptual framework for STS was achieved through the integration of two broad academic fields: (1) the interactions of science and scientists with social issues and institutions *external* to the scientific community, and (2) the social interactions of scientists and their communal, epistemic, and ontological values *internal* to the scientific community.

The label "STS" changes from country to country and over time. Today there are a number of STS types of science curricula worldwide, for instance: "science-technology-citizenship" (Kolstø, 2001a; Solomon & Thomas, 1999), "nature-technology-society" (Andersson, 2000), "science for public understanding" (Eijkelhof & Kapteijn, 2000; Osborne et al., 2003), "citizen science" (Cross et al., 2000; Irwin, 1995; Jenkins, 1999), "functional scientific literacy" (Ryder, 2001), "public awareness of science" (Solomon, 2003b), variations on "science-technology-society-environment" (Dori & Tal, 2000; Hart, 1989), and "cross-cultural" school science (Aikenhead, 2000; Cajete, 1999). These STS types of science programs are often seen as vehicles for achieving such goals as "science for all" and "scientific literacy," and for improving the participation of marginalized students in school science.

Although the traditional vision of school science has been the status quo for many years, an STS type of vision of school science has experienced a renaissance since World War II (Jenkins, 2004; Solomon, 2003). As a result, a considerable amount of research has accumulated over the past 40 years that now provides solid evidence for understanding the educational needs of most students. This article synthesizes major findings of this research. I place the research findings in a practical context of the political realities faced by teachers and educators.

Research should inform our rational choices when we develop curriculum and instruction. Evidence-based decisions require us to consider what would likely be successful and useful for students in a typical classroom (i.e. educationally sound propositions). Politics, however, can force us to compromise our choices when we confront non-rational realities such as historical precedence, pressure from universities, directives from professional interest groups, and science teachers whose professional identities are at odds with an STS approach to school science. There is always a tension between *educational soundness* and *political reality*. This article explores this tension so we might better understand the choices we make and the compromises we think we must live with.

Major Failures of the Traditional Science Curriculum

An STS approach to science education arises from a particular vision of school science (described above) but is motivated by three major evidence-based failures of the traditional approach to teaching science: crises in student enrolment, myths conveyed to students, and a ubiquitous failure of school science content to have meaning for most students, especially outside of school. Each issue is examined in turn.

The first failure concerns the chronic decline in student enrolment due to students' disenchantment with school science, particularly for young women and students marginalized on the basis of their culture (Gardner, 1998; Hurd, 1991; Seymour & Hewitt, 1997). Low enrolments have reached crisis proportions in many countries (Frederick, 1991; Osborne & Collins, 2000). Evidence suggests that an STS perspective in a science curriculum can improve the recruitment of students (Campbell et al., 1994; Holton, 2003; Solomon, 1994).

A second and related major educational failure of the traditional science curriculum concerns the dishonest and mythical images about science and scientists that the curriculum conveys

(Aikenhead, 1973; Gaskell, 1992; Knain, 2001; Millar, 1989). As a consequence, some strong science students lose interest in taking further science classes, some students become interested in science for the wrong reasons, and many students become citizens (some in key positions in government and industry) who make decisions predicated on myths about the nature and social aspects of the scientific enterprise.

A third documented major failure dates back to the 1970s research into student learning: *most students tend not to learn science content meaningfully*, that is, they do not integrate it into their everyday thinking (Anderson & Helms, 2001; Hart, 2002; Osborne et al., 2003). Many research programs in science education have attempted in different ways to solve this lack of meaningful learning (Millar et al., 2000). However, even for students preparing for science-related careers, very few of them integrate the science curriculum content into their thinking in science-rich workplaces, no matter how successful they are at passing science courses (Cobern, 1993; Duggan & Gott, 2002; Lawrenz & Gray, 1995). Thus, a corpus of research suggests that learning canonical science content meaningfully is simply not achievable for the great majority of students in the context of traditional school science (Aikenhead, 2003; Shapiro, 2004).

But there is a political reality for many of these students. Even though they do not achieve a meaningful understanding of science content, they need to acquire science credentials to enter post secondary educational institutions. Their educational/political dilemma is easily solved when they learn how to pass science courses without achieving the meaningful understanding assumed by teachers and curriculum developers. This occurs when students (and some teachers) play “Fatima’s rules,” school games such as rote memorization and ingratiation (Aikenhead, 2000; Larson, 1995).

For the small minority of students who have a worldview in harmony with a scientific worldview, a meaningful understanding of canonical science is their goal. They are the elite who seldom play Fatima’s rules. STS science education, however, focuses on the needs of all students (science for all; Fensham, 1985). Research into those needs is summarized here, organized into the following topics: learning to use science in other (non-school) contexts, relevance, student learning, and teacher orientations.

Learning to Use Science in Other Contexts

Although the goal of meaningful learning is largely unattainable, it seems to be achieved to some degree in out-of-school contexts in which people are personally involved in a science/ technology-related everyday issue (Davidson & Schibeci, 2000; Dori & Tal, 2000; Layton et al., 1993; Wynne, 1991). Thirty-one different case studies of this type of research were reviewed by Ryder

(2001) who firmly concluded: *When people need to communicate with experts and/or take action, they usually learn the science content required*.

Even though people seem to learn science content as required, this learning is not often the canonical content transmitted from a traditional science curriculum. Research has produced one clear and consistent finding: *most often, canonical science content is not directly useable in science-related everyday situations*, for various reasons (Furnham, 1992; Hennessy, 1993; Layton, 1991; Solomon, 1984; Wynne, 1991). This research result can be explained by the discovery that canonical science content must be *transformed* (i.e. deconstructed and then reconstructed according to the idiosyncratic demands of the context) into knowledge very different in character from the canonical science in the typical science curriculum. This happens as one moves from canonical science content for explaining or describing, to practical content for taking action – "transformed science" or "citizen science" (Fourez, 1997; Irwin, 1995; Jenkins, 2002; Layton, 1991). When the science curriculum does not engage students in the difficult process of *transforming* abstract canonical content into content for taking action, canonical science remains unusable outside of school for most students (Layton, et al., 1993). And when students attempt to master unusable knowledge, most end up playing Fatima's rules.

A recurring evidence-based criticism of traditional school science has been its lack of relevance for the everyday world (Osborne & Collins, 2000; Reiss, 2000). The issue of relevance is at the heart of most STS science curriculum and instruction.

Relevance

Educational relevance always confronts political expediency in science classrooms. Educational relevance and political expediency can be addressed simultaneously by asking, "*Who* decides what is relevant?" (Fensham, 2000), rather than asking, "Relevant to whom?" or "Relevant to what?" The answer to the question "Who decides?" has received sufficient research attention to guide science curriculum policy makers towards an educationally sound alternative to traditional school science. I synthesize this research by using seven categories of relevant science (based on Fensham, 2000).

Wish-they-knew science is typically embraced by academic scientists, education officials, and many science educators when asked: What knowledge is of most worth? (Fensham, 1992; Walberg, 1991). The usual answer, canonical science content, prepares students for success in university programs. But exactly how relevant is this wish-they-knew content for success in first year university courses taken by science-proficient students? Research evidence suggests it is not as relevant as one might assume, and on occasion, not relevant at all (Aikenhead, 2003). For example, students who had studied STS chemistry in high school (*ChemCom*) achieved the same marks as students who graduated from traditional chemistry courses (including advanced-placement chemistry) when enrolled in a first-year university chemistry course designed for non-science majors (Mason, 1996). One conclusion is evident: although the *educational* arguments favoring wish-they-knew science are particularly weak, political realities favoring it are overwhelmingly strong (Fensham, 1993, 1998; Gaskell, 2003).

Need-to-know science is defined by the lay public who has faced a real-life decision related to science and technology (Layton et al., 1993; Ryder, 2001; Wynne, 1991). What science did they need to know? One reason that people tend not to use canonical science content in their everyday world (in addition to it not being directly useable, as described above) is quite simple: canonical science content is the wrong type of content to use in most socio-scientific settings. Need-to-know science (e.g. citizen science and knowledge about science and scientists; i.e. STS content) turns out to have greater practical value than canonical science content.

Functional science is deemed relevant primarily by people with occupations or careers in science-based industries and professions. Industry personnel surveyed by Coles (1997) placed "understanding science ideas" at the lowest priority for judging a recruit to a science-based workplace. By conducting ethnographic research on the job with science graduates, Duggan and Gott (2002) in the UK, Law (2002) in China, and Lottero-Perdue and Brickhouse (2002) in the US discovered that the canonical science content used by science graduates in the workplace was so context specific it had to be learned on the job, and that high school and university science content was rarely drawn upon. On the other hand, Duggan and Gott's (2002) data suggested that procedural understanding (i.e. the thinking directly related to doing science-like tasks) was essential across most science-related careers. More specifically Duggan and Gott discovered one domain of concepts, "concepts of evidence," that was applied by workers in all science-related occupations. An STS perspective is pertinent here because workers are concerned with the correct understanding of concepts of evidence and about the value judgments used when dealing with social implications, for instance: Is the scientific evidence good enough to warrant the industrial or social action proposed? In this context, it would be useful for workers and the lay public to understand the ways in which scientific evidence is technically and socially constructed (Bingle & Gaskell, 1994).

By its very nature, *enticed-to-know science* excels at its motivational value. This is science content encountered in the mass media and the internet, characterized by its quest to entice a reader or viewer to pay closer attention. Millar (2000) in the UK and Dimopoulos and Koulaidis (2003) in Greece described how their longitudinal analyses of their respective national newspapers identified the science and technology knowledge that would be most useful in making sense of these articles and the stories they presented. Moral issues and public risk are often associated with enticed-to-know science because the media normally attends to those aspects of events. The more important everyday events in which citizens encounter science and technology involve risk and environmental threats (Irwin, 1995).

Have-cause-to-know science is science content suggested by experts who interact with the general public on real-life matters pertaining to science and technology, and who know the problems the public encounters when dealing with these experts. In Law's (2002) study, her Chinese experts placed high value on a citizen's capability to undertake self-directed learning, but placed low value on a citizen knowing particular content from the traditional science curriculum, a result reminiscent of research related to functional science. Have-cause-to-know science is a feature of the Science Education for Public Understanding Project, SEPUP, in the US (Thier & Nagle, 1996). In the Netherlands, Eijkelhof (1990) used the Delphi research technique to gain a consensus among societal experts to establish the content for an STS physics module, "Ionizing Radiation;" while in the UK, Osborne and colleagues (2003) used the same technique to establish a consensus in the UK on what "ideas about science" (STS content) should be taught in school science.

For *personal-curiosity science*, students themselves decide on the topics of interest for school science, and relevance takes on a personal though perhaps idiosyncratic meaning because students' cultural self-identities are expressed (Brickhouse, 2001; Carlone, 2004; Häussler & Hoffmann, 2000; Reiss, 2000). Two unavoidable conclusions surfaced in this research: traditional science education played a meager to insignificant role in most of the students' personal lives; and school science will only engage students in meaningful learning to the extent to which the curriculum has personal value and enriches or strengthens students' cultural self-identities. Sjøberg (2000) surveyed over nine thousand 13-year-old students in 21 countries to learn about their past experiences related to science, their curiosity towards certain science topics, and their self-identity as a future scientist. Sjøberg (2005) recently initiated an extensive international study of personal-curiosity science, the Relevance of Science Education (ROSE) project.

A more holistic yet abstract concept of relevance for school science was advanced by Weinstein's (1998) research; a concept he called *science-as-culture*. He identified a network of communities (webs of scientific practice) in students' everyday lives (e.g. health systems, political systems, and environmental groups). Each community network interacts with science professionals, resulting in a cultural *commonsense notion of science*. As a category of relevance, science-as-culture serves in part as a super ordinate category to the need-to-know, functional, enticed-to-know, have-cause-to-know, and personal-curiosity science categories. Science-as-culture can also be found in some project-based learning in which local, science-related, real-life problems are addressed by students in an interdisciplinary way (e.g. Calabrese Barton & Yang, 2000; Roth & Désautels, 2004) and in a cross-cultural way (e.g. Aikenhead, 2002).

In conclusion, the research on relevance reviewed here unequivocally points to the need to learn scientific and technological knowledge *as required*. Thus, a clear curriculum policy can be proposed: a central goal of an STS science curriculum should be to teach students *how to learn* science and technology canonical content as required by the contexts that students find themselves in (Jenkins, 2002). To prepare students for the diverse world of citizenship or science-related occupations, it would not seem to matter what science content is placed in the curriculum, as long as it enhances students' capability *to learn how to learn* science content within a relevant context. The selection criteria, which were suggested by the research on relevance reviewed above in the seven categories of relevance, allow us to achieve the goal "to learn how to learn science content" equally well as the status quo criterion "prerequisite coherence with first-year university courses." An STS curriculum policy based on learning how to learn will produce a much different science curriculum than a policy based on screening students through pre-university course content. These two curriculum policies define the difference between science for all and science for the elite.

Ideologies inherent in any science curriculum can be categorized in terms of two fundamentally different presuppositions of school science (Aikenhead, 2000; Weinstein, 1998): (1) the enculturation of students into their *local, national, and global communities*, communities increasingly influenced by advances in science and technology, and (2) the enculturation of students into the *disciplines of science*. Science educators must choose between the two types of enculturation. Cultural relevance favors the former position for most students because from their point of view, relevance concerns the degree to which curriculum content and classroom experiences speak to the students' cultural self-identities (Brickhouse, 2001; Carlone, 2004; Reiss, 2000).

Research clearly suggests that any science curriculum, either STS or purely scientific, dedicated to the enculturation of all students into scientific ways of thinking will constantly be undermined by students and teachers playing Fatima's rules.

Student Learning

What students learn, whether planned or unplanned, is given high priority in arguments concerning educational soundness (Gaskell, 1994). As is evident throughout this article, an STS science curriculum has various interconnected outcomes: (1) to make the human and cultural aspects of science and technology more accessible and relevant to students (e.g. the sociology, philosophy, and history of science, as well as its interrelationships with society); (2) to help students become better critical thinkers, creative problem solvers, and especially better decision makers, in a science-related everyday context; (3) to increase students' capabilities to communicate and be self-assertive with the scientific community or its spokespersons (i.e. listen, read, respond, etc.); (4) to augment students' commitment to social responsibility; and (5) to generate interest in, and therefore, increase achievement in learning how to learn canonical science content found in the science curriculum.

Research into student learning (Aikenhead, 2003) is summarized here in the following sequence: the canonical science content acquired, assessment in quasi-experimental studies and other investigations, and student decision making.

Science Content Acquired

As mentioned above, there are several reasons to explain the difficulty most students have when trying to learn canonical science content meaningfully in the context of school science. Researchers once felt that these difficulties might be overcome by placing this content in a context that emotionally connected with a student's world, particularly a student's cultural self-identity. A considerable amount of research has consistently yielded one of two outcomes. This first is a neutral outcome. Based on standardized achievement tests of canonical science, there was no significant effect on students' scores when instruction time for the canonical content was reduced to make room for the history of science, the nature of science, or the social aspects of science (e.g. Eijkelhof & Lijnse, 1988; Irwin, 2000; Klopfer & Cooley, 1963; Welch, 1973). Thus, there would seem to be little educational advantage for a teacher "to cover" the entire canonical science curriculum but instead, greater advantage to teaching fewer canonical science concepts chosen because of their relevance to an STS perspective (Eijkelhof, 1990; Kortland, 2001; Häussler & Hoffmann, 2000).

A second research outcome was discovered. On occasion, students in STS science courses appeared to fair *significantly better* on achievement tests of canonical science than their counterparts in traditional courses (e.g. Carlone, 2004; Häussler & Hoffmann, 2000; Mbajiorgu & Ali, 2003; Solomon et al., 1992; Yager & Tamir, 1983).

Assessment Studies

There are now a wide variety of research instruments and techniques (both quantitative and qualitative) with which to assess students' acquisition of STS content taught in science courses (Aikenhead, 2003; Manassero-Mas et al., 2001; Manassero-Mas & Vázquez-Alonso, 1998; Vázquez-Alonso & Manassero-Mas, 1999). By using these instruments and techniques, assessment studies have been able to document the following claims:

- Students in STS science classes (compared with traditional classes) can significantly improve their understanding of social issues both external and internal to science, and of the interactions among science, technology, and society; but this achievement depends on what content is emphasized and evaluated by the teacher. The teacher makes the difference.
- Students in STS science classes (compared with traditional classes) can significantly improve their attitudes towards science, towards science classes, and towards learning, as a result of learning STS content.
- Students in STS science classes (compared with traditional classes) can make modest but significant gains in thinking skills such as applying canonical science content to everyday events, critical and creative thinking, and decision making, as long as these skills are explicitly practiced and evaluated in the classroom.
- Students can benefit from studying science from an STS perspective provided that: the STS content is integrated with canonical science content in a purposeful, educationally sound way; appropriate classroom materials are available; and a teacher's orientation towards school science is in reasonable synchrony with an STS perspective.
- Some students can enhance their socially responsible actions when taught by certain teachers.

In addition, researchers found that even though STS content made intuitive sense to many students, the students still required guidance from their teacher on how to apply their intuitive knowledge to a particular event.

Students' ability to interpret the news media is another expectation of most STS curricula. Ratcliffe (1999), for instance, investigated the evaluation reports (critiquing science articles in the *New Scientist*) written by three groups: school students (11 to 14 year-olds), college science students (17 year-olds), and science baccalaureate graduates (22 to 35 year-olds). Although the skills increased with formal training, years of experience, and self-selection into science, as one would expect, Ratcliffe discovered that the skills of evidence evaluation (a component of "functional science;" i.e. concepts of evidence) were evident across all three populations, and she suggested that these abilities could be developed further through explicit teaching methods.

The impact of history of science materials was investigated by Solomon et al. (1992) in an 18-month action research project. Interestingly, students' facile, media-icon, image of scientists were *not replaced by* realistic images developed through learning the STS content, but instead, realistic images were *added to* these preconceptions in students minds (i.e. concept proliferation rather than concept replacement). From a student's point of view, learning means they now have a choice between two images, and the choice depends on the context. This result has major implications for the importance of context in the assessment of student learning.

Decision Making

The wise use of knowledge in making decisions enables people to assume social responsibilities expected of attentive citizens or key decision makers employed in public service or business and industry. Thus, decision making is often at the center of an STS science curriculum, and it serves as a classroom vehicle to transport students into their everyday world of: need-to-know science, functional science, enticed-to-know science, have-cause-to-know science, personal-curiosity science, and culture-as-science. Generally the classroom objective is to create a sound simulation of an everyday event (e.g. Kolstø, 2001b; Kortland, 2001; Ratcliffe, 1997), although this approach has been criticized for not being authentic enough (Roth & Désautels, 2004). Decision making necessarily encompasses a wide scope of other types of knowledge: always values and personal knowledge, and often technology, ethics, civics, politics, the law, economics, public policy, etc. (Jiménez-Aleizandre & Pereiro-Muñoz, 2002; Kolstø, 2001a). In research into conflicting testimonies of scientific experts on science-related controversial issues, for instance, even the scientific technical information itself was found to carry political-ideological baggage (i.e. values).

Besides students making moderate gains in their decision-making skills, perhaps the most pervasive result from the research into student decision making is the priority students gave to values over scientific evidence. This result may be due to the fact that values *are* more important in our culture when making a decision on most socio-scientific issues, even for science teachers and scientists themselves. Bell and Lederman (2003), for instance, investigated how 21 university research scientists made socio-scientific decisions (e.g. fetal tissue implantations, global warming, and smoking and cancer). Using questionnaires and telephone interviews, the researchers concluded that all participants considered the scientific evidence, but they "based their decisions primarily on personal values, morals/ethics, and social concerns" (p. 352). Should students be any different?

In Brazil, dos Santos (2004) conducted research into the effect of student discussions on socio-scientific issues in classrooms using the STS textbooks *Chemistry and Society* (*Química & Sociedade*, módulo 1 & 2; dos Santo et al., 2003). These discussions were shown to improve the classroom interaction between the teacher and his students.

In summary, the research literature is unambiguous concerning the positive outcomes in student learning in STS science classrooms. These students learn traditional science content as well as, or better than, students in traditional courses. At the same time, students in STS courses make significant gains on some STS content and modest gains on complex STS objectives such as thoughtful decision making. Therefore, we can conclude that STS approaches to school science are educationally sound.

Researchers who observed experimental STS classrooms consistently remarked on the students' heightened interest in school science, an outcome that some predicted would have a positive effect on their teacher's orientation to STS approaches to teaching science and technology (e.g. Osborne et al., 2003).

Teacher Orientations

Political reality, in the form of science teachers' orientations toward STS school science, has undergone extensive research. These findings are almost as negative as those concerning students achieving a meaningful understanding of canonical science.

Teachers construct their own meaning of any curriculum as they negotiate an orientation towards it and decide what to implement, if anything, in their classroom. Over the years, researchers have studied teachers' rejection, acceptance, and idiosyncratic modulation of an intended STS science curriculum. Several general conclusions about teachers' orientations can be drawn from this literature. First, a small proportion of science teachers are always supportive of an STS science curriculum. Thus, there will always be a few science teachers who teach from an STS point of view (humanistic science teachers), and who gladly volunteer for any research study, R&D project, or action research that promises to enhance their STS orientation. Similarly there will be a nucleus of teachers committed to pre-professional training and screening students for university entrance (tradition enthusiasts). These teachers resist and some actively undermine any STS innovation in school science. There exists a third group of science teachers who can be persuaded to move in either direction for a variety of different reasons (middle-of-the-road teachers). All three types of teachers are found in studies reported in the research literature.

Challenges to Curriculum Change

Normally science teachers are attracted to, and socialized into, specific scientific disciplines in university programs where teachers are certified to be loyal gatekeepers and spokespersons for science; and in return they enjoy high professional status and a self-identity associated with the scientific community. As substantiated by years of research, a teacher's values, assumptions, beliefs, ideologies, professional self-identity, status, and loyalties must be in harmony, more or less, with an STS approach to science education before a teacher will teach an STS curriculum. Changing any one of these influences on a teacher's orientation is very difficult for most middle-of-the-road teachers, and is usually impossible for tradition enthusiasts (e.g.; Kortland, 2001; Osborne et al., 2003; Sáez & Carretero, 2002). Taken together this cluster of salient influences has been referred to by some researchers as "the culture of school science."

When asked by researchers if teaching from an STS perspective is a good idea (terms such as "socially relevant" are actually used), most science teachers (about 90%) overwhelmingly endorse it. Yet when asked to implement such a curriculum, teachers provide many reasons for not doing so. These reasons are listed here but in no particular order of importance because their presence and priority change from study to study: lack of teaching materials (although when they are provided, other reasons surface); unfamiliarity with student-centered, transactional, teaching and assessment methods (e.g. group work or divergent-thinking); greater than normal emphasis on oral and written language, and the complexity caused by combining everyday and scientific genres; lack of confidence with integrated content; fear of losing control over the class (e.g. open-ended activities and unpredictable outcomes – teachable moments); uncertainty about a teacher's role in the classroom (e.g. facilitator) in spite of attending in-service workshops; a reliance on a single national textbook that contains little or no STS content; an unease with handling controversial issues, or even group discussions of a social or ethical nature; uncertainties over assessing students on "subjective" content; inadequate background knowledge and experiences (i.e. pre-service teacher education programs); no opportunity to work with an experienced competent teacher or with scientists in industry; lack of school budget to support the innovation; lack of administrative or colleagues' support; lack of parental or community support; no clear idea what the STS innovation means conceptually or operationally; predictions that students will not appreciate or enjoy philosophical, historical and policy issues in a science class (e.g. "students want to light Bunsen burners and get the right answer"); a preoccupation with preparing students for high-stake examinations and success at university; pressure from university science departments to raise standards and cover more content in greater depth; an unease over the reduced time devoted to canonical science content and to covering the traditional curriculum; pressure to comply with state content standards defined by the current US reform movement; identifying oneself with scientists (e.g. lecturer expert) rather than with educators; the fact that non-elite and low achieving students enroll in STS science courses; greater need for cultural sensitivity with some STS topics such as social justice in the use of science and technology; and beginning teachers' survival mode discourages them from taking seriously STS ideas developed in their teacher education courses (Aikenhead, 2003). One is faced with an inescapable conclusion: *there are daunting challenges to educators wishing to change the traditional science curriculum into an STS one*.

Success at Implementation

Successful implementation of STS science teaching has occurred under favorable circumstances. Success seemed to be associated with teaching grades 7 to 10 rather than higher grades, perhaps because teachers were not confronted as much with the litany of obstacles to implementation listed above. Action research studies have been consistently successful (e.g. Keiny, 1993), perhaps because of their relatively high proportion of human resources for the participating teachers and the relatively high proportion of eager participants (humanistic science teachers).

Research has identified the following favorable circumstances: involvement of teachers in policy and curriculum development; involvement of teachers in producing classroom materials; establishment of supportive networks of teachers that included teachers experienced with STS science teaching who take leadership roles; a predisposition towards exploring new avenues of pedagogy and student assessment; a willingness to deal with degrees of uncertainty in the classroom; a substantial in-service program offered over a long period of time, coordinated with pre-service methods courses and student teaching where possible; teacher reflection via diaries or journals and via discussion; a recognition of the rewards from becoming socially responsible in their community, from enhancing their curriculum development and writing skills, and from improving their vision of science teaching; a responsive and caring project staff to provide the top-down guidance for achieving a balance with grass-roots initiatives; contact with working scientists who convey intellectual, moral, and political support; an openness to evidence-based decisions founded on formative assessment and classroom experiences; and a focus on individual, autonomous, professional development into becoming, for example, a continuous learner rather than a source of all knowledge (Aikenhead, 2003).

By way of an example, one in-depth research study offered insight into features of middle-of-the-road teachers who composed and taught STS science lessons in spite of a lack of curriculum materials. Bartholomew and colleagues (2004) in the UK followed and supported 11 volunteer teachers who were interested in implementing the UK national science curriculum's "ideas about science," specific ideas empirically derived from a large Delphi study (mentioned earlier in this article; Osborne et al., 2003). The researchers were interested in "what it *means* to integrate teaching about the nature of science, its practices and its processes, with the body of canonical content knowledge in a way which reinforces and adds to the teaching of both" (p. 11, original emphasis). The researchers identified five "dimensions of practice." Each dimension consisted of two extreme orientations that characterize the less successful and more successful teachers (respectively):

1. Teachers' knowledge and understanding of STS content:

from "anxious about their understanding" to "confident that they have a sufficient understanding."

2. Teachers' conceptions of their own role:
   from "dispenser of knowledge" to "facilitator of learning."
3. Teachers' use of discourse:
   from "closed and authoritative" to "open and dialogic."
4. Teachers' conception of learning goals:
   from "limited to knowledge gains" to "includes the development of reasoning skills."
5. The nature of classroom activities:
   from "student activities are contrived and inauthentic" to "activities are authentic and owned by students."

These dimensions are not mutually independent. They do help, however, to locate teachers' orientations to an STS perspective, more so than vague feelings of comfort or discomfort usually reported in the research literature.

Success at changing a science curriculum is possible for some teachers under supportive circumstances, with most but not all students (i.e. not those who would benefit from the privilege of an elitist orientation to school science). The importance of the role of students in curriculum change was a finding to emerge from this research literature as well.

Pre-Service Experiences

As with in-service studies, research into pre-service science teachers' orientation to an STS perspective did not find encouraging results. Pre-service teachers have loyalties and self-identities recently established in their university science programs. Researchers who followed these teacher education students into their practice teaching found that little or no STS instruction occurred, in spite of the students' grasp of, and commitment to, this content. Some researchers concluded that these pre-service teachers mimicked the pure content orientation of their recent university science classes. David (2003) and Schwartz and Lederman (2002) discovered a different reason to explain the reluctance of pre-service teachers to include STS content in their lessons: novice teachers naturally lack confidence in teaching canonical science content, and until a reasonable confidence can be attained, other instructional outcomes are relegated to a low priority.

Background knowledge of STS content seems to exert an influence in some pre-service settings, but not in all; especially when apprentices are placed in an unsupportive school setting. It turns out that school politics have a far greater effect on a student teacher's professional identity than our educationally sound university methods classes. Educational soundness bows to political reality.

School Politics

The challenge of implementing change within a single classroom is one issue. How a teacher's colleagues, administration, and parents react to the change is quite another issue. Recent in-depth research into school politics is both insightful and discouraging (e.g. Carlone, 2003). Science education always occurs within the context of a school's culture. One way in which research has articulated an understanding of that culture is through an analysis of "actor-networks," teacher loyalties, and cultural self-identities with respect to the status quo (Carlone, 2003; Gaskell, 2003; Gaskell & Hepburn, 1998). A large-scale implementation of an STS science curriculum requires an actor-network larger than one or two teachers (Hughes, 2000). Political reality dictates that an expanded actor-network would need to be formed in concert with socially powerful groups to support change at the school culture level. Science teachers must renegotiate the culture of their school science (Aikenhead, 2000).

Conclusion

An STS approach to science education aims to develop a student-centered orientation that animates students' cultural self-identities, their future contributions to society as citizens, and their interest in making personal utilitarian meaning of scientific and technological knowledge.

Is STS science education credible? The research literature presents us with two clear answers: educationally it is unmistakably credible, but politically it is not. Therefore, all future innovative STS projects will need to incorporate both an educational and political component if innovators are to make a significant difference to what happens in a science classroom.

Future development of STS science education will need to avoid some of the limitations of past projects, such as their small size and their lack of collaboration with teachers *and* students. As an alternative to small-scale studies, developers can engage a whole school jurisdiction through enacting larger-scale projects (Elmore, 2003). However, a change from a traditional curriculum to an STS science curriculum may require even a broader context than just a school system. Significant change requires a multi-dimensional context of scale that includes diverse stakeholders of social privilege and power, over a long period of time (Sjøberg, 2002). Successful collaboration requires new partnerships among educators, researchers, and stakeholders, forging new actor-networks in support of STS science education.

The largest obstacle to changing the curriculum is change itself. Change is well-known to the scientific community because scientists shift paradigms from time to time, but not without difficulty. I predict that the time is now ripe for science educators to shift from a traditional paradigm to an STS paradigm for school science, in order to ensure educational excellence and relevance for all students.

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