Beyond STS: A Research-Based Framework for Socioscientific Issues Education

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ABSTRACT: An important distinction can be made between the science, technology, and society (STS) movement of past years and the domain of socioscientific issues (SSI). STS education as typically practiced does not seem embedded in a coherent developmental or sociological framework that explicitly considers the psychological and epistemological growth of the child, nor the development of character or virtue. In contrast, the SSI movement focuses on empowering students to consider how science-based issues reflect, in part, moral principles and elements of virtue that encompass their own lives, as well as the physical and social world around them. The focus of this paper is to describe a research-based framework of current research and practice that identifies factors associated with reasoning about socioscientific issues and provide a working model that illustrates theoretical and conceptual links among key psychological, sociological, and developmental factors central to SSI and science education. © 2005 Wiley Periodicals, Inc. Sci Ed 89:357–377, 2005

INTRODUCTION

As the 21st century unfolds, professional associations (e.g., American Association for the Advancement of Science, 1989, 1993; National Science Education Standards, 1996; CMEC’s Pan-Canadian Science Project, 1997; Queensland School Curriculum Council, 2001) in science recognize the importance of broadly conceptualizing scientific literacy

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to include informed decision making; the ability to analyze, synthesize, and evaluate information; dealing sensibly with moral reasoning and ethical issues; and understanding connections inherent among socioscientific issues (SSI) (Zeidler, 2001). Achieving a practical degree of scientific literacy necessarily entails practice and experience in developing habits of mind (i.e., acquiring skepticism, maintaining open-mindedness, evoking critical thinking, recognizing multiple forms of inquiry, accepting ambiguity, searching for data-driven knowledge). Habits of mind may suffice when arriving at individual decisions based on an informed analysis of available information; however, they may not be sufficient in a world where collective decision making is evoked through the joint construction of social knowledge. In the real world of dirty sinks and messy reasoning, arriving at ideal personal decisions through objective evaluation of neutral evidence is a phantom image.

It is clear from recent international research in science education that current reform initiatives in our field demand increased emphasis on the nature of science (NOS) and scientific inquiry, as well as development of broad conceptual frameworks encompassing progressive visions of scientific literacy that entail a commitment to the moral and ethical dimensions of science education—including the social and character development of children (Zeidler & Keefer, 2003). In particular, students are expected to develop an understanding of the epistemology of scientific knowledge as well as the processes/methods used to develop such knowledge. In addition to other considerations, it is believed that students’ understanding of science as a “way of knowing” is absolutely necessary if informed decisions are to be made regarding the scientifically based personal and societal issues that increasingly confront our students. Such decisions necessarily involve careful evaluation of scientific claims by discerning connections among evidence, inferences, and conclusions. Students capable of such decisions display a functional degree of scientific literacy.

The focus of this paper is to provide a synopsis of current research and practice that identifies factors associated with reasoning about SSI and distinguishes it from science–technology–society (STS) education. While the study of SSI is conceptually related to past research on STS education, it is important to point out that they represent unique approaches. STS education, as typically envisioned and practiced, does not seem to be embedded in a coherent developmental or sociological framework that explicitly considers the psychological and epistemological growth of the child, nor the development of character or virtue. The lack of a theoretical framework with respect to STS materials has been noted by others (Hodson, 2003; Jenkins, 2002; Shamos, 1995), suggesting that STS may be an underdeveloped idea in search of a theory. Because we suggest substantial reconsideration of the use of the STS approach, it is important to consider limitations identified with STS education; therefore, we do so in the following section.

PROBLEMS WITH STS EDUCATION

By the late 1970s, many science education researchers became focused on developing a theme of study that reflected the combined influences of science, technology, and society. It was agreed that science would become more meaningful to students when placed in the context of how it affects technology and how technology, in turn, directs society. In science, technology, and society (STS) education, science teachers use curricula that engage students due to their social dimensions. Aikenhead (1994) summarized STS teaching as follows:

STS science teaching conveys the image of socially constructed knowledge. Its student-oriented approach... emphasizes the basic facts, skills, and concepts of traditional science... but does so by integrating that science content into social and technological contexts meaningful to students. (p. 59)
In 1982, the National Science Teachers Association (NSTA) published a position paper describing characteristics of a scientifically literate person as one who would understand and be knowledgeable of the connections and interdependency of science, technology, and society (NSTA, 1982). This shift in emphasis was solidified with the publication of the NSTA 1985 Yearbook, which was devoted to STS teaching (Bybee, 1985). Unfortunately, STS education has become relatively diffuse over the course of its tenure, consisting of approaches as disparate as isolated courses addressing STS issues or ancillary text boxes in science textbooks (Pedretti & Hodson, 1995). Shamos (1995) noted, quite correctly, that the problem with STS curriculum is that many of the issues under study (e.g., nuclear power, global warming) are not particularly exciting or relevant to students because they are removed from their everyday personal experiences. While STS education typically stresses the impact of decisions in science and technology on society, it does not mandate explicit attention to the ethical issues contained within choices about means and ends, nor does it consider the moral or character development of students.

Recently, some science educators have advocated a more issues-driven STS curriculum in the form of science–technology–society–environment education (STSE) (Hodson, 1994, 2003; Pedretti, 1997). It has become clear, however, that while STSE represents an improvement over STS strategies, it does not directly address the personal and individual moral and ethical development of students and it is fair to say that most science educators do not see the subtle distinctions between them. Traditional STS(E) education (or perhaps STS(E) education as currently practiced by and large) only “points out” 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. Hence, STS(E) approaches have become somewhat marginalized in the curriculum and in practice. What was once described as a megatrend in science education (Roy, 1984) has been relegated to brief mentions in current school science textbooks as well as in science teacher preparation texts (see, e.g., Chiapetta & Koballa, 2002; Trowbridge, Bybee, & Powell, 2000). This decline in emphasis in STS(E) education is part of a striking paradox, for the commitment to the inextricable connections between science, technology, society and the environment remains a major theme in current science reform documents such as the United States National Science Education Standards and Project 2061’s Benchmarks for Science Literacy.

One likely reason for the recent decline in interest in STS(E) may be a lack of focus or well-developed unifying theoretical basis. Even staunch supporters of STS have acknowledged the absence of a coherent and cohesive framework for STS. Consider the following statements regarding STS:

In this essay I have suggested that science, technology, society (STS) consists of several seemingly competing, if not conflicting perspectives because they relate to different notions of power, policy, and method. Nevertheless, the perspectives can be combined. Combining the perspectives does not mean however that we create a unitary approach of STS. What I intend is rather a pluralistic and open approach. To open the doors among the different perspectives is a major challenge for STS which may also require a thorough deliberation of the different related policy interests. (Fuglsang, 2001, p. 46)

Ziman, another ardent proponent of STS education, writes, “The fundamental purposes of STS education are genuinely and properly diverse and incoherent” (1994, p. 22). Although these candid admissions of the considerable difficulties in both describing the purposes of STS and melding the myriad STS factions could be interpreted as assertions merely acknowledging the complexity of STS, we suggest that the reported pluralism and incoherence
support the claim that STS is incomplete or underdeveloped as a pedagogical strategy. Instead, STS is a “context for a curriculum.” (Yager, 1996, p. 13)

Hughes (2000) has provided a post-modern analysis of reform curriculum and identified several reasons why three decades of STS education is out of touch with students, leaving them ill prepared to deal with scientific and technological controversy. Her central argument is that STS marginalizes socioscientific material and reinforces gender gaps because of how science is embedded in a masculine “hard” science perspective at the exclusion of “softer” socioscience orientations that allow for contextualized examination of issues and values implicit in scientific development.

...when socioscience is the icing on the cake, not an essential basic ingredient, part of a good-quality product but not fundamental to teaching science, dominant discourses of science as an abstract body of knowledge are not destabilized and implicit gender hierarchical binaries are readily reinforced. (Hughes, 2000, p. 347)

Similarly, Bingle and Gaskell (1994) have further noted that much of STS education, as practiced, is most closely aligned with Latour’s (1987) notion of “ready-made science” that carries with it the connotation of positivist knowledge claims at the expense of constitutive values that stress “science-in-the-making” and suggests a social constructivist view of contextual values for evaluating scientific knowledge claims. These authors stress that where SSI arise, it is legitimate for individual citizens to acknowledge and evaluate contextual factors deemed meaningful with respect to the scientific claims under consideration: “A social constructivist view of science... challenges the scientists’ position of privilege because individual citizens have just as much access to the standards of evaluating the impact of the social context as do scientists themselves, a prospect that would probably be unsettling to most scientists” (Bingle & Gaskell, 1994, p. 198).

Whereas the overarching purpose of the STS approach is to increase student interest in science by placing science content learning in a societal context, SSI education aims to stimulate and promote individual intellectual development in morality and ethics as well as awareness of the interdependence between science and society. SSI therefore does not simply serve as a context for learning science, but rather as a pedagogical strategy with clearly defined goals. Certainly, knowledge and understanding of the interconnections among science, technology, society, and the environment are major components of developing scientific literacy; however, these interconnections do not exist independently of students’ personal beliefs. It is our stance that STS(E) approaches can be remodeled and substantially improved by adding an essential missing component—consideration of each student’s own moral and ethical development.

BEYOND STS: PRESUPPOSITIONS OF THE SSI DOMAIN

While STS has been defined as a context for science education (Yager, 1996), the current usage of “socioscientific issues” refers to a distinctly more developed pedagogical strategy. In contrast to STS, the SSI movement focuses specifically on empowering students to consider how science-based issues and the decisions made concerning them reflect, in part, the moral principles and qualities of virtue that encompass their own lives, as well as the physical and social world around them (Driver et al., 1996; Driver, Newton, & Osborne, 2000; Kolstø, 2001a; Sadler, 2004). Accordingly, SSI education is equated with the consideration of ethical issues and construction of moral judgments about scientific topics via social interaction and discourse. As Zeidler et al. (2002) point out, “Socioscientific issues then, is a broader term that subsumes all that STS has to offer, while also considering...
the ethical dimensions of science, the moral reasoning of the child, and the emotional
development of the student” (p. 344). Further, recent research (Zeidler & Keefer, 2003) in
the area of SSI has provided theoretical and conceptual links among key psychological,
sociological, and developmental factors associated with SSI education. We envision SSI
in a manner that considers how controversial scientific issues and dilemmas affect the
intellectual growth of individuals in both personal and societal domains.

In order to advance the claim that science educators should attend to SSI related to cul-
tivating the morality of our students to achieve a “functional” view of scientific literacy,
a coherent conceptual framework must be developed that is flexible enough to allow for
multiple perspectives while enabling educators and curriculum specialists to better under-
stand the moral growth of the child. One framework recently proposed because of its utility
in addressing socioscientific discourse in terms of the psychological, social, and emotive
growth of the child is derived from a cognitive-moral reasoning perspective (Zeidler &
Keefer, 2003). This initial model served as an impetus for our article by identifying potential
lines of research that might prove promising in the development of an SSI framework.
We have now further extended and refined that model with new research from within the
science education community and related research external to science education. It consists
of themes that collectively attend to many of the factors inherently limited by or missing
from STS education. This framework should be viewed as a tentative conceptual model that
identifies four areas of pedagogical importance central to the teaching of SSI: (1) nature of
science issues, (2) classroom discourse issues, (3) cultural issues, and (4) case-based issues.
These issues can be thought of as entry points in the science curriculum that can contribute
to a student’s personal intellectual development and in turn, help to inform pedagogy in
science education to promote functional scientific literacy (see Figure 1).

Figure 1. Socioscientific elements of functional scientific literacy.
It should be noted that while our view of cognitive and moral development is conceptualized, in part, from a neo-Kohlbergian perspective, it does not preclude (and in fact, invites) the use of post-modern perspectives of developmental reasoning (e.g., see Hughes, 2000). While these issues certainly cannot comprise all the sufficient conditions of scientific literacy (functional or otherwise), we suggest that these are critical and necessary issues for science educators to grapple with in order to promote functional scientific literacy. For example, NOS issues become important because they reveal how varied epistemological views influence the way in which students select and evaluate evidence, and are considered to have bearing on their pre-instructional views of SSI. Discourse issues direct our attention to how students construct arguments and utilize fallacious reasoning, and compel us to consider how prior belief convictions help frame emotional responses, principled commitments, or stances on moral issues. Cultural issues remind us that discourse is futile without mutual respect and tolerance of dissenting views, while underscoring that the decisions students make are the result of realizing that as moral agents, they are impacted by normative values as well as cultural beliefs about the natural world. Case-based issues enable science educators to move beyond STS curriculum and cultivate habits of mind that promote ethical awareness and commitment to issue resolution and the moral sensitivity to hear dissenting voices by examining how power and authority are embedded in scientific enterprises.

Other authors use the term “functional” when speaking of scientific literacy (Jenkins, 1990, 1997; Ryder, 2001; Shamos, 1995); however, it is important to note that they tend to do so from what can be described as a technocratic perspective. For example, Ryder (2001) presents an analysis of some 31 studies ranging in degree of technocratic decision making on controversial topics (in that there is a lack of clear consensus within the scientific community about data related to these topics). These topics range from risk assessment in genetic counseling situations to managing methane from a waste disposal site. The authors do acknowledge that the studies selected for review are not necessarily representative of the many contexts of science, and the examples tend to focus on arguments based on utility in a democratic and technologically sophisticated society. While it cannot be denied that these aspects of science are important because of their inherent connections to NOS (e.g., understanding the role of models in science, assessing the validity and quality of data, and uncertainty in science), we believe that this view is too narrow with regard to promoting functional scientific literacy in that it pays scant attention to the role of personal epistemological and intellectual development in the context of varied cultural settings. For Shamos (1995), functional scientific literacy seems to be relegated to those who are the science elite having the expert content knowledge to fully appreciate the scientific and technological intricacies of issues (thereby achieving “true scientific literacy”) and have more than a general sense of Hirsch’s (1987) notion of “cultural literacy” (i.e., general scientific terms familiar to citizens in western society). An individual who possesses functional scientific literacy for Shamos, therefore, is one who has “command of a science lexicon, [and] also be able to converse, read, and write coherently, using such science terms in perhaps a non-technical but nevertheless meaningful context” (1995, p. 88). In a comprehensive review of the literature, Laugksch (2000) points out that such conceptualizations of functional scientific literacy are embedded in a meaning of literate that “require[s] the scientifically literate individual to use science in performing a function (italics added) in society” (p. 84). Again, our view of functional scientific literacy affirms what the views above do not; that any view of functional scientific literacy falls short of the mark if it ignores the fundamental factors aimed at promoting the personal cognitive and moral development of students.

Although Kohlberg (1986) provided educators and researchers interested in the area of moral reasoning and development with a rich conceptual basis to raise important questions about the nature of moral education, new questions have emerged about the adequacy of
the assumption that all one has to do to bring about changes in moral behavior is to induce changes in moral stages or structures. Furthermore, new questions have also emerged about the distinction between reasoning about formal societal constructs (e.g., laws, duty, social institutions) and engaging in the resolution of differences among individuals via argumentation and discussion during face-to-face interactions. The former type of reasoning deals with what Rest et al. (1999) term “macromorality,” while the latter deals with issues of “micromorality.” The difference can be likened to examining societal conventions from a theoretical perspective (e.g., principles of justice, meta-ethics) and understanding a particular praxis of social constructs (e.g., face-to-face negotiations, normative ethics). Once this distinction is made, it exposes a more robust conceptualization of the complex relationship that exists between moral reasoning and action and has implications for decisions related to pedagogy. For example, researchers point out that the role of affect and emotions in moral functioning had been overlooked in past research, and that the particular realm of one’s life being considered (e.g., family, school, peers, workplace, intimate relationships) plays a normative role in moral decision making and character formation (Berkowitz, 1997, 1998; Nucci, 1989, 2001; Sadler & Zeidler, 2004; Turiel, 1998; Zeidler & Schafer, 1984, Zeidler et al., 2002).

THEMATIC AREAS OF RECENT RESEARCH CONNECTED TO SSI

An overview of the four pedagogical issues (nature of science, classroom discourse, cultural, and case based) identified above is presented in order to synthesize current lines of research relevant to the exploration of SSI in science education and further articulate a research-based model of issues central to moral education in the context of science education. The purpose is to provide educators and researchers with a thematic understanding of how these areas are at once fundamental and interdependent, and when linked through the exploration of the domains of SSI, address morality.

(1) **Nature of Science Issues** reveal the emphasis placed on students’ epistemological beliefs as they pertain to decisions regarding SSI (e.g., Bell, 2004; Bell, Lederman, & Abd-El-Khalick, 2000). Epistemological orientations regarding the nature of science influence how students attend to evidence in support of, or in conflict with, their pre-instructional belief systems regarding social issues. In this context, moral reasoning proper is understood to be the result of the opportunity for learners to make meaning using empirical and social criteria in both formal and informal educational contexts through rational discourse. Abd-El-Khalick’s (2001) and Bell’s (2003) research has suggested that students’ decisions regarding SSI are analogous to decisions engaged by scientists regarding the justification of scientific knowledge in that both processes require the use of rational discourse and invoke value judgments and common sense. These findings highlight the importance of tapping students’ epistemological orientations (including NOS views) in the process of evaluating scientific data regarding social issues.

Likewise, Zeidler et al. (2002) have shown that students who harbor naïve and relativistic conceptions of science will likely dismiss scientific knowledge as irrelevant to decision making when reasoning about SSI because they tend to distort whatever data, evidence, or knowledge claims are available to them for the purpose of supporting a predetermined viewpoint with respect to the issue under consideration. Related research informing the issues of socioscientific reasoning and NOS confirms student reliance on personal relevance over evaluative decisions based on contemplation of presented evidence (Sadler, Chambers, & Zeidler, 2004). In this study, students rated articles according to which had more “scientific merit,” but in determining which articles they found to be most convincing, many (40%)
selected articles that most complemented their own personal beliefs independently of their scientific merit. This pattern of responses suggested that for some students, scientific merit (e.g., evidence, data) and persuasiveness were not synonymous. In order to fully appreciate the empirical nature of science, students must understand what constitutes data and how it can be utilized in the process of decision making. However, if that student is confused by what data is, then assertions or arguments evoked hold little meaning. In analyzing students’ comments about how data were used to support positions on global warming, Sadler, Chambers, and Zeidler (2004) also revealed that nearly half (47%) of the students lacked adequate conceptions of scientific data. Some of the students comprising this group were able to recognize data without the ability to describe its use or significance, whereas others could not even distinguish among data, unfounded opinions, and predictions.

Bell and Lederman (2003) have examined the reasoning patterns of university professors representing various fields (including science educators, science philosophers, and research scientists) on SSI and found similar reasoning patterns among these groups, including emphases on personal philosophy and commitments over reasoning based on scientific evidence. Although the participants of this study held varied views of the NOS, their decision-making strategies and actual decisions on science and technology-based issues yielded no discernable patterns unique to particular NOS views. While all of these individuals showed some degree of “superficial” evidence-based reasoning, the primary influence guiding their decisions were personal values, factors related to morality or ethics, and social considerations. The authors suggested in very clear terms that moral development is a factor of interest when assessing decision-making strategies on SSI. Their research findings also provided supporting evidence for earlier work that revealed explicit links between college students’ levels of moral reasoning and decision making on SSI irrespective of their science content knowledge level of sophistication (Zeidler & Schafer, 1984).

Similarly, Walker and Zeidler (2003) found that students’ reference to empirical evidence supporting various positions during a debate activity in high school was limited following online exploration of SSI with previous instruction regarding NOS and exposure to multiple articles of evidence used to gather support and frame arguments for their debate position. Yet when other members of the class voted as to which group presented the best argument, the majority (75%) of the students chose the group as being the most convincing that utilized a wide base of background information, had the input of different people, quoted statistics and generally were convinced by their arguments even when presented with a position contrary to their own. The findings underscore the need for explicit instruction in NOS, so that careful evaluations of evidence regarding SSI and subsequent decisions can be utilized.

This line of research has also revealed more direct transfer of NOS considerations when reasoning about SSI during informal debate or discourse particularly when the SSI issues centered around genetically modified foods and global warming (Sadler, Chambers, & Zeidler, 2004; Walker and Zeidler, 2003; Zeidler et al. 2002), suggesting that the degree of personal relevance of the issue is associated with increased validation of knowledge claims. It reasonably follows that the degree to which students perceive personal relevance related to scientific topics will determine, in part, the seriousness of the issues at-hand and the merit of conflicting or competing claims. If a goal of teaching NOS in science classrooms is to develop students’ abilities to critically evaluate competing scientific claims, then we should be guiding them in the process of synthesizing and applying their understanding of the nature of science as they evaluate and make decisions regarding socioscientific issues.

The significance of this lies not so much in that future generations of students may be able to articulate the meaning of the nature of science and describe its relevant attributes (although that would be a pedagogically notable benchmark), but rather that NOS understanding can benefit them in evaluating the efficacy many kinds of claims—scientific or
otherwise—based upon the merit of supporting evidence in everyday life. This goal of developing transferable reasoning skills is one that is central to promoting the use of SSI in science curricula.

(2) Classroom Discourse Issues stress the crucial role discourse plays in peer interactions and its impact on reasoning. This research underscores the importance of developing students’ views about science through argumentation in the constructions of shared social knowledge via discourse about SSI (e.g., Zeidler et al., 2003). While many science educators acknowledge the importance of rich and diverse classroom discussions in the promotion of scientific literacy (Aikenhead, 1985, 2000; Driver, Newton, & Osborne, 2000; Vellom, 1999; Zeidler, 1984, 1997; Zeidler, Lederman, & Taylor, 1992), those who seek to study it have difficulty locating substantive argumentation or classroom discussions in school (Newton, Driver, & Osborne, 1999), or find the quantity and quality of discussion with explicit focus on science content very low (Levinson, 2003). Perhaps this is because teachers find it difficult to implement sustained student discourse with confidence because of the complex nature of argumentation. This is precisely what Levinson (2003) found in his intensive case study of one “Science for Public Understanding” college class whose focus was on exploring controversial science issues (i.e., SSI). Despite the fact that the intent of the course was to allow students to develop and express an informed personal viewpoint on SSI, the teachers who co-taught the class dominated much of the classroom discourse. Levinson further suggested that because of their inherent complexity, attending to moral and ethical issues may be an unrealistic expectation for science teachers without some type of support from other teachers representing interdisciplinary studies and/or professional development to aid in facilitating the dynamics of argumentation and discourse.

Settelmaier (2003) focused on high school science students’ exchanges using a “dilemma” approach. While the results revealed that dilemma-based stories were a viable tool for introducing SSI which challenged students’ rational, social, and emotional skills, as well as grounding the practice of critical self-reflection concerning their personal value and beliefs systems, several problematic factors in using SSI in the classroom were identified including logistical and planning problems of integrating coverage of content with moral dilemmas and matching the appropriateness of the dilemmas with student interests. Students can easily go off-task if the topic is not well focused, extends too long, or the outcomes are not clear. It may be the case that students simply do not have occasion to practice tolerating ambiguity—whether it be in the form of anomalous data or conflicting points of view.

Additional considerations entailing fallacious argumentation have been identified and explored (i.e., validity concerns, naïve conceptions of argument structure, effects of core beliefs on argumentation, inadequate sampling of evidence altering representation of argument and evidence) and serve as a reminder of the complex nature of discourse involving SSI (Zeidler, 1997; Zeidler et al., 2003). However, the value of argument in the development of moral reasoning has been amply demonstrated in the research literature (Berkowitz & Oser, 1985; Berkowitz, Oser, & Althof, 1987; Keefer, 2002; Keefer, Zeitz, & Resnick, 2000) in terms of creating dissonance thereby allowing opportunity for re-examining one’s beliefs and thought-processes. Being exposed to and challenged by the arguments of others provides the opportunity to attend to the quality of claims, warrants, evidence, and assumptions among competing positions. The idea of creating dissonance through the use of anomalous data has broad meaning in the context of SSI which not only supports the use of conflicting empirical data, but further taps into potentially conflicting counter positions and arguments that arise through dialogic interaction between or among discussants in which logically supported position statements may conflict with a person’s pre-existing beliefs regarding a given scientific concept or issue.
Driver et al. (1996) have demonstrated how students can handle conflicting evidence related to SSI. They indicated that through carefully planned science instruction, students draw on past experiences and combine them with new ideas to explain decisions in scientific contexts. Dialogic interaction, also referred to as transactive discussions in the moral education research literature, has been shown to improve science learning and lead to more robust ways to conceptualize the physical world: “Whereas transaction can foster students’ logical development by focusing on scientific problems and issues, teachers can foster the development of social and moral reasoning by focusing on ethical and social issues” (Berkowitz & Simmons, 2003, p. 133). It is important to note that transactive discourse occurs when one student can clearly internalize and articulate the thoughts, arguments, or position of another student. Their reasoning then becomes transformational in the sense that one individual’s reasoning becomes integrated with that of another. Berkowitz and Simmons reported that students who use more transactive discussions during classroom discourse also learn to solve scientific and mathematical problems more effectively, consequently enhancing the development of scientific reasoning and problem-solving strategies.

In a comprehensive review of the literature, Sadler (2004) summarizes trends related to argumentation as a means of expressing informal reasoning and reiterates that the personal experiences of decision-makers emerged as a consistent normative influence on informal reasoning related to SSI. More specifically, informal reasoning was found to either mediate scientific knowledge or prevent the consideration of scientific knowledge. Sadler cites research that suggests conceptual understanding of content improved informal reasoning on SSI, but more work in this area is needed. Kuhn (1993) further points out that SSI will necessarily entail the use of informal reasoning as much as they are complex, open ended, and often consist of contentious problems without predetermined solutions. Informal reasoning is compatible with the kinds of dilemmas that face students confronted with real-world issues in that the issues at-hand are more times than not, dynamic (i.e., premises may change as new information and perspectives arise).

It would seem, then, that opportunity to engage in informal reasoning through argumentation allows for the evaluation of evidence as well as thought, but finding appropriate pedagogical strategies to seamlessly integrate such dynamic social interaction in the science classroom remains a high priority. Teaching science in this context includes attention and sensitivity to students’ moral commitments, emotions, and moral behavior. The development of character in children (as seen via the development of moral reasoning) becomes an additional important pedagogical outcome arising from the intrinsic nature of argumentation as pedagogy.

(3) Cultural Issues highlight pluralistic and sociological (subsuming gender) aspects of science classrooms. By explicitly attending to cultural issues, science educators recognize, acknowledge, and maximize opportunities afforded by diverse assemblies of learners. The diversity of modern science classrooms includes learners from various cultures (e.g., Cobern & Loving, 2000; Lemke, 2001), developmental abilities (e.g., Mastropieri & Scruggs, 1992; McGinnis, 2000), and genders (e.g., Brickhouse, 2001; Tsai, 2000). This cultural/sociological perspective toward education underscores the necessity to appreciate students as moral agents intimately involved with their own cultural, natural, and technological environments. Regarding individual students as moral agents interacting with their classroom contexts and experiences emphasizes the moral nature of education in general and teaching in particular. The essence of good teaching, in this view, must include the ethical and moral development of young people (Clark, 2003; Loving, Lowry, & Martin, 2003). In fact, ethical and cognitive growth appear to be tightly linked in the development of intercultural understanding (Endicott, Bock, & Narvaez, 2002).
Cultural issues are particularly significant for educational experiences related to SSI. Whereas moral theorists adopting cognitive-developmental perspectives on morality (e.g., Kohlberg, 1986; Rest et al., 1999) have assumed the primacy of moral principles, critical theorists who adopt cultural perspectives on morality (e.g., Belenky et al., 1986; Gilligan, 1987; Noddings, 1984; Partington, 1997; Snarey, 1985) have expanded the scope and challenged the construction of moral discourse in order to include care, emotion, and contextual factors. The contributions of multicultural (Boyes & Walker, 1988; Snarey, 1985) and feminist (Donenberg & Hoffman, 1988; Hekman; 1995; Gilligan, 1987; Noddings, 1984) research on morality inspired some science education researchers to look beyond isolated cognitive factors (viz. situated cognition) contributing to socioscientific decision making in order to perceive the significance of affect.

Zeidler and Schafer (1984) produced some of the first empirical evidence suggesting the importance of emotions in the resolution of SSI. Although a priori notions of morality drove their research design consistent with a Kohlbergian perspective, qualitative analyses of dyadic interviews led the authors to postulate the significance of emotional reactions to controversial environmental issues. Sadler and Zeidler (2004; in press) extended the investigation on the role of emotions in informal reasoning regarding SSI. Both studies focused on student reactions to, perceptions of, argumentation toward, and resolutions of genetic engineering issues. These findings confirmed the significance of emotion for the resolution of SSI. More specifically, participants actively displayed a sense of empathy toward fictitious characters described in scenarios to which they were responding as well as to friends, family members, and acquaintances experiencing situations reminiscent of these scenarios. For example, one participant’s decision making regarding cloning issues was driven primarily by her feelings toward a very close family member who desperately wanted to have children but remained infertile even after conventional fertility treatments. This individual and many others like her in the study exhibited a genuine sense of care that ultimately guided her negotiation and resolution of SSI.

Howes (2002) also noted the appearance and use of empathy and other relationally based concerns in her teacher-research studies with 10th-grade biology students. Three main aspects of a semester-long human genetics course were examined: (1) a unit focusing on prenatal testing for genetic conditions, (2) a set of imaginary cases posed to individual students during interviews, and (3) students’ writing and classroom talk concerning the role of science in society. During the instructional unit on the subject of prenatal tests, the girls in this study considered the comfort and safety of the fetus, and occasionally of the woman carrying the fetus, as primary aspects in making decisions concerning prenatal testing. This may have been an artifact of disincentives to discuss abortion in a high-school classroom, especially on the teacher’s part—deflecting the more deeply emotional and controversial decisions concerning abortion to those concerning prenatal tests alone. These girls explicitly utilized the aspects of comfort and safety when arguing for their decisions as to whether tests should be utilized in particular fictional cases, and used stories from direct personal experience, or related those they had heard from female adults, to illustrate their points. Boys were not studied in the prenatal testing instructional context. In the second research context, boys and girls were presented with similar fictional cases in which they were asked to put themselves in the place of a scientist in charge of ameliorating an urgent situation (e.g., the imminent extinction of an endangered animal, or a town suffering from a cholera outbreak). The small sample from this study indicated that girls put the safety and comfort of both the suffering parties and the scientist her/himself in the forefront of their decision making more than boys. This finding is complicated in the third portion of the study. In writing and discussion throughout the semester, both girls and boys strongly stated that
the role of science in society was to provide cures for human diseases, to avoid disturbing ecosystems, and, in general, to do good for the Earth and for humanity. Their passion in this regard is also evident in preservice elementary teachers, as indicated by Cobern and Loving’s (2002) survey study.

The empathy and care demonstrated in these studies is consistent with notions of emotion-based morality and care originally conceptualized in research with women (Belenky et al., 1986; Gilligan, 1987; Noddings, 1984). In addition, feminist critiques of science have led to a notion that leaving emotional, political, and social influences out of scientific decision making is not only impossible, but dangerous. Importantly, however, feminist researchers insist that “care” and “emotion” not be assigned solely to women, as this supports a dichotomy that equates men with rationality and women with emotion (Harding, 1998; Hughes, 2000). Helping students to practice both of these segments of their personalities and knowledge-making skills may be where much of the promise of feminist approaches lies (Gilligan, 1987; Tong, 1996).

Several researchers have corroborated the importance of this perspective in the context of SSI (Korpan et al., 1997; Sadler & Zeidler, 2004, 2005; Zeidler & Schafer, 1984). For example, Sadler and Zeidler (2005) not only concluded that individuals may rely on emotions for the resolution of SSI, but that informal reasoning based on emotion was often equivalent to strictly cognitive approaches to decision making in terms of logical constructs such as internal consistency and coherence. Whereas the Kohlbergian paradigm suggests that emotive decision making represents inherently underdeveloped moral reasoning, Sadler and Zeidler used an evaluative framework derived from argumentation and informal reasoning theory and research (Kuhn, 1991; Toulmin, 1958) that did not discount any modes of decision making a priori. Rather, the quality of decision making was assessed based on logical criteria of informal reasoning. Using this framework, it was concluded that evaluative distinctions among emotive and other forms of reasoning in terms of their decision-making adequacy were unfounded.

These findings draw attention to the importance of cultural issues and individual students’ beliefs when addressing SSI in science classrooms. Particular situations are, by definition, embedded in particular cultures and thus intertwined with particular relationships (Gruen, 1994; Plumwood, 1993). Recommendations that science education be grounded in local community issues (Aikenhead, 1997) and in students’ interests (Calabrese Barton, 1998a, 1998b; Seiler, 2001) draw on the conclusion that individual students create identities through experiences and perspectives shaped by a culturally diverse society. Here is where we find a link between feminist and cultural perspectives, as both sets of theorists recognize personal identity as “embedded in individual and social circumstances” (Kozoll & Osborne, 2004). That identity shaped by culture is made clear through the “worldview” perspective as developed by Cobern (1993), who states that “a people’s world view provides a special plausibility structure of ideas, activities, and values that allows one to gauge the plausibility of any assertion” [emphasis in original] (p. 57). While students’ cultural experiences, therefore, will certainly influence their decisions, it is also clear that personal identities are not fixed, but vary with setting and are fashioned through students’ social, intellectual, and moral growth (Hughes, 2000; Kozoll & Osborne, 2004). Kozol and Osborne (2004) offer the intriguing possibility that science education can support students’ development when it “opens up the horizons from within which science and self are understood and contributes toward the evolution of both” (p. 170).

Explorations of identity, culture, and their relationships to science, while describing personal identity as influenced by context (e.g., classroom, family, ethnic group), recognize identity as a vehicle through which individuals interact with and explain their world. Given this, it follows that we need research in this area to see how we might create culturally
relevant or culturally responsive pedagogy (see, e.g., Foster, 1995; Gay, 2000; Hollins & Oliver, 1999; Ladson-Billings, 1994; Quintanar-Sarellana, 1997; Smith, 2004; Tate, 1995) employing SSI contexts. Central to this research should be the results of SSI in teaching science with all students, as well as further learning concerning students’ identities and worldviews. In their complexity, SSI may offer multiple connections to varied interests and belief systems, thus assisting students in creating pathways to science learning. However, we cannot say this with certainty, as the uses of socioscientific issues per se have not been widely examined in science classrooms with an eye to cultural and feminist perspectives. Research in this area may provide a richer picture of moral codes and ethical perspectives, thus supporting teachers in engaging their students in socioscientific issues.

Students possess diverse arrays of cultural experiences that necessarily contribute to the manners in which they approach and resolve controversial issues including SSI. Worldviews and identities engendering moral choices are brought into any classroom. Therefore, it is imperative for science educators to foster classroom environments that encourage the expression of diverse perspectives even when those perspectives are not consistent with traditional notions of science. In recognizing the moral nature of teaching and the fact that students are active moral agents, it is essential for teachers to understand that their classrooms cannot be value-free, but they certainly should be value-fair (Loving, Lowy, & Martin, 2003).

(4) **Case-Based Issues** reinforce the stance that in order to develop scientifically literate citizens, the science education community must reach beyond past STS practices which usually do not pay explicit attention to the moral growth of the child and instead involve students with the kinds of issues and problems to ponder that embrace both their intellect and their sense of character. Recent studies involving example cases of genetically modified foods (Walker & Zeidler, 2003), human genetic engineering (Sadler & Zeidler, 2004; Zohar & Nemet, 2002), animal experimentation (Simonneaux, 2001; Zeidler et al., 2002), and environmental dilemmas (Hogan, 2002; Kolstø, 2001b) provide strong support for the efficacy of using controversial socioscientific case studies to foster critical thinking skills and moral and ethical development. These studies strongly suggest that curricula using such issues provide an environment where students become engaged in discourse and reflection that affect cognitive and moral development. The essence of the strategy of using SSI has been described as follows:

If we hope to stimulate and develop students’ moral reasoning abilities, then we must provide students with rich and varied opportunities to gain and hone such skills. The present argument rests on the assumption that using controversial SSI as a foundation for individual consideration and group interaction provides an environment where students can and will increase their science knowledge while simultaneously developing their critical thinking and moral reasoning skills (Simmons & Zeidler, 2003, p. 83).

Similarly, other researchers have developed (or modified existing) protocols that have addressed the implementation of case-based issues in science classrooms. Pedretti (2003) has had successful experiences with preservice teachers who embraced the idea of incorporating SSI via STSE in the curriculum. Using Ratcliffe’s (1997) model as an organizational framework has allowed Pedretti’s (2003, p. 231) students to develop their own decision-making models for pedagogy outcomes and includes

1. **Options**—Identify alternative courses of action for an issue;
2. **Criteria**—Develop suitable criteria for comparing alternative actions;
3. **Information**—Clarify general and scientific knowledge/evidence for criteria;
4. **Survey**—Evaluate pros/cons of each alternative against criteria selected;  
5. **Choice**—Make a decision based on the analysis undertaken;  
6. **Review**—Evaluate decision-making process identifying feasible improvements.

Keefer (2003) has reported the results of using case studies with undergraduate and graduate science students and has noted that the values of the domain of concern for the issue, rather than gender or a general disposition for a particular moral orientation (contra Gilligan), accounted for differences in students’ reasoning. His work examined ethical care responses in professional contexts and led to an empirically derived model for decision making in practical contexts using moral case issues. Keefer’s (2003, p. 253) model entails the following:

1. identify the moral issues at stake;  
2. identify the relevant knowledge and unknown facts in a problem;  
3. offer a resolution;  
4. provide a justification;  
5. consider alternative scenarios that argue for different conclusions;  
6. identify and evaluate moral consequences;  
7. offer alternative resolution.

This moral heuristic has been used successfully in the analysis of engineering ethics case studies for professionals and is strikingly similar to the six-component model described above. Keefer makes it clear in his analysis that ethical instruction is most successful when it is integrated into those authentic contexts that will subsequently be practiced by students.

Another complementary approach to case-based SSI provides a more explicit critical examination of students’ personal interests and values as they provide arguments that evaluate scientific knowledge claims. Kolstø (2000) reports on a consensus project model used mainly with upper secondary science students which emphasizes that scientific knowledge is formulated by consensus building via critical discourse among (competent) peers. The major premise of the consensus approach is that a general knowledge of the human nature and limitations of scientific claims is needed to place scientific statements in adequate terms so consensus decisions regarding SSI can be achieved. Necessarily broad in nature, consensus projects tend to have four key attributes (Kolstø, 2000, p. 652):

1. Presentation and defense of data/conclusions against possible opposition from the teacher and fellow students with a goal toward consensus of issues;  
2. Views of professionals and nonprofessionals are solicited on a particular socioscientific issue so balanced recommendations can be formulated and passed on to politicians and/or policy-makers;  
3. Students search for a common conclusion on which they can all agree while seeking input from ‘experts’ defined as anyone with relevant knowledge exceeding general knowledge;  
4. Students write a report containing their assessments and conclusions, which is made available to the public and politicians and/or policy-makers.

Such an approach no doubt places great demands on the teacher whose role is that of a counselor, consultant and critic, as well as an expeditor. Students realize from the onset that their positions will be challenged and met with critical appraisal in the process of consensus building.
A last approach worth consideration in terms of the professional development of secondary preservice teachers is described by Loving, Lowy, and Martin (2003) where a science methods course has built-in explicit case studies related to professional codes of ethics. While the focus is on teaching and learning with respect to academic freedom, the cases are situated in real science classroom contexts. The authors note that preservice science teachers require practice in making decisions with ethical repercussions, and having explicit opportunities to engage in moral and ethical discourse is central to the development of the ethical teacher. Questions such as “What are your immediate moral intuitions and stirrings about this case?” and “Are you experiencing any conflicting moral feelings as you think about this case?” provided students with the opportunity to frame an issue and access it in a manner consistent with the kind of valid forms of informal reasoning students used to construe SSI found by Sadler and Zeidler (in press). While the focus for Sadler and Zeidler was not on teacher education, the college students in their study (both science and nonscience majors) reacted to and made decisions about multiple scenarios involving genetic engineering by displaying rationalistic, emotive, and intuitive informal reasoning patterns. Rationalistic forms of reasoning have typically been fostered and honored in science classrooms. However, the fact that students also use emotive and intuitive forms of reasoning in making decisions about SSI suggests that relational perspectives based on empathy and care, and initial “gut level” reactions where a sense of conscience is invoked, is a reasonable means to interpret and negotiate difficult moral dilemmas. As educators, we need to value students’ thinking, thereby providing them with opportunities to become personally engaged in issues.

From these perspectives, socioscientific issues may be equated with the consideration of ethical issues and construction of moral judgments about scientific topics via social interaction and discourse. Students will be confronted with multiple perspectives to moral problems that inherently involve discrepant viewpoints and information, sometimes at odds with their own closely held beliefs. The joint construction of scientific knowledge that is at once personally relevant and socially shared therefore relies on exposure to, and careful analysis of, cases involving considerations of data, evidence, and argumentation that may be in conflict with one’s existing conceptions regarding various socioscientific moral and ethical issues.

CONCLUSIONS AND IMPLICATIONS

As the cases described above help to illustrate, the SSI approach represents a reconstruction and evolution of the STS model that provides a means to not only address societal implications of science and technology, but also to tap into students’ personal philosophies and belief systems. As constructivist-learning theory suggests, each student’s knowledge is built as a result of the combination of all influences, be they external or internal. Where STS fails to overtly consider the epistemological foundations, moral and ethical development, and emotional aspects of learning science, SSI specifically targets these essential personal aspects of learning. The STS approach served to convince the educational community that science, technology, and society are not isolated from each other, but did not provide a focus that addressed the intrinsically personal nature of knowledge and belief about science. By addressing the moral, ethical, emotional, and epistemological development of the student, the SSI approach provides a nexus that unites the various forces contributing to the development of scientific knowledge. The introduction of case-based socioscientific issues represents a pedagogical strategy addressing not only the sociological but also the psychological ramifications of curriculum and classroom discourse. A major strength of the SSI approach therefore lies in its unification power, where the major forces resulting in
the construction of personal knowledge are simultaneously addressed in planned pedagogy based on a sound theoretical framework.

Neo-Kohlbergian research has led those concerned with moral reasoning to realize that simply possessing the reasoning competence to make decisions consistent with available structure does not ensure performance at that level across all contexts. Kohlberg came to realize and accept this toward the end of his research (Colby & Kohlberg, 1987), and other researchers have confirmed the lack of coherence between the ability to form higher moral judgments and the likelihood of exercising that reasoning in varied contexts (Carbendale & Krebs, 1992; Wark & Krebs, 1996). With the keen interest in recent years of couching science in real-world problems, this point becomes increasingly important. SSI by their very nature occur in a world where the ceteris paribus conditions are unlikely to be met. All things are not equal, and in fact, are a bit messier in most social settings and during deliberative contexts where competing interests obfuscate principled rules or acts.

If we are to use socioscientific issues as a basis for science curriculum, we will be placing scientific knowledge and its uses squarely within our and our students’ social, political, and cultural lives. We acknowledge science as a human production, and we recognize its role in a society that is less than perfect, but strives toward (at least in some of its ongoing streams) morality of a sort that values equity and justice for all. As Goodlad (2003) writes, “If our moral ecology encompasses equality and social justice, and if we want that moral ecology to guide our society, then equality and social justice must be taught—carefully taught” (p. 19). Science educators can look to scholarship in intercultural education to help us think about the role that socioscientific issues can play in helping students develop morally as well as cognitively. According to Endicott, Bock, and Narvaez (2002), “encountering multiple frameworks should be an effective way of enhancing both moral and intercultural schemas, thereby facilitating more advanced ethical and intercultural problem solving and attitudes” (p. 2). Cultural differences may imply ethical disagreements, and in our pluralistic society, these are things that our students need to learn about, and practice negotiating, within and without familiar settings and situations. Socioscientific issues provide engaging and complex contexts for such work.

Perhaps an even loftier goal for SSI education is the mobilization of students who will take action based on their newly acquired understandings of science and its ramifications. In a dramatic call for an intentionally politicized approach to science education, Hodson (2003) promotes an issue-based curriculum that is “...intended to produce activists: people who will fight for what is right, good and just; people who will work to re-fashion society along more socially-just lines; people who will work vigorously in the best interests of the biosphere” (Hodson, 2003, p. 645). Whether the development and implementation of SSI curriculum will result in the production of individuals who will be sociopolitically active remains to be seen; however, students exposed to such issues will be more likely to consider the moral, political, and environmental aspects of political decisions.

Students who are able to carefully consider SSI and make reflective decisions regarding those issues may be said to have acquired a degree of functional scientific literacy. Accordingly, these individuals may cultivate a positive skepticism concerning the ontological status of scientific knowledge. Their decisions ought to be tempered by an awareness of the cultural factors that guide and generate knowledge. Perhaps most importantly, their decisions should not occur in a vacuum. If educators structure the learning environment properly, then opportunities for the epistemological growth of knowledge as fostered by the SSI framework will help students recognize that the decisions we all face involve consequences for the quality of social discourse and interaction among human beings, and our stewardship of the physical and biological world. Moreover, if we as science educators
wish to cultivate future citizens and leaders who care, serve the community, and provide leadership for new generations, then we have a moral imperative to delve into the realm of virtue, character, and moral development.

REFERENCES


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