Troy D. Sadler

Moral and Ethical Dimensions of Socioscientific Decision-Making as Integral Components of Scientific Literacy

An argument is made that socioscientific decision-making occupies a seminal place in scientific literacy and attention to morality and ethics must be included in the science curriculum.

Science educators have appropriated many meanings for the phrase "scientific literacy" (Champagne & Lovitts, 1989). This paper advances an argument that in order to maintain the usefulness of such a malleable phrase, its users must explicitly address the context of its use. Based on the vision of science education articulated in standards documents from the United States (American Association for the Advancement of Science, 1990); (National Research Council, 1996) and abroad (Council of Ministers of Education Canada Pan-Canadian Science Project, 1997; Millar & Osborne, 1998; Queensland School Curriculum Council, 2001), this paper advances a conception of scientific literacy which involves the negotiation of socioscientific issues. In other words, becoming scientifically literate requires, at least in part, the ability to make informed decisions regarding socioscientific issues. Central to socioscientific issues are moral and ethical implications; therefore, the promotion of scientific literacy requires curricular attention to the moral and ethical implications of socioscientific issues. This paper reviews how the Science-Technology-Society movement has addressed socioscientific decision-making and outlines an alternative approach that more explicitly focuses on the moral and ethical implications of socioscientific issues.

Scientific Literacy Ambiguity

In the current era of standards and reform, the phrase "scientific literacy" has garnered a great deal of attention from the science education community. Despite the reform movement's emphasis on scientific literacy, the architects of modern science education reform did not coin the phrase; in fact, it has appeared in the literature for almost fifty years. Paul Hurd is credited with first publishing the phrase in 1958, but the notion that underlies scientific literacy for all citizens can be traced back to at least the beginning of the century (Laugksch, 2000). Despite (or maybe because of) the fact that scientific literacy has been a part of the landscape of science education for a considerable length of time, its meaning remains mired in debate.

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In today's educational environment, "scientific literacy" has become the descriptor of science education's ultimate aims. In many ways, it has become the criterion for assessing curriculum and pedagogy; new approaches are evaluated by the extent to which they promote scientific literacy. Consequently, researchers and practitioners have a tendency to conceptualize the construct in manners that support their own goals for education. In other words, educators substantiate their research and teaching agendas by linking them to the promotion of science literacy, which is frequently defined by their agendas

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(Champagne & Lovitts, 1989; DeBoer, 2000; Laugksch, 2000). This tautology leaves the field with many distinct perceptions of what scientific literacy entails. Most science educators would agree that promoting scientific literacy is *a* (if not *the*) primary goal of science education, but no such consensus exists regarding the meaning of scientific literacy itself. The multiple definitions of scientific literacy tend to focus on three main areas: processes, knowledge, and attitudes (Jenkins, 1990). Attempts to operationalize scientific literacy typically appeal to at least one of these areas, and the arguments usually proceed along the following lines: "The scientifically literate person accurately applies appropriate science concepts, principles, laws, and theories in interacting with his universe" (Rubba & Andersen, 1978, p. 450). This particular example highlights the knowledge dimension, but equally viable statements are made regarding the processes of science as well as attitudes towards science. Additionally, some delineations of scientific literacy combine multiple goals as in the case of equating the concept with building "scientific habits of mind" which involves processes, epistemic considerations, and attitudes (Zeidler & Keefer, 2003).

Responding to this apparent incongruity, some authors claim that scientific literacy is an ill-defined concept of little practical utility (Champagne & Lovitts, 1989; Laugksch, 2000). The fact that educators appropriate multiple meanings to the phrase supports the contention that scientific literacy is an ill-defined concept; however, this non-specificity does not necessarily condemn the concept. Scientific literacy can still be useful in describing the aims of science education so long as appropriate qualifiers and support are supplied. When appealing to scientific literacy, authors need to explicitly address their ideas regarding the concept and provide a rationale for their given perspectives. In the tradition of qualitative research (Lincoln & Guba, 1985), providing such a description shifts the assessment of applicability from the investigators or authors to the audience. Because scientific literacy can mean different things to different people, authors must qualify their use of the phrase so that their readers can choose to accept or reject the stated position.

Operationalizing Scientific Literacy

The standards documents provided by the American Association for the Advancement of Science (AAAS; 1990; 1993) and the National Research Council (NRC; 1996) as well as perceived needs of current elementary and secondary science students, provide the framework from which scientific literacy will be framed for this report. *Science for All Americans,* a seminal reform document, defines scientific literacy as a multifaceted construct including the following elements:

> being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes. (AAAS, 1990, pp. xvii-xviii)

The *National Science Education Standards* define a scientifically literate person as someone who is able to "use appropriate scientific processes and principles in making personal decisions" and "engage intelligently in public discourse and debate about matters of scientific and technological concern" (NRC, 1996, p. 13). Both of these conceptualizations characterize scientific literacy as an active objective; they provide benchmarks for using scientific knowledge and processes. A logical question to ask in response to this analysis is use of knowledge and processes towards what end? In answering this question, it is important to remember the documents' intended foci. We need look no further than the title of one, *Science for All Americans* (AAAS, 1990), and the opening sentence of the other, "scientific literacy has become a necessity for everyone" (NRC, 1996, p. 1). Scientific literacy is not a goal restricted to the academically elite or those who show the promise of becoming tomorrow's scientists, doctors, and engineers; scientific literacy is for every student. If this is the case, then scientific literacy cannot involve the level of technical sophistication required by particle physicists, molecular biologists, and chemical engineers. Most students will not become professional scientists and engineers and, therefore, will not need to master the specifics of the de Broglie hypothesis, posttranslational protein regulation, or any number of other science discipline-specific information. In fact, most professional scientists probably do not even understand intra-discipline complexities beyond their own specialties (Pool, 1991); it seems outlandish to expect student scientific literacy to eclipse that of practicing scientists.

What then do all students actually need to be able to do in order to achieve scientific literacy? They need to be able to use scientific processes and habits of mind to solve problems faced in everyday life and to confront issues that involve science and make informed decisions (Driver, Newton, & Osborne, 2000; Kolstø, 2001; Patronis, Potari, & Spiliotopoulou, 1999). Science pervades nearly all aspects of modern society and in order to ensure the proper functioning of such a society within the context of democracy, its citizens must be capable of considering and resolving scientific issues. In support of this contention, consider the science-related issues of crucial import as evidenced by their prominence in political campaigns, media reports, and personal decisions. A small sample of these issues includes cloning, stem cell research, alternative fuels, global warming, ozone depletion, nuclear energy, and genetically modified foods. Because the class of scientific issues that requires public input (as opposed to other scientific issues most frequently addressed by professional scientists) necessarily involves societal factors, these issues have been termed socioscientific issues (Kolstø, 2001; Zeidler, Walker, Ackett, & Simmons, 2002). Therefore, at least one component of scientific literacy must be the ability to negotiate socioscientific issues and produce informed decisions.

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Socioscientific Decision-Making

Socioscientific decision-making requires, at minimum, three interrelated aptitudes. 1) In order to negotiate and make decisions about socioscientific issues, individuals must possess requisite knowledge about the science underlying the issues or the skills needed to acquire that knowledge. This cannot be viewed as a prescribed list of facts because the issues themselves are constantly evolving and no static body of knowledge can fully prepare a decision-maker. The ability to find information and process new data is essential for handling new issues as they emerge in the context of real life (Bingle & Gaskell, 1994; Kolstø, 2001). 2) Socially and politically active participants in a society dependent on science and technology must also have an understanding of the nature of science (NOS). NOS components such as the efficacy of data and its analysis, the evolutionary and revolutionary nature of scientific epistemology, and the social embeddedness of scientific progress contribute to the status of scientific claims. In order to apply scientific knowledge, particularly to cases of social import, decision-makers need an understanding of the nature of scientific knowledge (Kolstø, 2001; Sadler, Chambers, & Zeidler, in press; Zeidler et al., 2002). 3) Finally, individuals making socioscientific decisions must have an appreciation for the moral and ethical dimensions associated with these issues. Despite the objectivity that positivist science attempts to portray, socioscientific issues involve moral and ethical dilemmas that lack an objective "Truth." Decision-makers cannot compartmentalize science and ethics and still deliver an informed decision; ethics and morality are inseparable from science in the context of socioscientific issues. Therefore, if scientific literacy incorporates socioscientific issues, programs that promote scientific literacy must explicitly attend to moral and ethical components (Bingle & Gaskell, 1994; Kolstø, 2001; Zeidler, 1984; Zeidler et al., 2002). The inability to successfully utilize any of these three aptitudes will significantly hamper one's ability to make judgments regarding socioscientific issues and by extension will limit scientific literacy.

Of the three aptitudes described, scientific knowledge acquisition, NOS understanding, and awareness of moral and ethical issues, the final is the most contentious suggestion for inclusion in science curricula. Arguing for science students to learn science content is not a difficult case to make. Understanding information from the domain of science is intuitively synonymous with science education. Likewise, the call for embedding NOS in science curricula is not particularly revolutionary. While debate exists over what exactly constitutes NOS and how these themes should be taught, ample support has been levied in favor of making NOS a significant component of modern science education (Abd-El-Khalick, Bell, & Lederman, 1998; McComas, Clough, & Almazroa, 2000). In contrast, strategies for dealing with ethical dilemmas are typically not associated with the canon of elementary or secondary school science. However, research in the area of socioscientific decision-making has produced mounting evidence that morality and ethics are central to the processes in which individuals engage when considering and resolving these issues.

Moral and Ethical Aspects of Socioscientific Issues

This section will review studies, in science education, which provide evidence that morality and ethics contribute significantly to socioscientific decision-making. Zeidler and Schafer (1984) analyzed college student ideas regarding an environmental dilemma. Trends emerged from the group discussions indicating that the participants incorporated morality in their decision-making. Several student groups concentrated on whether the actions proposed justified the end results. Other students displayed decision-making patterns whereby they integrated

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personal experiences, affect, and moral reasoning. Fleming (1986a; 1986b) also investigated influences on socioscientific decision-making. He interviewed adolescents as they considered nuclear power and genetic engineering. Fleming concluded that most students (70%) employed moral reasoning in the resolution of the issues posed. The propensity for individuals to rely on moral factors for socioscientific decision-making was also confirmed in Bell and Lederman's (2003) work with college professors. Each of the 18 participants responded to four socioscientific issues (fetal tissue implantation; the relationship between diet, exercise, and cancer; global warming; and the link between cigarette smoking and cancer). Eighty-five percent of the responses involved moral, ethical, or value considerations. Global warming was the only issue in which some participants failed to cite morals, ethics, or values. Pedretti (1999) conducted an intervention study with a combined class of fifth and sixth grade students as they studied a unit related to mining. In pre-intervention interviews, 22% of the students alluded to moral considerations such as assessing whether the options were "good" or "bad," but they offered little elaboration. Following the intervention, over half of the students talked about "good," "better," and "right" decisions and justified the use of these terms in a moral context. Transcript excerpts provided in the article revealed that students actively contrasted the notion of rights vs. societal laws, made utilitarian calculations of effects, and applied principles of justice. Pedretti (1999) also suggested that most students adopted one of two environmental ethical perspectives: homocentrism or biocentrism. Sadler and Zeidler (2004) chronicled the tendency for college students to construe genetic engineering issues as moral problems. These authors concluded that the participants employed the following morality frameworks as they considered negotiated gene therapy and cloning dilemmas: consequentialism, deontology, moral affect and moral intuitionism. In a follow-up study using similar kinds of genetic engineering prompts, Sadler (2003) substantiated the influence of both moral emotions and intuitions as seminal components of socioscientific decision-making.

Philosophers, ethicists, and science educators have argued that socioscientific issues naturally involve the moral domain (Andre, 2002; Carse, 1996; Zeidler et al., 2002), but whether actual decision-makers rely on moral principles and/or emotions in the negotiation of socioscientific issues is an empirical question. Taken together, the studies just reviewed present compelling evidence to support the contention that decision-makers do, in fact, employ morality and ethics as they work to resolve socioscientific issues. The result is consistent across a variety of age levels spanning middle school (Pedretti, 1999), high school (Fleming, 1986a), college (Sadler & Zeidler, in press; Zeidler & Schafer, 1984), and adult professionals (Bell & Lederman, 2003). In addition, these studies confirm the significance of morality in a variety of socioscientific decision-making contexts including environmental issues (Pedretti, 1999; Zeidler & Schafer, 1984), genetic engineering (Fleming, 1986a; Sadler & Zeidler, 2004), nuclear power (Fleming, 1986a), and health issues (Bell & Lederman, 2003). It should be noted that these findings do not suggest that decision-making of individuals are naturally moral in a normative sense. They confirm that decisions naturally involve moral considerations from a meta-ethical perspective. The section which follows will explore the extent to which science curricula has/has not reflected this conclusion.

STS: Intent and Limitations

The most significant and sustained curricular movement with ties to socioscientific issues is the science, technology, and society (STS) movement. This educational approach has attempted to bring scientific issues with social influences and ramifications into elementary and secondary classrooms. It was initiated as a means to accomplish goals of science education reform and is consistent with the promotion of scientific literacy as a chief goal in science education (Solomon & Aikenhead, 1994; Yager, 1996). STS education involves learning experiences in which students explore the relationships between science, technology, and society by focusing on real-life issues that involve these domains. Beyond this broad description, the particulars of STS education vary significantly among the curricula and instruction classified as such. Approaches under the STS heading may be as discrepant as a discrete course devoted to a particular topic, a methodological style of instruction in a specific science discipline, and an ancillary text box discussing the relationship between science and technology in a socially pertinent issue in the midst of a science textbook (Pedretti & Hodson, 1995). Despite the vast range of the STS movement and its admirable intentions, the movement has fallen short of developing the socioscientific decision-making aspects of scientific literacy. In the previous section, three aptitudes were presented as requisite components for socioscientific decision-making: content knowledge or acquisition, NOS understanding, and appreciation for the moral and ethical components. The STS approach attempts to address knowledge acquisition and to a lesser extent, NOS understanding, but explicit attention to moral and ethical components of socioscientific issues is not present in most (if any) STS curricula.

Positive reports on the efficacy of STS approaches populate the research literature landscape in science education for outcomes such as conceptual understanding of content material (Aikenhead, 1994; Tsai, 2000; Yager & Tamir, 1993), interest in learning about science (Aikenhead, 1994; Solbes & Vilches, 1997; Yager & Tamir, 1993), and appreciation for the interconnections between science, technology and society (Aikenhead, 1994; Rye & Rubba, 2000; Solbes & Vilches, 1997). However, the literature is devoid of any reports verifying improved decision-making with respect to the ethical implications of socioscientific issues as a result of STS education. This missing, but important link stems from a lack of attention directed towards the morality and ethics associated with these decisions. Support for this contention can be found in analyses of literature pertaining to the STS movement as well as examples from content-based textbooks and secondary science methods books.

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In a recently published anthology of STS research, Miller (2000) provides a description of what it means to be scientifically literate from an STS perspective. He suggests that scientific literacy is an understanding of basic science vocabulary and an appreciation for the nature of scientific inquiry.

> Individuals who demonstrate a high level of understanding on both dimensions are the most capable of acquiring and comprehending information about a science or technology policy controversy, and these individuals will be referred to as being "well informed" or "scientifically literate." (p. 29)

From this perspective, the mastery of science vocabulary and methods equips an individual to make responsible decisions about socioscientific issues. Distinct in its absence is any reference to the ethical dimensions inherent to "science or technology policy controversies." Another author from the same volume echoes these sentiments in levying criticism against science textbook treatment of STS issues. DeBettencourt (2000) cites problems with explanations, term confusion, and inadequate data among other concerns, but she never refers to the dearth of information regarding the ethical implications of the issues in question.

A critic could argue that the absence of moral and ethical dimensions of STS issues in research literature could just result from a bias in publication; perhaps researchers are just not interested in writing on the subject, but it actually is present in curricula. Unfortunately, this does not seem to be the case. Many commonly used secondary science textbooks do contain STS components, but they typically provide nothing more than widely interspersed boxes of text, disarticulated from other material, that highlights the interconnectedness of science, technology, and society (for examples see (Campbell, Mitchell, & Reece, 1997; Johnson, 1998; LeMay, Beall, Bobblee, & Brower, 1996; Martini, 1998; McLaughlin, 1999; Miller & Levine, 1998a; Sager, Ramsey, Phillips, & Watenpaugh, 1998; Spaulding & Namowitz, 1997; Tocci & Viehland, 1996). It is true that science textbooks are not the most important factor in determining classroom instruction; teachers should occupy that role, but there is little evidence to suggest that teachers are given the tools to go beyond STS approaches offered in texts. The materials used in the preparation of teachers typically do not address the morality and ethics of socioscientific decision-making. Current, popular secondary science education methods textbooks tend to discuss STS approaches either as stand-alone chapters or subsections related to instructional options, but they do little more than draw connections between the related domains and suggest increased student interest in this class of issues (for examples see Chiappetta & Koballa, 2002; Trowbridge, Bybee, & Powell, 2000).

This report is not meant to condemn the STS movement because as stated previously, the movement has produced positive outcomes in some areas; nor is this report attempting a thorough review of all STS curricula or research because such an undertaking would fill volumes. Its intent is not even to suggest that no STS instruction has ever accomplished the promotion of the socioscientific decision-making aspects of scientific literacy. However, it does aim to support the claim that the STS movement, in general, has fallen short of highlighting the moral and ethical dimensions of socioscientific issues, which necessarily restricts the curricula's ability to foster socioscientific decision-making. In discussing the rhetoric that characterizes the implementation of STS curriculum versus the results of its application, Pedretti and Hodson (1995) capture the movement's shortcomings.

> We want to enable students to move from the capacity to talk knowledgably about environmental and health issues and other matters with a scientific and technological dimension, toward engagement in personal action for effecting change—a much more radical view of STS education than is commonly the case. (p. 464)

Adopting a more radical view of STS so that students are empowered to engage in personal action is synonymous with the socioscientific decision-making aspects of scientific literacy advanced earlier in this paper. In order to move students beyond the capacity to talk about issues and identify the interconnectivity between science and society, as the more radical view suggests, the science education community needs to address the real-life ramifications of these issues including the moral and ethical dimensions.

To move forward in this area, science supervisors, department heads, teachers, curriculum designers, and the individuals who support them including university level science educators need to facilitate the inclusion of socioscientific issues in science classrooms with explicit attention paid to their ethical implications.

Implications

This paper has attempted to lay out a rationale for 1) offering the promotion of scientific literacy as a fundamental goal of science education, 2) including socioscientific issues as a significant component of scientific literacy, and 3) asserting that moral and ethical considerations are central to socioscientific decision-making. In addition it reviewed the science, technology, and society movement in order to gain perspective on how socioscientific issues have been treated in science curricula. Although STS approaches have successfully raised awareness of the importance socioscientific issues, they generally have not advanced the ethical dimensions of these issues. To move forward in this area, science supervisors, department heads, teachers, curriculum designers, and the individuals who support them including university level science educators need to facilitate the inclusion of socioscientific issues in science classrooms with explicit attention paid to their ethical implications. This recommendation should not be interpreted as a proposal requiring science teachers to become ethicists. It is, however, suggesting that promoting the ability to make informed decisions regarding scientific issues that students will inevitably confront in their everyday lives should be central to their experiences in science classrooms. Because morality and ethics are natural aspects of the process of negotiating socioscientific issues, they must be included in any educational program aimed at promoting responsible decision-making.

This conclusion still leaves the role of the teacher as an open question. While a background in ethics or moral philosophy might be helpful for teachers who wish to adopt the proposed approach, it is not necessary. What is necessary is the creation of classroom environments in which the expression of ideas, including those associated with personal value systems, is encouraged. This is a goal that teachers can achieve by fostering a tolerant community in their classrooms where students are able to voice dissenting opinions and explore their belief systems. In addition, students need to feel that their science experiences can encompass more than traditional images of objective data. Incorporating curricular activities such as role-plays and debates is one approach to achieving these goals (Simonneaux, 2001), and a variety of examples already exist (Brown & Dias, 2003; Cannon, Chun, & Kitchens, 2000; McLaughlin & Glasson, 2003; Racich, 2002; Sadler & Zeidler, in press; Sadler & Zeidler, 2003; Webster, 2002). Writing assignments designed to encourage student exploration of their own thinking regarding controversial socioscientific issues as well as the perspectives held by others provide other additional activities.

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As an example of what this approach might look like, consider the issue of genetically modified foods (GMF). International scientific, business, agricultural, and political communities are currently embroiled in debate over the status and accepted uses of animal and plant crops which have been genetically altered (Charles, 2001; Nottingham, 1998; Pence, 2002). This issue could naturally be positioned within a biology course. The issue could serve as a vehicle for introducing concepts related to heritability as well as the specifics of molecular genetic processes. Instruction might also focus on the mutual interactions of science and society. But the learning experiences should not be concluded by visiting only these content and NOS goals. If the true aim of this instruction is to help students build decision-making skills, teachers have a duty to broaden the discussion. Moral and ethical dimensions are central to the debate surrounding GMF, and learning experiences that do not address these dimensions present students with a partial view of reality and fetter their ability to make informed decisions. Ethical ramifications associated with producing, marketing, and consuming genetically modified foods as well as the policies which regulate these practices are as important to decision-making as genetics concepts. To focus attention on the morality and ethics inherent to GMF issues, teachers could encourage student to grapple with some of the following questions. Should organisms be unnaturally altered by gene replacements or additions? Will genetically modified crops impact natural populations of organisms? Can individuals and/or corporations patent genes? Do farmers have the right to raise crops of their choice? Can genetically modified foods reduce worldwide hunger? Do consumers have a right to know if products have been genetically altered? Should manufacturers be forced to divulge information that will adversely affect their business? Confronting students with these open-ended problems provides them with an initiation into the moral complexity of GMF. Teachers may choose to delve further by challenging students to explore the responses of various perspectives to these ethical quandaries and encouraging students to use these experiences to help build their own positions and rationales. In taking this type of approach, teachers need not provide students with prescribed solutions to any of the ethical questions just listed and therefore, do not require expertise in ethics and moral philosophy. Rather, teachers need to help students recognize the moral and ethical dimensions of socioscientific issues and encourage students to reflect critically on their own ideas as well as those of their classmates and potential stakeholders.

Critics might argue that genetically modified foods represent one of many socioscientific issues and may not be representative of others in terms of its ethical dimensions. While it is true that individual issues may vary in the extent to which ethics and morality impact decision-making, it seems likely that most possess at least some ethical dimensions. This trend will only increase as molecular genetics and other biotechnologies flourish, alternative fuel searches continue, and environmental concerns increase.

Conclusion

The following excerpt is taken from the preface of a recently published book on moral education:

> [The authors] believe that moral and civic messages are unavoidable in higher education and that it is better to pay explicit attention to the content of these messages and how they are conveyed than to leave students' moral and civic socialization to chance. (Colby, Ehrlich, Beaumont, & Stephens, 2003)

By substituting a few phrases, this statement reflects the central argument of this paper. Ethics and morality are unavoidable in the contemplation of socioscientific issues and it is better to pay explicit attention to these aspects than to leave a major facet of socioscientific decision-making to chance. Rather than overlooking or actively ignoring the ethical implications of socioscientific issues, educators have a responsibility to address them. If the promotion of scientific literacy is an important aim of science education, and socioscientific decision-making occupies a seminal place in scientific literacy, then attention to morality and ethics must be included in science curricula.

References

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*, 417-436.

Aikenhead, G. (1994). Consequences to learning science through STS: A research perspective. In J. Solomon, & G. Aikenhead (Eds.), *STS education: International perspectives on reform* (pp. 169-186). New York: Teachers College Press.

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

Andre, J. (2002). *Bioethics as practice*. Chapel Hill: University of North Carolina Press.

Bell, R. L., & Lederman, N. G. (2003). Understandings of the nature of science and decision making on science and technology based issues. *Science Education, 87*, 352-377.

Bingle, W. H., & Gaskell, P. J. (1994). Scientific literacy for decisionmaking and the social construction of scientific knowledge. *Science Education, 78*, 185-201.

Brown, T., & Dias, M. (2003). Demonstrations to save the world. *Science Scope, 26*(7), 20-24.

Campbell, N. A., Mitchell, L. G., & Reece, J. B. (1997). *Biology: Concepts and connections* (2nd ed.). Menlo Park, CA: Benjamin/Cummings Publishing.

Cannon, S. L., Chun, S., & Kitchens, P. J. (2000). Why not consider dialogue instead of debate? In T. R. Koballa, & D. J. Tippins (Eds.), *Cases in middle and secondary science education: The promise and dilemmas* . Upper Saddle River, NJ: Merrill.

Carse, A. L. (1996). Facing up to moral perils: The virtues of care in bioethics. In S. Gordon, P. Benner, & N. Noddings (Eds.), *Caregiving: Readings in knowledge, practice, ethics, and politics* (pp. 83-110). Philadelphia: University of Pennsylvania Press.

Champagne, A. B., & Lovitts, B. E. (1989). Scientific literacy: A concept in search of definition. In A. B. Champagne, B. E. Lovitts, & B. J. Callinger (Eds.), *This year in school science*. *Scientific literacy* (pp. 1-14). Washington: American Association for the Advancement of Science.

Charles, D. (2001). *Lords of the harvest: Biotech, big money, and the future of food*. Cambridge, MA: Perseus Publishing.

Chiappetta, E. L., & Koballa, T. R. (2002). *Science instruction in the middle and secondary schools* (5th ed.). Upper Saddle River, NJ: Merrill Prentice Hall.

Colby, A., Ehrlich, T., Beaumont, E., & Stephens, J. (2003). *Educating citizens: Preparing America's undergraduates for lives of moral and civic responsibility*. San Francisco: Jossey-Bass.

Council of Ministers of Education Canada Pan-Canadian Science Project. (1997). *Common framework of science learning outcomes: K-12*. Retrieved June 2, 2003, from <http://www.qscc.qld.edu.au/kla.sose.publications.html>.

deBettencourt, K. B. (2000). Science, technology, and the environment: Scientiific literacy for the future. In D. D. Kumar, & D. E. Chubin (Eds.), *Science, technology, and society: A sourcebook on research and practice* (pp. 141-166). New York: Kluwer Academic Press.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*, 582-601.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*, 287-312.

Fleming, R. (1986a). Adolescent reasoning in socio-scientific issues, part I: Social cognition. *Journal of Research in Science Teaching, 23*, 677-687.

Fleming, R. (1986b). Adolescent reasoning in socio-scientific issues, part II: Nonsocial cognition. *Journal of Research in Science Teaching, 23*, 689-698.

Jenkins, E. (1990). Scientific literacy and school science education. *School Science Review, 71*(256), 43-51.

Johnson, G. B. (1998). *Biology: Visualizing life*. Austin, TX: Holt, Rinehart and Winston.

Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education , 85*, 291-310.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education, 84*, 71-94.

LeMay, H. E., Beall, H., Bobblee, K. M., & Brower, D. C. (1996). *Chemistry: Connections to our changing world*. Upper Saddle River, NJ: Prentice Hall.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage Publications.

Martini, F. H. (1998). *Fundamentals of anatomy and physiology*. Upper Saddler River, NJ: Prentice Hall.

McComas, W. F., Clough, M. P., & Almazroa, H. (2000). The role and character of the nature of science in science education. In W. F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 41-52). Netherlands: Kluwer.

McLaughlin, C. W. (1999). *Physical science*. New York: Glencoe.

McLaughlin, J., & Glasson, G. (2003). Connecting biotechnology and society. *The Science Teacher, 70*(4), 48-52.

Millar, R., & Osborne, J. (Eds.). (1998). *Beyond 2000: Science education for the future*. London: King's College School of Education.

Miller, J. D. (2000). The development of civic scientific literacy in the United States. In D. D. Kumar, & D. E. Chubin (Eds.), *Science, technology, and society: A sourcebook on research and practice* . New York: Kluwer Academic Press.

Miller, K. R., & Levine, J. (1998b). *Biology* (4th ed.). Englewood Cliffs, NJ: Prentice Hall.

National Research Council. (1996). *National science education standards*. Washington: National Academy Press.

Nottingham, S. (1998). *Eat your genes: How genetically modified food is entering our diet*. London: Zed Books.

Patronis, T., Potari, D., & Spiliotopoulou, V. (1999). Students' argumentation in decision-making on a socio-scientific issue: Implications for teaching. *International Journal of Science Education, 21*, 745-754.

Pedretti, E. (1999). Decision making and STS education: Exploring scientific knowledge and social responsibility in schools and science centers through an issues-based approach. *School Science and Mathematics, 99*, 174-181.

Pedretti, E., & Hodson, D. (1995). From rhetoric to action: Implementing STS education through action research. *Journal of Research in Science Teaching, 32*, 463-485.

Pence, G. E. (2002). *Designer food: Mutant harvest or breadbasket of the world*. Lanham, MD: Rowman & Littlefield Publishers.

Pool, R. (1991). Science literacy: The enemy is us. *Science, 251*, 266-267.

Queensland School Curriculum Council. (2001). Studies of society and environment. Retrieved June 2, 2003, from <http://www.cmec.ca/science/framework/index.htm>.

Racich, M. (2002). 230 million tons of trash. *Science Scope, 25*(7), 34-35.

Rubba, P. A., & Andersen, H. O. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education, 62*, 449-458.

Rye, J. A., & Rubba, P. A. (2000). Student understanding of global warming: Implications for STS education beyond 2000. In D. D. Kumar, & D. E. Chubin (Eds.), *Science, technology, and society: A sourcebook on research and practice* (pp. 193-230). New York: Kluwer Academic Press.

Sadler, T. D. (2003). *Informal reasoning regarding socioscientific issues: The influence of morality and content knowledge*. Unpublished doctoral dissertation, University of South Florida.

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (in press). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education*.

Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education*, 88, 4-27.

Sadler, T. D., & Zeidler, D. L. (in press). Negotiating gene therapy controversies. *The American Biology Teacher*.

Sadler, T. D., & Zeidler, D. L. (2003). Teaching bad science: Highlighting the past to understand the present. *Science Teacher*, 70 (9), 36-40.

Sager, R. J., Ramsey, W. L., Phillips, C. R., & Watenpaugh, F. W. (1998). *Modern earth science*. Austin, TX: Holt, Rinehart and Winston.

Simonneaux, L. (2001). Role-play or debate to promote students' argumentation and justification on an issue in animal transgenesis. *International Journal of Science Education, 23*, 903-927.

Solbes, J., & Vilches, A. (1997). STS interactions and the teaching of physics and chemistry. *Science Education, 81*, 377-386.

Solomon, J., & Aikenhead, G. (1994). *STS education: International perspectives on reform*. New York: Teachers College Press.

Spaulding, N., & Namowitz, S. N. (1997). *Heath Earth Science*. Evanston, IL: McDougal Littell.

Tocci, S., & Viehland. (1996). *Chemistry: Visualizing matter*. Austin, TX: Holt, Rinehart and Winston.

Trowbridge, L. W., Bybee, R. W., & Powell, J. C. (2000). *Teaching secondary school science: Strategies for developing scientific literacy* (7th ed.). Upper Saddle River, NJ: Merrill Prentice Hall.

Tsai, C. (2000). The effects of STS-oriented instruction on female tenth graders' cognitive structure outcomes and the role of student scientific epistemological beliefs. *International Journal of Science Education, 22*, 1099-1115.

Webster, S. (2002). Investigating malformed frogs: Using the Internet to explore the impact of environmental changes in anurans. *The Science Teacher, 69*(3), 51-53.

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

Yager, R. E., & Tamir, P. (1993). STS approach: Reasons, intentions, accomplishments and outcomes. *Science Education, 77*, 637-658.

Zeidler, D. L. (1984). Moral issues and social policy in science education: Closing the literacy gap. *Science Education, 68*, 411-419.

Zeidler, D. L., & Keefer, M. (2003). The role of moral reasoning and the status of socioscientific issues in science education: Philosophical, psychological and pedagogical considerations. In D. L. Zeidler (Ed.), *The role of moral reasoning and discourse on socioscientific issues in science education* . Netherlands: Kluwer.

Zeidler, D. L., & Schafer, L. E. (1984). Identifying mediating factors of moral reasoning in science education. *Journal of Research in Science Teaching, 21*, 1-15.

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

Troy D. Sadler, Indiana University Bloomington, 201 N. Rose Ave., Suite 3002, Bloomington, IN 47405-1005, (812) 856-8145, <tsadler@indiana.edu>.