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ABSTRACT

Socioscientific issues encompass social dilemmas with conceptual or technological links to science. The process of resolving these issues is best characterized by reasoning which describes the generation and evaluation of positions in response to complex situations. This article presents a critical review of research related to informal reasoning regarding socioscientific issues. The findings reviewed address: (1) the role of socioscientific argumentation in classroom science; (2) the influence of ideas about the nature of science on socioscientific decision making; (3) the evaluation of information pertaining to socioscientific issues including student ideas about what counts as evidence; and (4) the influence of an individual's conceptual understanding on his/her informal reasoning. The synthesis of the current state of socioscientific issue research provides a comprehensive framework from which future research can be motivated and decisions about the design and implementation of socioscientific curricula can be made. The implications for future research and classroom applications are discussed. (Contains 56 references.) (Author)

Socioscientific Issue Research and Its Relevance for Science Education

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Invited Seminar presented to Science Education Graduate Students at the University of South Florida.

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Abstract

Socioscientific issues encompass social dilemmas with conceptual or technological links to science. The process of resolving these issues is best characterized by informal reasoning which describes the generation and evaluation of positions in response to complex situations. This article presents a critical review of research related to informal reasoning regarding socioscientific issues. The findings reviewed address 1) the role of socioscientific argumentation in classroom science, 2) the influence of ideas about the nature of science on socioscientific decision-making, 3) the evaluation of information pertaining to socioscientific issues including student ideas about what counts as evidence, and 4) the influence of an individual's conceptual understanding on his/her informal reasoning. This synthesis of the current state of socioscientific issue research provides a comprehensive framework from which future research can be motivated and decisions about the design and implementation of socioscientific curricula can be made. The implications for future research and classroom applications are discussed.

Socioscientific Issue Research and Its Relevance for Science Education

An Introduction to Socioscientific Issues

Social issues with conceptual or technological ties to science have captured the national spotlight during the recent past. Cloning, stem cells, genome projects, global warming, and alternative fuels have become common elements of the national vocabulary as well as the currency of political debates. Regardless of society's reluctance or enthusiasm towards the advent of these issues or its preparedness to deal with them, scientific issues with social ramifications will undoubtedly continue to arise and evolve. Advances in medical science and molecular genetics coupled with the environmental challenges produced by a burgeoning human population guarantee the prominence of these kinds of issues in the present and future. Because of the central roles of both social and scientific factors in these dilemmas, they have been termed socioscientific issues.

Several science educators have argued for the inclusion of socioscientific issues in science classrooms citing their central role in the development of a responsible citizenry capable of applying scientific knowledge and habits of mind (Driver, Newton, & Osborne, 2000; Kolstø, 2001a; Zeidler, 1984). Their efforts to infuse socioscientific issues into science curricula are not the first intent on making classroom science more reflective of the society in which it exists as opposed to an isolated, irrelevant academic discipline. The science, technology, and society (STS) movement has sought to educate students about the interdependence of these three domains since at least the early 1980's (Yager, 1996). However, STS education has become quite diffuse over the course of its tenure representing approaches as disparate as isolated courses focused on particular STS issues, pedagogical strategies that highlight the connections between science and society, and ancillary text boxes in the midst of science textbooks (Pedretti &

Hodson, 1995). In contrast, the socioscientific issue movement's aims focus more specifically on empowering students to handle the science-based issues that shape their current world and those which will determine their future world (Driver et al., 2000; Kolstø, 2001a).

Informal Reasoning & Its Relation to Socioscientific Issues

In the context of science, reasoning historically has referred to formal reasoning characterized by rules of logic and mathematics. The formal processes of deduction or induction lead thinkers to necessary conclusions, and positivist philosophers of science, such as Popper and Carnap, argued that these very processes distinguish the scientific enterprise from other ways of knowing the world (Curd & Cover, 1998). Thomas Kuhn (1962) challenged the significance of formal reasoning in science by proposing a novel model of scientific change and progress. Kuhn disputed the purported rationality of scientific theory change and the perpetual accretion of scientific knowledge. He described episodes of theory change as tumultuous periods during which scientists judge competing theories using a variety of criteria including social influences. The enduring theory rises to prominence through a process more reminiscent of political revolutions than episodes of formal reasoning. Kuhn's work directs attention to the fact that although formal reasoning may contribute to scientific discovery, it is not the only vehicle for producing progress.

Although the results of science may be presented in the language of formal reasoning and logic, the results themselves originate through informal reasoning (Tweney, 1991). Unlike scientific investigations, the premises of formal reasoning are fixed and unchanging, and conclusions are necessary derivatives. In informal reasoning, on the other hand, premises can change as additional information becomes available, and conclusions are not self-evident (Perkins, Farady, & Bushey, 1991). Informal reasoning involves the generation and evaluation of positions in response to complex issues that lack clear-cut solutions. Thinkers are engaged in informal reasoning as they ponder causes and consequences, pros and cons, and positions and alternatives (Means & Voss, 1996; Zohar & Nemet, 2002). Means and Voss (1996) provide an illustrative description in the following quotation. "Informal reasoning assumes importance when information is less accessible, or when the problems are more open-ended, debatable, complex, or ill-structured, and especially when the issue requires that the individual build an argument to support a claim" (p. 140). Given these accounts, scientific investigations, which seek to explain the unknown, seem far more analogous to informal reasoning than formal reasoning.

Socioscientific issues are ideal candidates for the application of informal reasoning (Kuhn, 1993). By definition, they are complex, open-ended, often contentious dilemmas, with no definitive answers. In response to socioscientific dilemmas, valid, yet opposing arguments can be constructed from multiple perspectives. Just as scientists employ informal reasoning to gain insights on the natural world, ordinary citizens rely on informal reasoning to bring clarity to the controversial decisions they face. The citizens of a democratic society built upon science and technology are constantly presented with socioscientific issues, and the processes of informal reasoning allow them to access these issues, formulate positions, and provide supporting evidence (Kolstø, 2001a; Patronis, Potari, & Spiliotopoulou, 1999; Tytler, Duggan, & Gott, 2001).

Rationale

The purpose of this article is to review key topics identified in the literature concerning socioscientific issues and synthesize their empirical findings as they relate to science education research and practice. Although socioscientific issue research remains a relatively new area of concern, influences on socioscientific decision-making as well as perspectives towards research are diverse (Driver et al., 2000; Kolstø, 2001a; Zeidler, in press). The following synthesis of the current state of socioscientific issue research provides a comprehensive framework from which future research can be motivated and decisions about the design and implementation of socioscientific curricula can be made. Assertions that socioscientific issues form an important component of scientific literacy (American Association for the Advancement of Science, 1990; National Research Council, 1996; Siebert & McIntosh, 2001) demand the exploration of how these issues can be most meaningfully incorporated in science curricula and classrooms. Meeting this challenge requires first, an assessment of what is known and second, an assessment of what needs to be known. This article provides a summary of current knowledge, identifies areas which require additional concentration, and makes recommendations for classroom considerations.

Literature Review

Formulating and supporting positions (i.e. informal reasoning) in response to socioscientific issues can be affected by numerous factors including argumentation skills, understanding of the nature of science, the ability to evaluate information and evidence, and conceptual understanding of the material that underlies the issue (Fleming, 1986b; Hogan, 2002; Kolstø, 2001b; Korpan, Bisanz, Bisanz, & Henderson, 1997; Patronis et al., 1999; Pedretti, 1999; Sadler, Chambers, & Zeidler, 2002; Zeidler, Walker, Ackett, & Simmons, 2002; Zohar & Nemet, 2002). None of these variables operates independently on informal reasoning, but in attempting to make contributions towards understanding socioscientific decision-making, researchers have isolated individual factors (or sets of factors) in order to make empirical analyses possible. In order to construct a comprehensive picture of socioscientific decision-making, seminal and current research on the aforementioned factors will be reviewed including 1) the role of socioscientific argumentation in classroom science, 2) the influence of ideas about the nature of science on socioscientific decision-making, 3) the evaluation of information pertaining to socioscientific issues including student ideas about what counts as evidence, and 4) the influence of an individual's conceptual understanding on his/her informal reasoning. The sections that follow explore the research which deals with each of these four areas and a graphic organizer (figures 1-4) is presented for each topic. The organizers present succinct summaries of the empirical highlights from the studies reviewed.

The Role of Socioscientific Argumentation in Classroom Science

Argumentation as a field of study is concerned with how individuals make and justify claims and conclusions (Driver et al., 2000; Zohar & Nemet, 2002). Theorists divide arguments into three distinct categories: rhetorical, analytical, and dialectical. Analytical arguments describe formal reasoning processes and are formed in the language of logic. Rhetorical arguments involve the expression of one viewpoint; they are persuasive and explanatory in nature. This class of argumentation characterizes the traditional didactic approach to teaching in which an instructor is the sole arbiter of information and presents a static notion of science. Dialectical arguments, also known as dialogical or multivoiced ((Driver et al., 2000), entail the contemplation of complex issues with multiple perspectives and no clear-cut solutions (van Eemeren et al., 1996). In short, dialectical argumentation emanates from informal reasoning. Just as logic, or analytic argument, serves as the language of formal reasoning, dialectical argument serves as the language of informal reasoning (Kuhn, 1991). Because the negotiation and resolution of socioscientific issues involves informal reasoning, subsequent references to argumentation will specifically address dialectical arguments.

Research from a variety of fields supports the notion that argumentation serves as an effective means of accessing an individual's informal reasoning (Kuhn, 1991; Means & Voss, 1996; Zohar & Nemet, 2002). General research trends also suggest that people of all ages have difficulty in constructing well-substantiated arguments (Driver et al., 2000; Kuhn, 1991; Kuhn, 1993; Perkins et al., 1991; Perkins & Salomon, 1989). The section which follows will review results of four recent studies which relate specifically to socioscientific argumentation. Figure 1 presents a summary of the major findings.

[Insert Figure 1 here.]

Kortland (1996) investigated middle school student argumentation patterns regarding environmental issues related to waste management and recycling. In the study's first stage, the author conducted structured interviews with 8 students (4 female and 4 male) aged 13-14 years attending a Dutch junior secondary school. The interviews were conducted in order to provide baseline data on student argumentation skills for facilitating the design of a classroom intervention. During the individual interviews, the students were asked to choose between consumer products packaged in different materials that would have differential environmental impacts. (The students were not explicitly informed of the differential impacts.) The interviewer then asked probing questions to encourage students to provide arguments in support of their decisions. The interviews were transcribed and analyzed with a set of a priori categories designed by the investigator to assess argumentation patterns. The results suggested that students frequently made both implicit and explicit comparisons between their potential choices and that in most cases, the criteria offered by students were valid in terms of supporting the original claim. However, the students limited their arguments to include only those factors which provided direct support for their stated position (i.e., no counterclaims or rebuttals were offered), and the clarity of many individuals' overall argumentation was somewhat suspect. Kortland concluded that the students possessed the ability to structure a basic argument, but he noted the limited range, clarity, and application of the arguments advanced.

Kortland (1996) hypothesized that the naïve arguments presented by students were due to two factors: inexperience in the formulation of arguments and lack of knowledge concerning the socioscientific issue of concern. To address these potential problems, the researcher designed and implemented an intervention with a different class of students from the same school during the following year. The intervention extended over ten 45 minute class periods. The intervention curricula focused on the formation and evaluation of arguments and content knowledge that underlies solid waste management and recycling issues. Twenty-seven (14 female and 13 male) 13 and 14-year-old students participated in the study. The students responded to pre- and posttest questionnaires designed to elicit argumentation, and their answers were subjected to the same type of qualitative analysis as the interviews from the study's first stage. The researcher also observed and recorded a classroom discussion during which students were encouraged to form arguments supporting their ideas concerning the waste issue. By comparing the argument patterns in the first stage interviews and the classroom discussion, Kortland concluded that the intervention accounted for negligible improvements in argumentation skills. However, analysis of the pre- and posttest questionnaires revealed improved validity and clarity of the criteria used to support student choices. The author suggested that the students maintained the basic level of argumentation evidenced prior to intervention, but improved understanding of the socioscientific issue itself led to more coherent decisions. This topic, the role of conceptual understanding, will be discussed in more depth in an upcoming section of this review.

Contrary to the Kortland (1996) study, results from a research project with Greek school children suggest that middle schoolers are able to develop well-formulated arguments regarding socioscientific issues (Patronis et al., 1999). This case study of an intact class of 14-year-old students (no additional information was provided concerning the number of students in the class) chronicled an extended learning experience (several months) related to a local environmental issue. The students worked in small groups to develop and plan a strategy to deal with the environmental issue. Each group presented their plan to the entire class and participated in a class discussion regarding the merits and problems associated with each plan. The culminating activity was a class vote for the best proposal. During the group work, a sub-sample of students were individually interviewed in order to reveal patterns of thinking behind the work being completed. The class sessions were videotaped and each group's discussions were audiotaped. Transcripts were produced for the interviews, small group discussions, class presentations, and whole-class debate. The researchers employed a qualitative analysis, borrowing from the work of Toulmin (1958), to assess the structure and nature of student argumentation. In the context of this study, structure referred to processes students used to express their ideas, and nature was related "to the different kinds of pragmatic arguments" (p. 748). The authors used the nature category to distinguish between "qualitative arguments" characterized by social, ecological, economic, and practical concerns and "quantitative arguments" which involved numerical calculations most commonly associated with school science. The results indicated that students did formulate reasonable arguments for supporting and refuting the plans that they themselves had developed. The researchers suggested that the personal connections students held with the local issue and the personal investment in the solutions proposed accounted for the better-than-expected patterns of argumentation.

While these results are encouraging for educators interested in incorporating socioscientific decision-making in the classroom, it is difficult to assess the validity of the claims made by the authors. It seems reasonable that personal interest and investment in an issue could improve argumentation related to that issue, but sufficient documentation is not provided in the Patronis et al. (1999) paper to warrant this conclusion. The qualitative taxonomy provided in the article does not provide a means for assessing the quality of arguments, and the authors do not include enough examples of student arguments to enable a reader to judge the trustworthiness (Lincoln & Guba, 1985) of the conclusions. The report demonstrates that the students in this study made some arguments concerning their potential solutions, but the reader is left wondering whether those arguments are as sophisticated as the authors claim or more reminiscent of the relatively naïve arguments revealed in the Korpan (1996) study.

Jiménez-Aleixandre et al. (2000) explored classroom argumentation in the context of genetics. They worked with an intact 9th grade biology class in Spain; the students were 14 and 15 years old. Six one-hour class sessions were observed, videotaped, and audiotaped over the course of two weeks. The teacher presented four standard genetics lessons (i.e. they did not deviate from how she had taught genetics in the past) which included lectures, small group activities, and basic genetic problem-solving like punnett squares. During the 5th and 6th class sessions, the students worked in small groups to resolve a socioscientific issue involving genetic and environmental variability of farm-raised chickens. Argumentation skills were not specifically addressed as a part of the curriculum. The researchers analyzed the transcripts recorded from all of the small group discussion sessions, but the research report concentrated on the dialogue of one group composed of four female students because this group's interactions were representative of patterns observed in other groups. The investigators were interested in two aspects of the student discussions: "argumentative operations" and "epistemic operations." Argumentative operations represented the structure of student argument as defined by Toulmin's (1958) argument pattern. To assess this component, the researchers dissected student dialogue and categorized statements in terms of data, claims, warrants, backing, qualifiers, and rebuttals. The analysis of epistemic operations focused on the kind of knowledge or cognitive operations used in an argument. The a priori list of epistemic operations, derived from fields such as history, philosophy of science, and classroom conceptual ecology, included causality, definition, classification, consistency, plausibility, and appeals to analogies, exemplars and authority.

Discussions among all the small groups exhibited widely varying argumentation patterns in terms of quality. Arguments ranged from sophisticated, those which included justification and backings, to naïve, those which contained isolated claims with no data support or backing. The group on which the report focused made far more claims than warrants, qualifiers, and rebuttals. Of the argumentative statements expressed, 66% were claims while only 21% were warrants, and 10% reported pieces of data. No qualifiers or rebuttals were offered. More alarming than the relatively limited argumentation was the fact that many students did not contribute to the discussions and appeared unequipped to do so. In the exemplar group, two students were responsible for over 75% of the dialogue and virtually all of the argumentation. The other two group members contributed little more than comments about the logistics of the assignment. They were either unable or unwilling to produce arguments. The students were very limited in terms of the epistemic operations with which their arguments addressed. Most of the argumentation focused on causality and appeals to analogies. The concentration on causality was due in part to the nature of the assignment itself; the students appeared far less concerned with issues of consistency and plausibility.

In another study of ninth grade student argumentation about genetic dilemmas, Zohar and Nemet (2002) assessed the effects of a twelve week intervention. The study was conducted with students attending two junior high schools in Israel. A total of nine intact classes (186 students) participated, and each class was diverse with respect to socioeconomic status and academic ability level. Prior to the intervention, all of the classes had studied the basic principles of genetics. During the intervention, students were exposed to advanced genetic concepts related to genetic engineering, applied human genetics, and the social issues associated with these topics. Four classes (87 students), which served as the control group, received "conventional instruction;" these students worked through a specially prepared collection of material that followed a "traditional textbook approach" with no special attention paid to processes of informal reasoning or argumentation. The five classes (99 students) exposed to the experimental treatment received explicit instruction in argumentation skills in addition to the genetics curriculum, and the students practiced argumentation in the context of human genetic dilemmas.

Pre-instruction written tests of argumentation revealed that most students (90%) in both control and experimental groups could formulate simple arguments, which were defined as claims or assertions supported by at least one justification. However, only 16.2% of the respondents referred to correct, specific biological knowledge in support of their positions. Following the intervention, students from the control and experimental groups scored significantly higher on a multiple-choice test of genetics than they had prior to instruction. However, the experimental group outperformed the control, indicating that either the interventions were not equivalent or that argumentation instruction and practice can lead to improved conceptual understanding. Post-intervention analyses of argumentation, which involved written tests similar to the pre-test, revealed marked differences between the two groups. Whereas the control group showed no significant improvement in argumentation, students in the experimental group formulated qualitatively improved arguments in contexts similar to the dilemmas they had experienced during the intervention as well as transfer problems that deviated substantially from the material they had already seen. Class discussions with the experimental group also revealed improvements in the use of argumentation skills. Discussions that occurred after instruction included a higher incidence of explicit conclusions (as opposed to implicit claims), an increase in number and complexity of justifications per conclusion, and a decrease in the number of unjustified conclusions. The researchers also measured the quality of classroom argumentation by tracking conversational turns throughout the discussions. Conversational turns occurred when a different student began talking; fewer conversational turns per minute indicated that individual speakers were providing more information. The post-instruction discussion had significantly fewer conversational turns than the pre-instruction discussion. The authors also noted that the mean number of "idea units" per conversational turn was higher in the second discussion, but this trend was not statistically significant. The class discussion results coupled with the individual written samples led the researchers to conclude that properly designed curriculum integrating socioscientific content and argumentation can improve both conceptual understanding and argumentation.

The Influence of Ideas about the Nature of Science on Socioscientific Decision-making

For centuries, philosophers have debated the demarcation of science as distinct from other ways of knowing (Curd & Cover, 1998). Although questions of rationality, realism, objectivity, and empirical underdetermination still plague philosophical explorations of science, science educators have proposed a basic characterization of the scientific enterprise to help non-scientists understand the field's strengths and limitations (Abd-El-Khalick & Lederman, 2000;

Aikenhead & Ryan, 1992; Lederman, 1992; McComas, Clough, & Almazroa, 2000). This basic description and characterization of science epistemology has become known as the nature of science (NOS). Among the constructs that are central to the consensus view of NOS are the following ideas. Some scientific knowledge is relatively stable; whereas, less substantiated knowledge is tentative and subject to change given new evidence or reinterpretation of existing evidence. Science relies on empirical evidence, and scientists employ creativity in order to obtain and interpret this evidence. Scientific research and cultural norms mutually shape one another. The pursuit of scientific progress often encounters (or creates) ethical and moral considerations. Several authors (Kolstø, 2001a; Sadler et al., 2002; Zeidler et al., 2002) have suggested that an individual's understanding of NOS inevitably alters the manner in which she/he responds to situations involving science including socioscientific issues. The claim is that a person's understanding about the epistemology of science will influence the application of the content knowledge. In other words, nature of science conceptualizations affect the interpretation of scientific knowledge which in turn influences informal reasoning related to issues contingent on that knowledge. This section will review three studies that empirically tested this assumption. Figure 2 presents a summary of these findings.

[Insert Figure 2 here.]

Exploring the relationship between student conceptions of NOS and their reactions to socioscientific issues was the primary goal of research reported by Zeidler et al. (2002). This study involved a diverse group of subjects from the United States: 9th and 10th grade general science students, 11th and 12th grade honors science and physics students, and individuals enrolled in college preservice science education courses. From an initial sample of 248 individuals, 82 subjects were selected to participate in dyadic interviews based on their responses to an open-ended questionnaire focused on the use of animals for scientific research. The 41 pairs of students (27 high school and 14 college) were grouped so that their beliefs and opinions about animal research differed from one another. An interviewer asked the participants a series of questions related to animal rights and research issues. The interviews were semi-structured, and the two students were free to interact and respond to the comments made by the other. All of the participants also responded to an open-ended questionnaire designed to elicit their beliefs about the nature of science. Responses to the two written questionnaires and transcripts from the interviews were qualitatively analyzed to reveal possible relationships between NOS conceptualizations and socioscientific decision-making.

Zeidler et al. (2002) concluded that in the context of the animal rights issue, beliefs about NOS were related to decision-making in at least three distinct ways. 1) Students acknowledged the social and cultural influences affecting how individuals view science. This issue was particularly important as students considered how scientists collected, interpreted, and reported data related to the benefits and problems associated with using animals in research. 2) Several students commented on the importance of empirical evidence in the determination of positions regarding socioscientific issues. Their belief in the centrality of data as a part of the nature of science affected their decisions. 3) The authors also noted the tendency for students to compartmentalize personal knowledge and scientific beliefs. Several students felt that knowledge and information produced in the process of science was isolated and independent of their own belief systems. Consequently, the opinions of students who adopted this perspective were impervious to scientific information. The researchers reported "only a few discernible instances of a clear relationship [between NOS and reactions to a socioscientific issue]" (p. 359). However, the patterns revealed suggest that although detecting unambiguous NOS influences may be empirically challenging, a person's beliefs about the practices and epistemology of science can have a profound effect on informal reasoning related to socioscientific issues.

The relationship between NOS conceptualizations and socioscientific decision-making was also a research focus for Sadler et al. (2002). In this study, 84 students (14 to 17-years-old) enrolled in biology classes at a high school in the Southeastern United States responded to open-ended questionnaires regarding their beliefs about NOS in response to a socioscientific issue. The students read two articles, constructed specifically for the study, that offered opposing positions on the issue of global warming. The follow-up questionnaire was designed to elicit student ideas about the following aspects of NOS in the context of the global warming debate: data use and interpretation, cultural influences on the progress of science, the evolution and inconsistency of some scientific ideas, and factors which constitute "scientific merit." To improve the trustworthiness of the conclusions drawn from the questionnaires, the researchers interviewed a subset (n=30) of students from the original sample.

Echoing the results of the Zeidler et al. (2002) study, Sadler et al. (2002) found students' appreciation of the social embeddedness of science (or lack thereof) to be a considerable influence on socioscientific decision-making. Several students held the belief that economic interests and personal perspectives affected the selection and presentation of data and information related to the issue of global warming, thereby altering the manner in which the students would use that information. However, a minority of the sample articulated the opposite view: social and cultural factors do not influence the global warming debate. The adoption of this perspective resulted from the naïve belief that science and its findings are isolated from the broader structure of society. A similar perspective was revealed in the comparison between student ideas about that which constitutes scientific merit and that which they find personally convincing. The students were asked to select both the article that possessed more scientific merit and the article which was more persuasive. Because both of the articles contained the same types of data in terms of quantity and quality, and both were written in a similar style with comparable rhetoric, the authors hypothesized that student assessment of merit would influence their determination of persuasiveness. Although the majority of participants did choose the same article for both questions, 40% of the students reported that even though one article had more scientific merit, they found the other article more convincing. This result also supported one of the Zeidler et al. (2002) conclusions: students had a tendency to compartmentalize scientific evidence and the information they use to make personal decisions. This apparent exclusion of science from the personal domain unavoidably affects an individual's informal reasoning regarding socioscientific issues.

Bell and Lederman (in press) investigated the relationship between NOS and socioscientific decision-making by examining the beliefs and opinions of professors from around the United States. The authors argued that adults such as professors (as opposed to students) had more opportunities to make decisions regarding socioscientific issues as well as a greater likelihood to have formed stable views about the nature of science. The volunteer subjects had all earned doctoral degrees but represented many academic fields including science related disciplines (natural sciences, science education, engineering, and philosophy of science) and non-science disciplines (humanities and education). Each of the 21 participants responded to an open-ended questionnaire that elicited patterns of decision-making in response to four socioscientific issues: fetal tissue implantation; global warming; the relationship between diet, exercise and cancer; and the link between cigarette smoking and cancer. They also responded to the V-NOS(B), an open-ended response instrument designed to explore views on the nature of science (Abd-El-Khalick, Bell, & Lederman, 1998). Following completion of the instruments, one of the investigators conducted semi-structured phone interviews with each of the participants to confirm, probe, and elaborate the written responses.

The subjects were divided into two groups based on divergent views of NOS. Nine participants, who held similar NOS ideas, composed each group while three were excluded from this portion of the study because they possessed mixed NOS views inconsistent with either of the two identified positions. One group possessed views consistent with current conceptions of NOS as delineated in the science education reform documents (AAAS, 1990; 1993; NRC, 1996); whereas, the other group adopted an absolutist perspective on NOS. The researchers compared the decisions, the factors influencing those decisions, and the reasoning patterns that produced those decisions between the two groups. The results failed to confirm the hypothesized prediction that divergent NOS conceptualizations would produce divergent socioscientific decisions. No significant differences were detected in the decisions made by the participants in each group. The analysis of factors which contributed to those decisions suggested that NOS aspects were considered (at least implicitly) in the determination of a position but the influence of NOS was relatively minor as compared to personal, social, and moral considerations. Although the two groups held different beliefs on the epistemic status of empirical evidence, every participant in both groups cited the role of scientific evidence as an integral aspect of their decision-making. However, the authors concluded that empirical evidence was not a primary factor in the reasoning patterns of either group. In short, the participants' reactions and responses to socioscientific issues appeared to be unaffected by their divergent views on the nature of science.

While the results of Bell and Lederman's (in press) study are significant, they may not necessarily inform the question of how NOS conceptualizations influence socioscientific decision-making in students or the general public. The participants were a highly educated group of individuals working in academia. The extent to which this group may differ with respect to their beliefs about the epistemology of science may be miniscule as compared to the views held by secondary students or adults who do not spend most of their time involved in formal education. The fact that professors who adopt divergent philosophical perspectives do not differ significantly in their socioscientific decision-making does not necessarily imply that other individuals will not be influenced in their decision-making by their perceptions of how science works and what scientific evidence reveals. Some differences in views on NOS may not result in distinct socioscientific decisions, but as the studies cited earlier (Sadler et al., 2002; Zeidler et al., 2002) suggest, understanding certain NOS aspects (namely social embeddedness, tentativeness, and empirical dependence) will influence informal reasoning.

Evaluation of Information Pertaining to Socioscientific Issues

In the context of socioscientific issues, information, data, and knowledge claims possess central importance to informal reasoning. In order to evaluate alternative positions, one must collect information about those options. Given the complexity of socioscientific issues, most of the populace must rely on the reports of others as their primary information sources, and people often receive conflicting reports. This section will review research that has addressed how individuals negotiate multiple, sometimes contradictory information in the process of informal reasoning. Figure 3 provides a general summary of the four studies reviewed.

[Insert Figure 3 here.]

Kolstø (2001b) performed a qualitative study to detect the manner in which students evaluate information and knowledge claims as they prepare for socioscientific decision-making. He interviewed 22 Norwegian students (16-years-old) from four different high schools and asked direct questions focused on how students judged specific pieces of information that they had read related to a scientific issue with social importance. Student responses formed a two-dimensional matrix: the students based their judgments on two factors, the informational statements themselves or the authorities who provided the information; and they also showed two general modes of judgment, acceptance or active evaluation. Students accepted or evaluated the information, or they accepted or evaluated the source of information. Some students accepted knowledge claims at face value; whereas, others reported that any knowledge claims must be subject to evaluation. Students in the second group described ways to test for the reliability of information by seeking independent support for the statements.

Other responses focused on the source of information rather than the knowledge claims themselves. Students were willing to accept authority figures based on two general criteria. Some sources were deemed legitimate if they conveyed confidence in their research, while others gained acceptance because of perceived expertise in a specific area. In other words, information was accepted because its source was an expert. A final group of students was willing to judge the validity of information on its source but would not accept the authority without an evaluative process. Students providing these responses based their analyses on one of four standards: assessment of risk, interest, neutrality, or competence. Some students equated the credibility of a source with his/her discussion of risk; the authority figures who talked about potential risks associated with the decision to be made were evaluated more positively than those who did not. Some students ascribed more validity to sources with vested interests, while others were more likely to respect the information provided by uninvolved, neutral sources. Finally, another group sought independent support of an authority's competence. Students were far more likely to evaluate the source of knowledge claims than the claim itself, a result which suggests a lack of content knowledge. It is not surprising that students lack content knowledge relative to socioscientific issues given the fact that these issues often stem from cutting-edge areas of scientific research. Many individuals with advanced training in science might not possess the necessary training and information to accurately judge reports from a burgeoning research area, so it is unrealistic to expect that novices should. Norris (1995) suggests that science teachers should train students to evaluate the believability of experts rather than the information they report for these reasons. Kolstø's (2001b) study reports that this goal is being realized; however, the students tended to engage in very shallow analyses. Even though many students evaluate the source of information, their conclusions are often short-sighted or inaccurate.

Korpan et al. (1997) assessed how students evaluate knowledge claims in a less direct manner than the previously cited studies. The researchers gave a series of four news briefs to college students ranging in age from 17 to 38 years old and asked them to identify additional information needed to confirm the reports. The fictitious articles were pre-patterned so that each included an acknowledgment of the group performing the research, a description of the issue, and independent support for the findings. The following list provides the most frequently requested types of information: social factors influencing the report, details about a specific item in the text, additional data or statistics, related findings, and research methodologies. Subjects also made requests for many other types of information not easily classified. One of the most unexpected results was that even though the format of each article was identical, subjects made very inconsistent information requests. Only in the case of research methodology did a majority of subjects (52%) ask for the same type of information in response to all four articles. Subjects very rarely requested analogous pieces of information for more than one or two articles. These results suggest that even among quite similar decision-making situations (all of the articles involved science issues), context significantly influences an individual's informal reasoning.

Another interesting conclusion of the Korpan et al. (1997) study was the tendency for subjects to seek information concerning methodology as opposed to other factors like the implications of the conclusions. Participants more frequently sought information about how the research was conducted and what factors might have influenced the results. They were less interested in what was found or who conducted the research. These findings contradict those of the Kolstø (2001b) study, which suggested that people were more likely to question the authority of the researcher than the methodology. The apparent discrepancy is most likely due to one of two factors. Kolstø's (2001b) subjects were all 16 years old; whereas, the Korpan et al. (1997) subjects ranged in age from 17 to 38. Different reasoning strategies as a result of age may have contributed to the different findings. However, the difference might also have resulted from the research formats. The manner in which the researchers elicited data from their subjects might account for the different findings. Given this hypothesis, it is inappropriate to conclude that individuals are generally more likely to focus on either methodology or authority. They both likely factor into informal reasoning processes, but any stronger conclusions require additional research.

Whereas Kolstø (2001b) and Korpan et al. (1997) investigated how students responded to scientific evidence in an artificial context, Tytler et al. (2001) explored how individuals interacted with evidence in an actual socioscientific dilemma. A community in the UK was debating the construction of a recycled liquid fuel (RLF) burning cement kiln. RLF is discarded organic solvents that can be burned at extremely high temperatures for long periods of time. The use of RLF in a cement kiln eliminates the use of coal, a costly and polluting source of energy; however, RLF combustion releases dangerous byproducts such as dioxins, heavy metals, and volatile organic compounds. Tytler et al. (2001) conducted a case study based on this issue by analyzing all of the publicly accessible documents related to the debate including reports on public meetings, newspaper editorials, public register documents, and government reports. The authors also conducted semi-structured interviews with two members of a community action group opposed to the RLF kiln and one member of a committee formed by the company proposing the kiln to serve as a liaison between the company and the local public.

Tytler et al.'s (2001) analysis focused on how individuals, who were not professional scientists, construed, interpreted, and applied evidence as it related to the issue facing their community. The researchers concluded that the public relied on three major classes of evidence: scientific evidence, informal evidence, and wider issues that impinge on evidence. Scientific evidence included material data, sometimes referred to as "hard evidence." Although the public seemed to recognize the importance of material data, they did not rely on this class of evidence very often in the formulation and support of positions. Informal evidence, defined as common sense, circumstantial evidence, and personal experience, contributed far more significantly to the decisions made by the public. The authors suggested that community members used informal evidence as a means to bridge scientific or technical assertions with their own personal, political, and practical understandings. This "reconstruction" or "contextualization" of science for application in local settings has been documented by other researchers (Layton, 1991; Wynne, 1991). The final type of evidence employed (i.e. broader issues that impinge on evidence) dealt with the manner in which the issue was framed. Below, the authors describe the significance of this class of evidence:

> These dimensions could be seen as windows through which the issue, and the scientific evidence, is viewed. Each involves positions, which will flavour not only the interpretation of the science evidence ... but also will influence views about what counts as evidence, what evidence should be gathered, and what decisions flow from this. Science in this context is the servant of the wider concerns of all the players. (Tytler et al., 2001, p. 826)

In short, this final category of evidence represented personal values related to the environment, the economy, and moral commitments. The authors contended that these perspectives altered the manner in which individuals responded to the scientific and informal evidence.

In several of the studies already reviewed, evidence has emerged as an important component in the resolution of socioscientific issues. During the Kolstø (2001b) and Korpan et al. (1997) studies, students assessed the validity of evidence. The academics who participated in the Bell and Lederman (in press) study relied on evidence for their decision-making as did the community members from the Tytler et al. (2001) study. In a study described earlier, Sadler et al. (2002) explored student understanding of scientific evidence by asking participants to identify and describe the use of data cited in two different position papers regarding global warming. The authors were surprised to learn that only about half (47%) of the high school students participating were able to identify and explain the use of data in the context of the global warming issue. Fifty three percent of the students held naïve views about the meaning of data including 10% of the overall sample who could not make distinctions between scientific data, predictions, and hypotheses. The lack of familiarity with that which constitutes scientific data displayed in the Sadler et al. (2002) sample may have contributed to the tendency to rely on informal evidence, as opposed to scientific evidence in the Tytler et al. study (2001).

The Influence of Conceptual Understanding on Informal Reasoning

One of the primary goals for science education has been the promotion of conceptual understanding of science content knowledge (Jenkins, 1990; Laugksch, 2000). It seems intuitively obvious that science students should learn science concepts. However, what students are able to do with that conceptual understanding is considerably less obvious. Research on transfer, the application of learned knowledge in novel situations and contexts, suggests that classroom learning is infrequently applied in all but the most similar circumstances (Detterman, 1993; Haskell, 2001). From this vantage, conceptual understanding of science content would not appear to be a very significant factor in non-school contexts such as real-life socioscientific issues. However, a common assumption among science educators holds that understanding science content is necessary for informed (as opposed to whimsical or poorly thought-out) decisions regarding socioscientific issues (American Association for the Advancement of Science, 1990; National Research Council, 1996; Patronis et al., 1999; Pedretti, 1999).

Research from the broader traditions of psychology and education has produced mixed results with respect to the extent to which conceptual understanding influences informal reasoning. In reviewing thirty years of research from the cognitive sciences, Perkins and Salomon (1989) conclude that decision-making requires a basic understanding of pertinent concepts. In the context of a socioscientific issue like genetic engineering, this claim is analogous to asserting that an individual must have some basic knowledge of heredity to meaningfully engage in informal reasoning. Beyond this most fundamental application of knowledge, the influence of conceptual understanding on informal reasoning, argumentation, and decision-making is rather minimal according to current research. Kuhn (1991) reports that no studies have shown a significant relationship between knowledge base in a content area and the cognitive skills used in that area. In a study involving students from many different grade and ability levels, Perkins et al. (1991) conclude that the quality of informal reasoning is independent of conceptual understanding of related content knowledge. Means and Voss (1996) do report that knowledge is related to informal reasoning and argumentation. However, they conclude that while increased knowledge confers quantitative differences in reasoning such as the number and type of claims and justifications offered, the quality of reasoning and argumentation is not significantly affected by conceptual understanding. The remainder of this review will explore the link between informal reasoning and conceptual understanding in studies involving socioscientific issues. Figure 4 summarizes these findings.

[Insert Figure 4 here.]

Results from a few studies already reviewed, address the relationship between informal reasoning and conceptual understanding. In their study of argumentation patterns in response to genetic dilemmas, Zohar and Nemet (2002) reported that although control group scores on a conceptual test of genetics significantly improved as a result of instruction, argumentation from the same group remained unchanged. This result implies that argumentation skills do not necessarily improve with greater conceptual understanding. As mentioned earlier, argumentation and informal reasoning are related in that informal reasoning is expressed through argumentation, but they represent different processes. The conclusion that argumentation skills were independent of knowledge gains does not necessarily preclude a link between informal reasoning and conceptual understanding, but the study does not support that link.

In the community case study based on a local environmental issue (Tytler et al., 2001), members of the general public relied more frequently on "informal evidence" than "scientific evidence." (Recall that informal evidence was defined to include common sense, circumstantial evidence, and personal experience; whereas, scientific evidence was delineated as hard evidence or material data.) The scientific evidence was most frequently referred to and applied by science experts or professional scientists involved in the debate. The non-scientist participants used informal evidence "as a bridge between technical assertions and personal or practical or political understandings" (p. 825). It might have been the case that the general public lacked the necessary conceptual knowledge to access the scientific evidence. This is certainly not the only interpretation of the patterns reported: the public might have understood but chosen to ignore the scientific evidence in favor of the informal evidence. Regardless of the actual content knowledge of these participants, this case revealed a situation in which conceptual understanding could have potentially affected socioscientific decision-making.

In a pair of papers, Fleming (1986a; 1986b) explored student reasoning by means of a qualitative analysis of semi-structured interviews based on socioscientific issues. He interviewed 38 adolescents (mean age: 17.3 years-old) who had completed at least one general course in both biology and chemistry. He concluded that the dominant reasoning pattern involved social knowledge which included an individual's ideas about him/herself, morality, and society. However, the author was also interested in the influence of nonsocial cognition which was defined as the use of knowledge about the physical world (i.e. scientific content knowledge). The focus of the second paper (Fleming, 1986b) was an assessment of how students used their understandings of science in the analysis of socioscientific issues. The researcher distinguished between the meaningful application of scientific knowledge and simply using science terms.

Whereas 91% of the respondents incorporated science terminology in their interview responses, few students actually drew on scientific knowledge in the articulation of their positions. (The author did not report on the number of students in this category; he just stated comments including scientific information were so few that they were considered insignificant.) These results could be interpreted in two ways: the students could have possessed the science knowledge but chosen to rely on social knowledge, or they could have lacked the science knowledge making its application impossible. Fleming (1986b) opted for the latter conclusion:

> Adolescents' knowledge of the physical world appeared to be restricted to a few words heard in science class. Knowledge of the physical world is rarely, if ever, used when analyzing and discussing socio-scientific issues. School science is the source of the colloquial expressions. It is not, from students' perspectives, a source of useful information for analyzing socio-scientific issues. (p. 698)

It would be reasonable to expect that older students possess greater conceptual understanding of ideas that underlie socioscientific issues and therefore, be more likely to apply that knowledge in the resolution of those issues. However, a study with students younger than any of those cited previously in this section provides the first strong evidence for a positive association between conceptual understanding and informal reasoning. Hogan (2002) worked with a group of 24 (8 female and 16 male) eighth grade students who had spent the previous academic year studying aquatic ecology as a part of their science classes. Each volunteer was interviewed individually to assess his/her prior knowledge of aquatic ecology. The researchers rated the students' ecological understanding on a five-point scale. Following the interviews, the students worked in groups of three to make environmental management decisions related to controlling aquatic, invasive exotic species. (Although the students had been exposed to the basics of aquatic ecology, invasive exotic species had not been a topic of instruction.) The next phase of the experiment involved individual interviews during which the students reflected on their decisions and the group interactions. The researcher also interviewed an environmental scientist with extensive experience handling the type of problem encountered by the students in their group work.

Not surprisingly, the reasoning of the professional scientist who specialized in aquatic ecology revealed a richer collection of background knowledge, a greater appreciation for pertinent issues, and more sophisticated justifications and explanations. The student groups addressed the same themes that the scientist considered important, but each individual group typically adopted a narrow focus, concentrating on only one or two themes. The author suggested that the limited knowledge of a group of any three participants, as compared to the knowledge of the scientist, restricted the group's ability to consider multiple factors leading to their relatively naïve management decisions. Concluding that middle schoolers do not reason about environmental issues as well as environmental scientists is not particularly significant; however, even among the student groups, a trend developed that supported the link between informal reasoning and conceptual understanding. Whereas, most groups were relatively heterogeneous in terms of the ecological knowledge of the members, the members of one group all scored very well on the knowledge assessment. Only four students from the entire sample scored a 5 (out of 5) on the knowledge assessment, and three of them were in one group. The author repeatedly commented on the relative superiority of this group's reasoning as compared to the other groups:

[the group's reasoning was] impressive in structure as well as content. (p.362)

> [they] displayed the ability to synthesize a range of information, draw well-supported inferences, and thoroughly consider the ramifications of alternative decisions. (p. 362)
>
> [the group] displayed the most integrative and thorough reasoning about the management decision. (p. 363)

In contrast to the other studies in this section, this report provided positive support for the claim that conceptual understanding of material that underlies socioscientific issues can improve informal reasoning.

Zeidler and Schafer's (1984) work with college students also substantiates the link between conceptual understanding and informal reasoning. The researchers selected two groups of undergraduates for their analysis: 86 environmental science majors and 105 nonscience majors. Each of the participants completed the Defining Issues Test (DIT), a general measure of moral reasoning; the Environmental Issues Test (EIT), a measure of moral reasoning on environmental problems; the Test of Ecology Comprehension (TEC), a conceptual test of environmental understanding; and the Ecology Attitudes Inventory (EAI), which is composed of three subtests, verbal commitment, actual commitment, and affect related to the environment. The researchers performed a 2x2 repeated measures ANOVA to assess group (science vs. nonscience majors) differences in moral reasoning applied to different contexts (EIT vs. DIT) as well as a multiple regression analysis to evaluate the relative contributions of DIT, TEC, and EAI scores to the EIT outcome variable.

While the environmental science majors scored higher on the overall measure of environmental attitude, the groups were not significantly different in terms of affect defined as emotive feelings towards the environment. The science majors also performed better on the comprehension test, but no significant differences between the groups emerged in response to the general measure of the moral reasoning, the DIT. Both groups displayed significantly higher forms of moral reasoning on the EIT than the DIT, but the science majors outperformed the nonscience majors on the EIT. The fact that both groups displayed positive attitudes towards the environment, suggested that the differences in conceptual understanding contributed to the disparity in moral reasoning between the groups. This hypothesis was examined by means of a multiple regression analysis. All of the variables tested, including the ecology comprehension test, significantly contributed individually to performance on the EIT. While moral reasoning, the target of EIT scores, is not synonymous with informal reasoning, moral reasoning forms an integral part of informal reasoning (Andrew & Robottom, 2001; Solomon, 1994; Zeidler, 1984). Zeidler and Schafer's (1984) research challenged past findings (Iozzi, 1977) that suggested moral reasoning was independent of context. By revealing the context dependence of moral reasoning, Zeidler and Schafer (1984) uncovered a possible relationship between conceptual understanding of material and moral reasoning regarding issues related to that material. Because moral reasoning is a component of informal reasoning in the context of socioscientific issues, it follows that conceptual understanding may be an important variable for informal reasoning.

Summary and Implications

Research related to informal reasoning and socioscientific issues has focused on the following four distinct but related areas: 1) argumentation as a means of expressing informal reasoning, 2) the influence of ideas about NOS, 3) the ability of individuals to evaluate information pertinent to socioscientific issues, and 4) the role of conceptual understanding. (For graphical summaries of the research related to each of these variables see Figures 1-4.) By exploring the studies contributing to these areas, a picture of what is known as well as what still needs to be learned emerges.

Before summarizing the effects of the variables just listed, a trend across all of the research should be noted. Personal experiences of the decision-makers emerged as a consistent influence on informal reasoning related to socioscientific issues (Bell & Lederman, in press; Fleming, 1986a; Fleming, 1986b; Patronis et al., 1999; Pedretti, 1999; Sadler et al., 2002; Tytler et al., 2001; Zeidler & Schafer, 1984; Zeidler et al., 2002). In some cases, personal experience seemed to mediate scientific knowledge (Tytler et al., 2001; Zeidler & Schafer, 1984); whereas, other studies suggested personal experience was used to the exclusion of scientific knowledge (Sadler et al., 2002; Zeidler et al., 2002). These results should not be surprising given the well-established role of prior knowledge and personal experiences in learning (Berk, 2000; Bransford, Brown, & Cocking, 1999; Flavell, Miller, & Miller, 2002). Recognizing and considering how personal experiences affect socioscientific decision-making should become an explicit focus for both research and curriculum development.

Based on the literature, the promotion of argumentation skills appears to be a difficult educational goal. Of the four reports, that investigated argumentation in the context of socioscientific issues, only one (Zohar & Nemet, 2002) reported significant gains in argumentation skills in response to intervention. However, two of the studies that failed to enhance argumentation skills did not explicitly address argumentation during the course of the intervention. Furthermore, argumentation and the informal reasoning that underlies it are complex processes that require time and practice to develop (Berkowitz, Oser, & Altof, 1987; Driver et al., 2000; Means & Voss, 1996). In fact, it is reasonable to expect that significant improvements (via classroom learning) in argumentation and informal reasoning will only occur following extended learning experiences focused specifically on this goal.

The studies that examined the influence of NOS conceptions on socioscientific decision-making report mixed results. In a study involving college and university professors (Bell & Lederman, in press), researchers did not detect significant differences in decision-making patterns despite divergent views on NOS. However, studies involving high school and college students (Sadler et al., 2002; Zeidler et al., 2002) reported significant interactions between NOS conceptions and socioscientific decision-making. This discrepancy might be attributable to how NOS was used and explored in each of the studies. While the authors of all three studies share a common notion of NOS, their subjects' levels of NOS understanding were vastly different. The students were concerned with NOS aspects like empirical evidence and social embeddedness; whereas, the differences in NOS conceptions held by the professors involved epistemological and methodological issues. The combined results suggest that basic ideas concerning NOS may influence informal reasoning associated with socioscientific issues, but discrepancies in the more philosophical aspects of NOS do not affect informal reasoning.

Given the fact that socioscientific issues often involve scientific ideas from the frontiers of research, most people must rely on outside sources of information to form positions regarding these issues. Information of this type is transmitted to decision-makers through a variety of sources including newspapers, magazines (both news magazines and special interest magazines), the internet, politicians, teachers, friends, and family. Research on how people evaluate information pertaining to socioscientific issues suggests that most individuals are ill-prepared for the task. Individuals usually adopt two strategies: evaluation of the information provided or evaluation of the information's source. The strategies themselves are valid, but the manner in which individuals carry-out the evaluations is questionable. The studies cited revealed that individuals often accept information at face value, use inconsistent evaluative criteria, and focus on superficial elements of the information and/or source (Kolstø, 2001b; Korpan et al., 1997). In addition, research on the interpretation of scientific evidence revealed a limited capacity for many individuals to perceive and use scientific data (Sadler et al., 2002; Tytler et al., 2001). These findings suggest that information evaluation needs to be a strong component of socioscientific issue curricula and instruction.

The studies related to the influence of conceptual understanding on informal reasoning regarding socioscientific issues suggest some tentative, yet consistent trends. Two of the studies reviewed (Fleming, 1986b; Tytler et al., 2001) revealed that a lack of conceptual understanding limited informal reasoning. The other reports (Hogan, 2002; Zeidler & Schafer, 1984) suggested that conceptual understanding improved informal reasoning on socioscientific issues. While these conclusions seem intuitively obvious, they are relatively unique within the broader literature base of informal reasoning and conceptual understanding (Kuhn, 1991; Means & Voss, 1996; Perkins et al., 1991). Given the lack of evidence from other fields regarding the link between conceptual understanding and informal reasoning and the tangential nature of the findings reported herein (none of these studies were specifically focused on the role of conceptual understanding), additional work in the area is necessary. Future research needs to specifically address how conceptual understanding is related to informal reasoning in the context of socioscientific issues.

Implications for Science Education

The articulation of the overall goals of science education are one of the helpful accomplishments of the science education reform documents (AAAS, 1990; NRC, 1996). The ideas are not revolutionary in that the sentiments of the documents have historical foundations that span a century (Laugksch, 2000), but the collection and communication of these ideas bolster their significance and serve to unify goals of science education. Consider the vision laid out in the opening lines of *Science for All Americans:*

> Education has no higher purpose than preparing people to lead personally fulfilling and responsible lives. For its part, science education...should help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them also to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. (AAAS, 1990, p. xiii)

Critics might argue that these idealistic aims are beyond attainment in real-life science classrooms complete with limited supplies, expanding class roles, discipline problems, extra-curricular distractions, etc. But if science educators are not aiming to help students lead productive lives, capable of thinking for themselves and equipped to participate meaningfully in society, then why do science educators teach?

Incorporating socioscientific issues in classroom science is one path towards realizing the lofty goals laid out in the reform documents. Socioscientific issues are by no means the only means of promoting scientific literacy, but they can provide a powerful vehicle for teachers to help stimulate the intellectual and social growth of their students. If we want students to think for themselves, then they need opportunities to engage in informal reasoning, including the contemplation of evidence and data, and express themselves through argumentation. As the cited research (Driver et al., 2000; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Kortland, 1996; Patronis et al., 1999; Zohar & Nemet, 2002) suggests, socioscientific issues can provide a context for informal reasoning and argumentation. In order to participate thoughtfully in societies which depend on science and technology, individuals require some appreciation for the nature of science, and the literature supports the interrelatedness of socioscientific issues and NOS considerations (Bell & Lederman, in press; Sadler et al., 2002; Zeidler et al., 2002). This review is not suggesting that by simply being exposed socioscientific issues, students will become better informal reasoners capable of analyzing complex arguments and will develop mature epistemologies of science. On the contrary, the reviewed research suggests that producing these kinds of changes are quite difficult to achieve. However, socioscientific issues can provide a forum for working on informal reasoning and argumentation skills, NOS conceptualizations, the evaluation of information, and the development of conceptual understanding of science content. The findings reviewed in this article offer some recommendations for educators who currently employ socioscientific issues in their classrooms or plan to do so in the future. The following items summarize the most pertinent considerations raised by the research.

- Personal experiences can mediate or obfuscate scientific knowledge in the consideration and resolution of socioscientific issues.
- Individuals do not necessarily naturally construct well-reasoned arguments concerning socioscientific issues. The development of effective argumentation requires explicit instruction and ample opportunities for practice.
- Promoting the development of sophisticated NOS beliefs is an important stand-alone goal of science education (Abd-El-Khalick et al., 1998; Lederman, 1992; McComas et al.,

2000); in addition, NOS instruction likely enhances student experiences with socioscientific issues.

- Students would benefit from strategies for interpreting and evaluating data and information regarding socioscientific issues and opportunities to exercise those strategies.
- Individuals require an understanding of content material that underlies socioscientific issues in order to engage thoughtfully in informal reasoning regarding those issues.

Socioscientific issues have the potential to contribute significantly to the enhancement of science education at multiple levels including middle school (Chiappetta & Koballa, 2002; Hogan, 2002), high school (Jiménez-Aleixandre et al., 2000; Simonneaux, 2001), and college (Siebert & McIntosh, 2001; Zeidler et al., 2002). Researchers should continue to explore how individuals perceive, interpret, negotiate, and resolve these socioscientific issues, as well as seek optimal methods for incorporating these issues into science classrooms.

Figure 1. Graphic overview of research related to socioscientific argumentation. (SSI represents socioscientific issues).

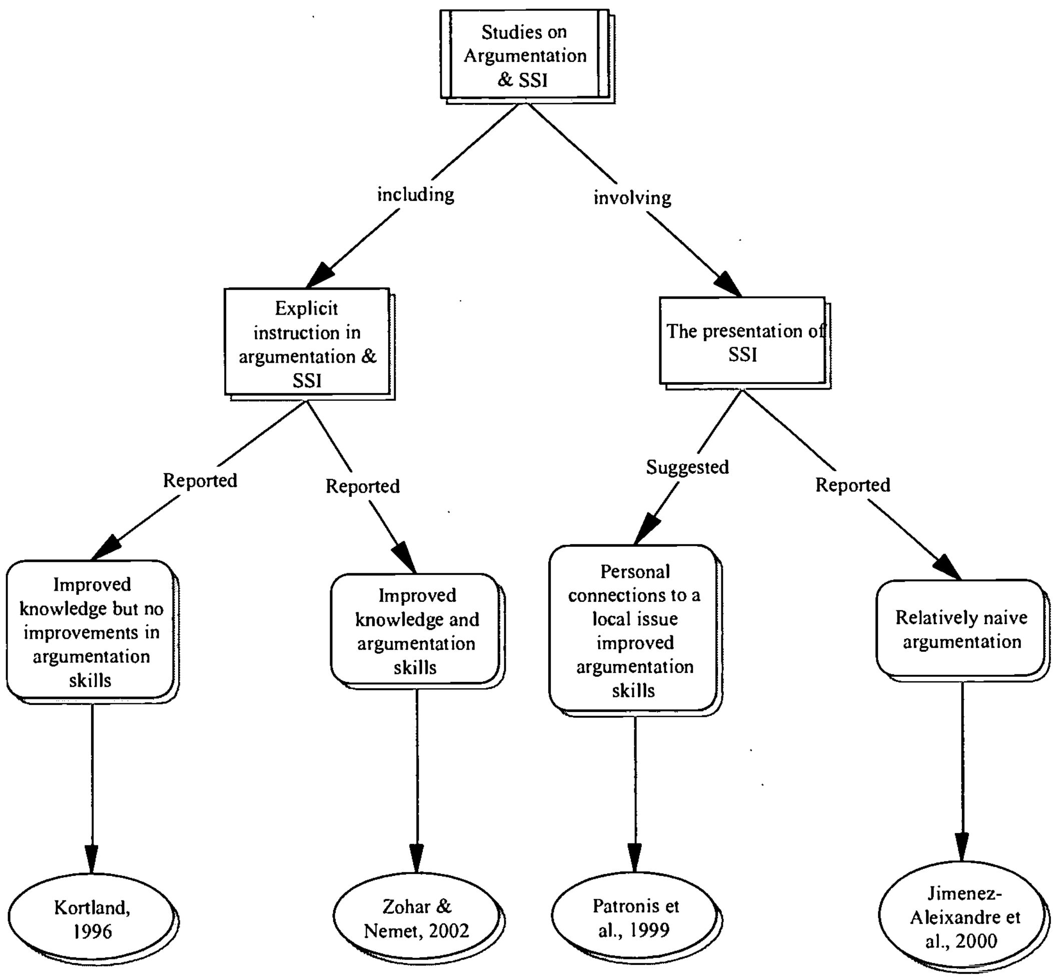

Figure 2. Graphic summary of research related to the influence of nature of science (NOS) conceptualizations on informal reasoning regarding socioscientific issues (SSI).

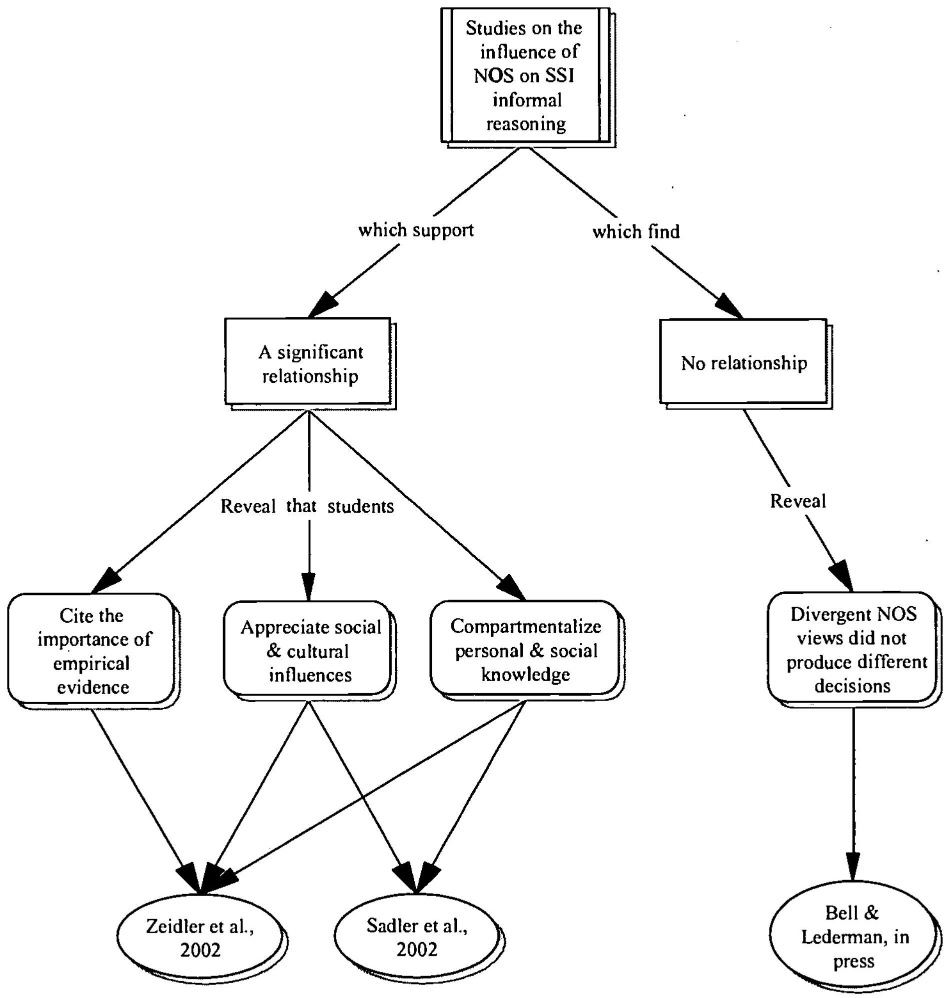

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Figure 3. Graphic summary of research related to how individuals evaluate information regarding socioscientific issues (SSI).

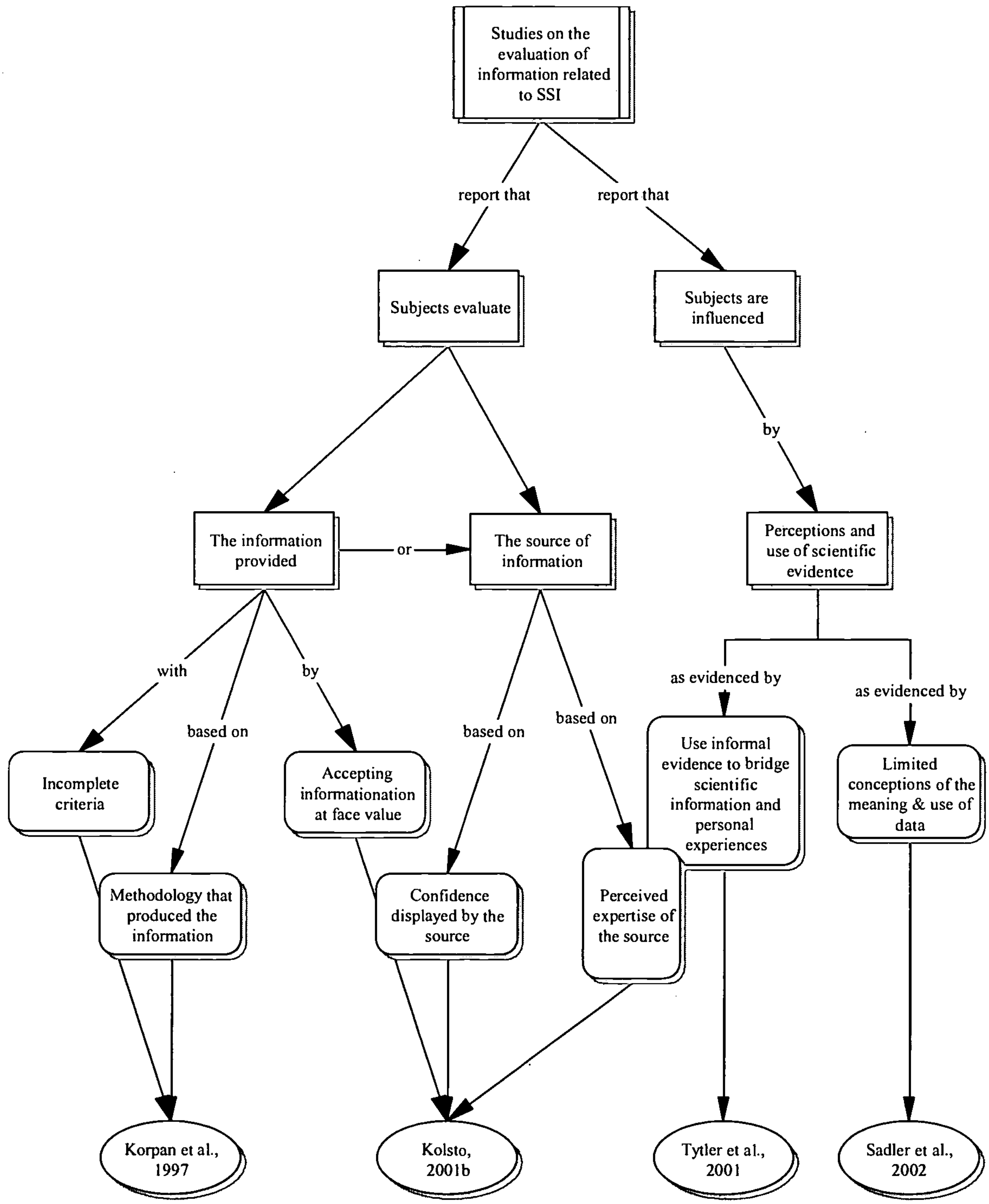

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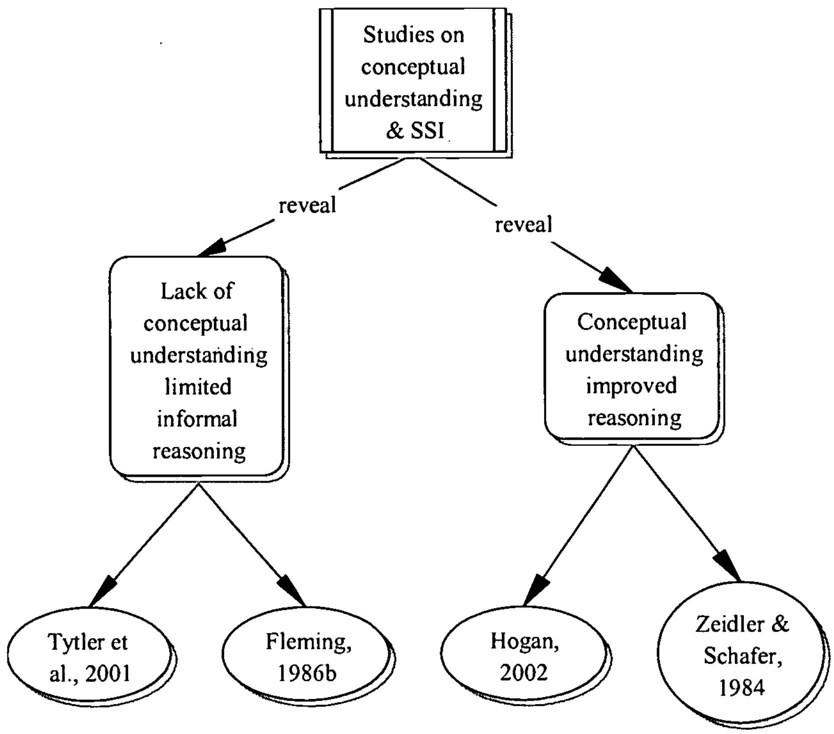
Figure 4. Graphic summary of research related to the influence of conceptual understanding on informal reasoning regarding socioscientific issues (SSI).



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