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What Do Students Gain by Engaging in Socioscientific Inquiry?

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Abstract The question of what students gain by engaging in socioscientific inquiry is addressed in two ways. First, relevant literature is surveyed to build the case that socioscientific issues (SSI) can serve as useful contexts for teaching and learning science content. Studies are reviewed which document student gains in discipline specific content knowledge as well as understandings of the nature of science. SSI are also positioned as vehicles for addressing citizenship education within science classrooms. Although the promotion of citizenship goals seems widely advocated, the specifics of how this may be accomplished remain underdeveloped. To address this issue, we introduce *socioscientific reasoning* as a construct which captures a suite of practices fundamental to the negotiation of SSI. In the second phase of the project, interviews with 24 middle school students from classes engaged in socioscientific inquiry serve as the basis for the development of an emergent rubric for socioscientific reasoning. Variation in practices demonstrated by this sample are explored and implications drawn for advancing socioscientific reasoning as an educationally meaningful and assessable construct.

Key words socioscientific issues · scientific literacy · reasoning · citizenship · complexity · perspective · skepticism · inquiry

Socioscientific issues (SSI) have come to represent important social issues and problems which are conceptually related to science. Whereas scientific knowledge and inquiry practices can be useful for the negotiation of SSI, scientific practices alone can not marshal solutions. Issue solutions are necessarily shaped by moral, political, social and economic concerns; therefore, inquiry and negotiation of SSI require the integration of science

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concepts and processes with social constructs and practices. Many educators have recently argued that the thoughtful negotiation of SSI is fundamental to modern notions of scientific literacy and that socioscience is a necessary element of today's science classrooms (e.g., Driver, Newton, & Osborne, 2000; Hughes, 2000; Zeidler, Walker, Ackett, & Simmons, 2002). However, as admitted advocates of socioscientific curricula, we must also recognise the inherent challenges of using SSI in educational contexts. SSI curricula, especially programs which immerse learners in active investigations of contemporary issues, can consume significant chunks of classroom time; and given the standards – and standardised test-driven culture of today's schools, the allocation of scarce instructional time and resources is no small issue (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006). Therefore, the question which serves as the title of this paper is an important practical question. University-based researchers may theorise about the virtues of using SSI in science education contexts, but policy makers and classroom practitioners require more direct, evidence-based answers to the question of what students gain by engaging in socioscientific inquiry.

In this paper, we explore rationales for teaching science via SSI by first reviewing empirical work related to SSI as contexts for science content instruction. Then, the role of SSI in establishing citizenship as an aspect of science education is discussed. Next, we identify and explore specific practices, associated with the negotiation of SSI, which are central to "informed citizenship." These findings are used to operationalise *socioscientific reasoning* and establish a framework for assessing the construct. The framework is used for analysis of data collected from middle school students engaged in the negotiation of SSI as a means of developing an emergent rubric for the specific practices subsumed by socioscientific reasoning.

SSI as Contexts for Science Content

One response to the question of how students benefit from socioscientific inquiry relates to how the issues can be used as platforms for learning science content. Student inquiry into socioscientific issues provides robust context for situating important science content and processes. Situated cognition and situativity theory suggest that when developing a learning environment one should situate the disciplinary content and methods within a broader contextual framework that frames and gives meaning to the content. By situating the content in terms of its broader contextual framework, students learn the "whats" of a discipline in terms of those situations that give them meaning (Bransford, Brown, & Cocking, 1999; Greeno, 1998). Situation theorists contend that all learning, whether it is positioned in impoverished or dynamic contexts, is situated. The actual learning will be distributed across learning environments which can include multiple participants, tools, learning artifacts, and driving questions (Barab & Plucker, 2002). The learning experiences of a classroom full of students dutifully copying answers from a textbook to a worksheet with a series of closed-ended genetics questions will undoubtedly be distinct as compared to a class engaged in the investigation of genetic engineering through a web-based virtual environment that allows groups of students to use genetics concepts in the service of their inquiries. In both cases, emergent knowledge will be situated, but it seems that the latter situation will afford the development of more integrated and useful concepts.

While we acknowledge that significant work remains to be completed in documenting the link between SSI curricula and learning science content knowledge as presumed by situativity theory, evidence is mounting to suggest that SSI can, in fact, serve as useful contexts for science learning. For example, Pedretti (1999) presents a case study in which fifth and sixth grade students learn geological science through classroom – and museum exhibit-based explorations of mining. Walker (2003) provides another case study which documents improvements in high school student understandings of genetics as they work through a web-enhanced curriculum focused on genetically modified foods. Barab et al. (Barab, Sadler, Heiselt, Hickey, & Zuiker, in press) document statistically significant pre-/post-test gains in environmental science content knowledge related to a socioscientific investigation of water pollution. Applebaum, Barker, and Pinzino (2006) describe a year long study, situated in high school anatomy classes, during which SSI are infused in the curricula. Students experiencing the SSI curricula perform statistically significantly better on a test of anatomy and physiology concepts than students taught with more traditional approaches to anatomy instruction. Finally, Zohar and Nemet (2002) report the results of a controlled, experimental study in which in-tact classes received intervention or control instruction. The intervention focused on human genetics and associated SSI such as genetic counseling, gene therapy and cloning; whereas, the control treatment presented the same underlying genetics content without socioscientific emphases. The intervention classes outperformed their peers on a test of genetics content knowledge.

In addition to science content, as defined from traditional content domains, SSI also have the potential to serve as effective contexts for understanding the nature of science (NOS). SSI have been used as research tools to elicit student views on the nature of science, and researchers have argued that this work also supports the use of these issues as pedagogical contexts (Sadler, Zeidler, & Chambers, 2004; Zeidler et al., 2002). More recent studies have tested this assumption. Khishfe and Lederman (2006) compare gains in NOS understandings among high school students in two explicit NOS interventions. One of the interventions integrates NOS instruction with a focus on global warming, and the other NOS treatment is not integrated with a SSI. Results show improvements in NOS understandings among students in the integrated NOS-SSI treatment. These NOS gains are as positive as those recorded for the other group but do not exceed the comparison group gains. Similar results, improved NOS understandings in response to explicit instruction in the context of SSI, are also reported by Lewis, Amiri, and Sadler (2006) in a study in which SSI related to human health care are consistently embedded throughout a year-long high school anatomy course.

Citizenship Education

Educators have also rationalised the use of SSI in terms of their potential to foster citizenship education. Socioscientific curricula have been positioned as vehicles for promoting democratic citizenship through science education because the focal issues are relevant and can bridge school science and students' lived experiences (Cajas, 1999; Kolstø, 2001a; Zeidler, Sadler, Simmons, & Howes, 2005). Life in the 21st century is irrefutably associated with science and technology, and formal education should help students prepare for active participation in modern democracies. Science education, in particular, should assume increasingly more prominent roles in citizenship education. It can no longer remain common school practice for civic issues to be handled only within the confines of social studies classrooms. As the two excerpts below suggest, educators must leverage science learning experiences as vehicles for equipping tomorrow's consumers, voters, watch dogs, and decision-makers:

> What is clear is that ordinary citizens will increasingly be asked to make judgements about matters underpinned by science knowledge or technological capability, but overlaid with much wider considerations. Those without a basic understanding of the ways in which science and technology are impacted by, and impact upon, the physical and the sociopolitical environment will be effectively disempowered and susceptible to being seriously misled in exercising their rights within a democratic, technologically-dependent society. (Hodson, 2003, pp. 650–651)

> ... [S]cience education must serve as a foundation for the education of an informed citizenry who participate in the freedoms and powers of a modern, democratic, technological society. With the rapid development of scientific knowledge and the advent of new technologies, all members of society must have an understanding of the implications of that knowledge upon individuals, communities, and the "global village" in which we now live. (Berkowitz & Simmons, 2003, p. 117)

While the notion of promoting citizenship in science learning contexts is theoretically appealing, it remains somewhat nebulous from a pragmatic perspective. General exposure to complex SSI in educational contexts should ideally help students deal with similar kinds of issues faced in their actual lives, but this assertion may not be enough to feature SSI in an already crowded science curriculum. Given the current political climate of most schools, SSI advocates must be able to identify tangible learning gains from their educational programs. The documented relationship between SSI curricula and content knowledge gains offers an example of such a concrete outcome, but it does not necessarily highlight the citizenship goal. Based on our experiences using SSI in educational contexts, we contend that student experiences with these kinds of issues promote other forms of practice, related to the citizenship goal, that are as significant, if not more significant, than traditional content.

Aspects of Socioscientific Reasoning

We present socioscientific reasoning as a theoretical construct which subsumes aspects of practice associated with negotiation of SSI and addresses the citizenship goal. In our own work (Barab et al., in press; Sadler & Zeidler, 2005; Sadler, Zeidler, & Chambers, 2004), the following have emerged as among the most significant practices for decision-making in the context of SSI:

(1) Recognising the inherent *complexity* of SSI.
(2) Examining issues from multiple *perspectives*.
(3) Appreciating that SSI are subject to ongoing *inquiry*.
(4) Exhibiting *skepticism* when presented potentially biased information.

In the sections which follow, each of these practices will be more fully explored and situated with respect to relevant literature.

Complexity

By definition, SSI are complex, open-ended, potentially contentious problems which lack simple and straightforward solutions (Sadler, 2004). In framing socioscientific reasoning, we suggest that advanced practice should include the ability and predisposition to conceptualise the inherent complexity of SSI and avoid simplifying the issues by focusing on a single factor in exclusion of its broader contextual significance. Equally undesirable would be the tendency for students to attempt solving SSI based on simple cause and effect reasoning. In contrast, more sophisticated socioscientific reasoning would involve recognising multiple, dynamic interactions within SSI which preclude simple, linear solutions. Several reports have explicitly highlighted participant perceptions of SSI complexity as a desired educational outcome. Specific contexts for these studies have ranged from local environmental issues (Kortland, 1996; Pedretti, 1999) to use of nuclear fuels (Yang & Anderson, 2003) and genetic engineering (Sadler & Zeidler, 2005). In framing a case study of student environmental management decision-making, Hogan (2002) highlights key features of ecological systems including complex connections among interacting elements, temporal and spatial dynamism, and significant degrees of uncertainty and unpredictability. Although Hogan is specifically referring to ecological systems, we believe these characterisations naturally extend to other socioscientific contexts, a conclusion which Hogan seems to endorse herself:

> Scientists in a multitude of disciplines are acknowledging that deterministic views of the universe as a machine that is ruled by linear cause and effect need to give way to a systems view that focuses on relationships, contextuality, and integration (Capra, 1996; Gallagher & Appenzeller, 1999). Likewise, many practical, socioscientific problems are not conducive to being decomposed and handled one dimension at time, but rather must be considered in all of their systemic complexity. (p. 364)

King and Kitchener's reflective judgment model describes the development of epistemologies associated with reasoning regarding ill-structured problems (King & Kitchener, 1994). While this work explores a domain broader than our own and adopts a developmental framework which we are not necessarily asserting for socioscientific reasoning, parallels certainly exist between reflective judgment and the perception of SSI complexity (Zeidler, Callahan, Cone, & Burek, 2006). The reflective judgment model postulates that individuals progress from prereflective stages in which knowledge is certain and absolute to quasireflective stages in which knowledge is viewed more subjectively and contextually and finally to reflective stages in which knowledge is perceived as a construction from multiple sources and its certainty is justified probabilistically. This progression from objectivity to relativism to probabilism mirrors the variance that could be expected in the complexity aspect of socioscientific reasoning. Students who approach a SSI as if its best solution involves deciphering a relatively simple cause and effect relationship display patterns consistent with prereflective thinking. Those who recognise the issue's complexity, but deal with multiple forms of information relativistically reflect quasireflective thinking. Finally, students who perceive issue complexity and adopt rational strategies for evaluating conflicting forms of evidence engage in thinking consistent with reflective stages.

Perspectives

The contentious nature of SSI is due, in part, to the various, well-reasoned positions that may be assumed by interested parties. Well-meaning and thoughtful individuals can adopt dissimilar but equally plausible solutions to SSI based on differences in personal priorities, principles, and biases. Unique perspectives can lead individuals to construe SSI in very different manners and advocate contradictory resolution strategies (Sadler & Zeidler, 2005). Our treatment of the diversity of perspectives suggests that no single perspective is necessarily privileged, but it should not be assumed that all perspectives are equally defensible.

Recent work in the area of argumentation has emphasised the importance of students coming to recognise perspectives other than their own particularly when other perspectives directly challenge the ideas they hold. As Zeidler (1997) points out, encouraging students to thoughtfully consider alternative perspectives, especially when a particular position is held strongly, presents substantial challenges. The entrenchment of one's own ideas tends to mediate the extent to which s/he is able or willing to carefully consider the views of another and evaluate counter-evidence (Chinn & Brewer, 1993). Given these patterns, several studies of argumentation in both scientific and socioscientific contexts have adopted pedagogies and assessment schemes which prioritize formation of counter-positions and rebuttals which are indicative of participant abilities to consider multiple perspectives (Erduran, Simon, & Osborne, 2004; Kuhn, 1991; Sadler & Donnelly, 2006; Zohar & Nemet, 2002). In terms of perspective-taking as an element of socioscientific reasoning, we suggest that advanced practice should entail the ability to analyse SSI and potential solutions from diverse perspectives and recognise substantive challenges to one's own espoused position. Less sophisticated forms of practice may involve the appreciation of conflicting perspectives only after specific prompting or an inability to conceptualise the problem beyond one's own personal framework.

Inquiry

The inquiry dimension of socioscientific reasoning references the fact that SSI are ill-structured problems subject to ongoing investigation. SSI are situated in the real world, and their underlying premises, conditions and other potentially significant information may not always be determined or known. SSI are necessarily characterised by a degree of uncertainty; stakeholders never know all that could be known or have the kinds of information that would be most helpful in terms of making decisions (Barab et al., in press). The fact that frontier science or "science-in-the-making" (Kolstø, 2001a) often undergirds SSI contributes to some of the uncertainty. The ideas of frontier science are still works in progress and may not be fully accepted by the entire scientific community (Bingle & Gaskell, 1994). The social dimensions of SSI also contribute to underlying uncertainty. Many SSI present situations which raise questions regarding the potential impacts of a projected course of action on human behaviors, well-beings, economies, or social norms (Zeidler et al., 2005). Taken together, scientific and social dimensions create many open questions and provide numerous possibilities for ongoing inquiry.

Advanced practice regarding the inquiry aspect of socioscientific reasoning should entail the ability to conceptualise SSI as areas of open inquiry. Furthermore, sophisticated decision-makers should be able to pose specific questions or information requests and lay out a plan for establishing at least some of the answers. Ideally questions and inquiry possibilities regarding both the social and scientific dimensions of an issue should be raised. The coordinated consideration of social and scientific questions as desired practice is supported by Yang and Anderson's (2003) work with high school students as they worked through problems in the use of nuclear energy. Less advanced practice would entail a singular focus on scientific OR social inquiry or failure to recognise the need for more information.

Skepticism

Skepticism is a habit of mind fundamental to inquiry and scientific practice more generally (NRC, 2000). It surely occupies an equally significant, if not more significant, role in socioscientific contexts. Kolstø (2001b) frames the issue of skepticism regarding SSI information in the following: "In addition to the scientific knowledge offered, one usually also has to deal with the issue of trustworthiness of knowledge claims from other actors engaged in the issue" (p. 878). The "actors" engaged in a SSI often possess vested interests, and these biases can potentially affect the focus of their inquiries, the manner in which they integrate scientific and social factors, evidence to which they attend, etc. This is not meant to imply that all stakeholders necessarily manipulate evidence and principles in the service of their cause, but perspective can certainly influence one's practice.

The extent to which students demonstrate skepticism in the context of SSI remains an open question. Kolstø (2001b) reports that "most pupils" in his study with 16-year-old students dealing with a local SSI recognised the need to carefully assess the reliability of information they received or the sources of that information. Other work (Sadler, Zeidler, & Chambers, 2004; Zeidler et al., 2002) has suggested that many students are not as skeptical of information as they ought to be. A significant proportion of high school students in both of these studies ascribed contradictory conclusions only to discrepancies in data (despite being assured that the scientist groups in question analysed identical data sets) and failed to recognise potential biases or unique analytical approaches. In terms of socioscientific reasoning, we suggest that advanced practice should include the ability to demonstrate skepticism in the face of potentially biased information and strategies to make well-grounded decisions regarding the selection of information sources. Less sophisticated practice would entail a tendency to accept information at face value without recognising potential biases.

Socioscientific Reasoning as a Construct

In presenting socioscientific reasoning, we have intended to introduce an educationally significant construct which captures important practices associated with the negotiation and resolution of SSI. Our intent is not to present another nebulous phrase to be used for the justification of practically any proposed intervention. The field of science education seems to already possess enough of these ubiquitous expressions: for example, scientific literacy, higher-order thinking, critical thinking, and scientific reasoning. For this reason, we have operationalised socioscientific reasoning in terms of four specific practices which are fundamental to the thoughtful negotiation of SSI. We view these practices as constitutive elements in that socioscientific reasoning, at least advanced socioscientific reasoning, must involve recognising the inherent *complexity* of SSI, examining issues from multiple *perspectives*, appreciating that SSI are subject to ongoing *inquiry*, and exhibiting *skepticism* when presented potentially biased information.

The individual aspects are certainly not unique to socioscientific reasoning. For example, decision-makers facing any ill-structured problem must deal with complexity, and constructs used to frame the resolution of ill-structured problems such as reflective judgment (King & Kitchener, 1994) and informal reasoning (Kuhn, 1991) tend to feature this practice. However, socioscientific reasoning is presented as a theoretical construct designed to uniquely capture the array of practices fundamental to the negotiation of SSI.

By proposing socioscientific reasoning as an educationally significant construct and framing it in terms of specific practices, we have intended to provide a more tangible response to the question guiding this paper: What do students gain by engaging in socioscientific inquiry? We see this as one step (of many) toward positioning socioscientific inquiry as a priority in science classrooms.

In the first part of this paper, we have reviewed the rationales for situating SSI in science classrooms and operationalised socioscientific reasoning as a desired educational outcome. In what follows, we explore the socioscientific reasoning of middle school learners with the goal of documenting practice among this group and establishing a rubric for the assessment of socioscientific reasoning. Each aspect of socioscientific reasoning has been discussed from a theoretical vantage; the work with middle school students enables empirical analyses of socioscientific reasoning as it is actually practiced by young learners. To accomplish these goals, we engage students in interviews during which they negotiate multiple SSI. We analyse these interviews as episodes of socioscientific reasoning and use the results to develop an emergent rubric.

Materials and Methods

Context of Study

Twenty-four sixth grade students from a middle school located in a Midwestern United States town participated in the study. These students were randomly sampled from among four science classes led by the same teacher. At the time of the interviews, the classes had just completed a ten day unit in which students explored a SSI in the context of a virtual world. The issue explored was based on pollution and water quality and situated in a 3D virtual, multi-user environment known as *Quest Atlantis.* Students used avatars to navigate the virtual space, collected scientific data (e.g., they "performed" water quality tests on a river flowing through the virtual environment), and talked with other users as well as non-player characters. These experiences were designed to help students build a multi-dimensional understanding of the water quality dilemma drawing on factors related to water chemistry, aquatic biology, human-nature interactions, resource management, economics, and politics. As the unit unfolded, students completed a series of "quests" which challenged them to evaluate evidence, synthesize their findings, and propose solutions to the observed problems. For a more detailed description of *Quest Atlantis* and the learning principles upon which it is based, see Barab, Thomas, Dodge, Carteaux, and Tuzun (2005). For an in-depth portrait of the water quality unit and a case study of its implementation, see Barab et al. (in press).

Data Collection

Drawing on our previous work with students negotiating socioscientific issues (Barab et al., in press; Sadler & Donnelly, 2006; Sadler & Zeidler, 2005), we designed interview protocols to provide participants with opportunities to demonstrate the aspects of socioscientific reasoning highlighted earlier in this paper. The protocols consisted of two written socioscientific scenarios with accompanying diagrams and a series of questions (see Appendix A). The first scenario involved water quality problems in the fictitious Branville

Bay. The issues raised in this scenario paralleled the problems participants faced as they negotiated the *Quest Atlantis* SSI. The second scenario concerned the fictitious city of Triveca and its dilemmas regarding energy production and pollution. Whereas the Branville scenario represented a near transfer context relative to the students' classroom experiences, the Triveca scenario offered a more distant transfer context.

Each interview was conducted individually with a single investigator and student and typically lasted 15–20 min. The interviews began with participants reading the Branville narrative, examining an associated diagram, and asking questions about the scenario. When the participant seemed to have a clear understanding of the situation, the interviewer posed a series of questions designed to elicit student perceptions of complexity, perspectives, inquiry, and skepticism. When issues regarding Branville had been sufficiently explored, the interviewer presented participants with the Triveca materials and the basic protocol was repeated. All of the interviews were recorded digitally and complete transcripts were produced.

Data Analysis

Data analysis was guided by the constant comparative approach (Glaser & Strauss, 1967; Strauss & Corbin, 1998). Analysis progressed in iterative cycles whereby researchers used interview data to establish an emergent rubric for the socioscientific reasoning aspects identified earlier. Transcripts were reviewed repeatedly in order to locate evidence supporting the four aspects of socioscientific reasoning. As the iterations unfolded, participant practices in each of the aspects were sorted relative to one another. Each aspect of socioscientific reasoning (i.e., complexity, perspectives, inquiry, and skepticism) was represented as a unique element within the rubric, and four performance levels were developed for each element. Once the emergent rubric was established, two investigators independently examined a random sample of five transcripts and "scored" the four elements for both scenarios. Inter-rater consistency exceeded 95%, and the apparent discrepancies were easily negotiated. Given the relatively high inter-rater consistency, a single investigator applied the rubric to the remaining transcripts.

Results

Participants demonstrated variability with respect to each of the four aspects of socioscientific reasoning. For each socioscientific reasoning aspect (i.e., complexity, perspectives, inquiry, and skepticism), we developed a four level ordinal scale. Each level was identified numerically (1–4) to indicate progressively more sophisticated practice. Higher levels represented more sophisticated practice. Levels of practice for complexity, perspectives, and inquiry emerged from and were used to categorise responses to both the Branville and Triveca scenarios. Because of the specific contexts for each of the scenarios, the final interview question, designed to elicit responses reflective of the skepticism aspect of socioscientific reasoning, was slightly different for each scenario (see Appendix A). The levels which emerged among the two scenarios for skepticism were sufficiently different across the two scenarios to warrant individualised assessment schemes. Levels for the complexity, perspectives and inquiry aspects of socioscientific reasoning are summarised in Table 1, and exemplar quotations taken directly from interview transcripts are provided.

Table 1 Rubric for the complexity, perspectives, and inquiry aspects of socioscientific reasoning

	Levels			
	1	2	3	4
Complexity	Offers a very simplistic or illogical solution without considering multiple factors.	Considers pros and cons but ultimately frames the issue as being relatively simple with a single solution.	Construes the issue as relatively complex primarily because of a lack of information. Potential solution tends to be tentative or inquiry-based.	Perceives general complexity of the issue based on different stakeholder, interests, & opinions. Potential solutions are tentative or inquiry-based.
Exemplar quote	I: Is this a difficult problem? P: Not really...cause I am sure they could just use that little sun thing that collects all of the sun stuff. (TV)	You need to have energy, but you don't want to pollute...I think they should put the nuclear power plant as far away as they can. (TV)	It could get difficult if you don't have all the facts and like you can't, there's not enough information to substitute on who really is the culprit. (BR)	You would have to first take both sides of the story and then you would have to do research to figure out like where the problems, where the fish are decreasing. (BR)
Perspectives	Fails to carefully examine the issue.	Assesses the issue from a single perspective.	Can examine a unique perspective when asked to do so.	Assesses the issue from multiple perspectives.
Exemplar quote	P: I'd stick with that [nuclear power]. I: Why do you think that would be the right decision? P: I have no clue. (TV)	P: They should add some more fish and cut the boating... It's the right decision and it's the only option they have. They don't have anything else to work with. (BR)	P: If the city doesn't have enough money, the coal would be better... I: Why might someone disagree with your solution? P: They might live closer to it [coal plant] and be affected more... (TV)	If you build a nuclear power plant, the city's environmental health could be destroyed... but it could be better using nuclear power but there is a risk if there are accidents... (TV)
Inquiry	Fails to recognise the need for inquiry.	Presents vague suggestions for inquiry.	Suggests a plan for inquiry focused on the collection of scientific OR social data.	Suggests a plan for inquiry focused on the collection of scientific AND social data.
Exemplar quote	I think we already have enough information.(BR)	They could just test the water. (BR)	I think they should survey another nuclear power plant... and see what sort of pollution results they have – what sort of air quality they have... (TV)	There are several questions that need answering. They need to start with a census of the fish...We also need to know about how different people use the bay...(BR)

Notes. All "exemplar quotes" are direct quotations provided by the participants unless otherwise noted. "I" represents an interviewer comment. "P" represents a participant comment.

"TV" indicates that the comment was excerpted from discussions of the Triveca scenario. "BR" indicates that the comment was excerpted from discussions of the Branville scenario.

Complexity

In terms of the complexity aspect of socioscientific reasoning, the least sophisticated forms of practice (Level 1) were demonstrated when participants perceived the issues as unproblematic or straightforward and posed very simplistic or illogical solutions. Responses in this level did not give consideration to competing interests. Participants offering Level 2 responses did reflect on potential benefits and disadvantages of a particular course of action but ultimately offered relatively simple solutions indicative of direct, causal reasoning. These responses indicated participants seeking a single cause and effect without recognising the multi-dimensional nature of the SSI under consideration. Participants providing Level 3 responses tended to offer tentative solutions; the source of uncertainty for this level of responses was a lack of information. These participants suggested that the issue was complex because they did not have all the necessary details. This position presumes that added detail would simplify and even solve the problem. The most sophisticated forms of practice (Level 4) were demonstrated by participants who perceived general complexity of the issues in terms of the competing interests, biases, and needs of the various stakeholders. Like Level 3, Level 4 solutions were also tentative or inquiry-based, but whereas Level 3 participants implied that acquiring necessary information would necessarily lead to an appropriate solution, Level 4 participants appreciated a deeper level of complexity based on incomplete data but also on an irreducibly complex network of social needs. Therefore, information alone cannot simplify the inherent complexity of the issue. Interview excerpts which exemplify each level are provided in Table 1.

Perspectives

The perspectives aspect of socioscientific reasoning reflected how participants were able to examine an issue from multiple perspectives. A couple of participants did not seem able to examine the issue critically from a single perspective, much less multiple perspectives. These cases served as the basis for the lowest performance level. It should be noted that both Level 1 perspectives responses were also rated as Level 1 for complexity. The reverse was not the case: a few individuals demonstrated the lowest level of complexity but were able to examine other perspectives when asked to do so. Level 2 captured responses which indicated participant ability to evaluate the issue only from a single perspective. The individuals offering these responses were not able to perceive potential objections to their solutions or realise other ways of examining the issue. The vast majority of participants provided Level 3 responses for both scenarios. These responses demonstrated ability to examine different perspectives when specifically prompted to do so by the interviewer. In cases of the most sophisticated practice (Level 4), participants provided analysis based on varying perspectives without having been asked to do so. These participants independently recognised the importance of considering multiple perspectives. See Table 1 for exemplars of each level.

Inquiry

Participants demonstrating the lowest levels of the inquiry dimension of socioscientific reasoning did not appreciate the need for additional information. These individuals asserted that they possessed all the information needed to come up with a solution. Level 2 responses recognised the need for more information, but the participants were only able to offer vague recommendations for what potential inquiries might entail. Simply suggesting “tests” for the water or air was common within this level. Participants offering Level 3 responses were able to outline an inquiry plan to more fully inform the decision. These responses focused on either scientific or social data but not an integration of the two. The highest level of practice (Level 4), demonstrated by only one participant in response to the Branville scenario was characterised by the ability to conceptualise inquiries that informed scientific and social dimensions of the issues. Table 1 provides inquiry level descriptions and interview excerpts to support these interpretations.

Skepticism

As mentioned earlier, the rubric levels for skepticism were the only ones to be differentiated according to scenario. The questions used to elicit this aspect of socioscientific reasoning were slightly different to reflect contextual nuances in each

Table 2 Rubric for the skepticism aspect of socioscientific reasoning

	Levels			
	1	2	3	4
Branville	Denies differences among stakeholder positions.	Ascribes differences in stakeholder positions to differences in information.	Ascribes differences in stakeholder positions to a desire to avoid blame.	Recognises conflicting interests and purposes among various stakeholders.
Exemplar quote	They [wildlife managers and port authorities] probably would say like the same things about the problem.	They have been around wildlife, probably water too, more than the port has because they probably know more about wildlife than the people at the port do and how the wildlife acts and behaves with different situations.	Maybe they don’t want to get in trouble because they are the ones that have to clean it up and everything and if they’re not cleaning it up then they will be able to get in trouble.	They probably more concerned with helping the ecosystem where the port authorities are more concerned with making sure the ships come in and drop off the stuff they need to drop off and probably more with making money than the environment.
Triveca	Declares no differences among stakeholders.	Suggests that differences likely exist among stakeholders.	Describes differences among stakeholders.	Describes differences and discusses the significance of conflicting interests.
Exemplar quote	[Scientists for both groups] would say if there has been problem in the past with nuclear power plants and would probably go for the coal plant...I think it [the comments of both groups] might be pretty close.	The scientists [hired by the mayor] probably supported the mayor and the scientists for the citizens probably supported them.	I think the mayor’s group said that it’s a lot better for the environment to have the nuclear power plant... And for the citizen’s group, they would say that it is more risky... and it’s [the nuclear plant] still producing waste.	One group is saying don’t do this...The other group is saying yes we should...it’s going to be a big argument because each scientist has a different way because that’s [representing different parties] their job.

scenario. Participant response patterns also differed enough to warrant unique rubric levels. To access the skepticism aspect of socioscientific reasoning in the Branville scenario, interviewers asked participants to discuss why wildlife managers and port authorities, groups possessing very different interests within the scenario, had conflicting positions. Participants offering Level 1 responses denied that the two groups were really at odds. These individuals suggested that everyone involved would desire to do what was "best" without recognising that ideal outcomes for one group may be incompatible with the desires of another group. Level 2 responses recognised conflict between the groups and ascribed it to differences in the information each group possessed. The underlying idea was that the groups would likely come to consensus given an opportunity to share data sets and expertise. Participants with Level 3 responses explicitly recognised the competing interests of stakeholders by suggesting that each group was trying to avoid blame. Level 4 responses captured more sophisticated articulations of the previous level. Participants making these responses were able to discuss conflicting interests and purposes beyond a relatively simple assessment of blame. The skepticism rubric levels for both scenarios are presented in Table 2.

To access the skepticism aspect of socioscientific reasoning in the Triveca scenario, interviewers asked participants to discuss what they think scientists representing two groups with competing interests would report in a public forum. Like the least sophisticated forms of practice in the Branville scenario, Level 1 responses asserted that there would be no differences in the reports of scientists employed by competing parties. Participants demonstrating Level 2 suggested that the groups would provide different information but were not able describe those differences. Level 3 responses moved beyond the previous category by describing the kinds of information that the groups would likely share. The most sophisticated responses (Level 4), demonstrated by only one participant, described likely differences and discussed the significance of conflicting interests in terms of how it might bias the interpretation and presentation of evidence. It should be noted that we are not suggesting that skepticism levels between the scenarios are necessarily equivalent (i.e., a Level 2 response in Branville is not necessarily equivalent to a Level 2 response in Triveca); however, we do assert that within each scenario the levels are organised by sophistication of practice (i.e, Level 4 in Branville demonstrates better practice than Level 3 in Branville).

Quantitative Analyses

Basic quantitative descriptions of the data are presented to more fully characterise results from this sample. The distribution of participant scores for each of the socioscientific reasoning aspects are presented in Figs. 1 and (for the Branville scenario) and 2 (for the Triveca scenario).

We also conducted a series of correlation analyses to explore potential relationships among the socioscientific reasoning aspects within a particular scenario as well as relationships between a single aspect as measured across the two scenarios. Because the rubric scales are ordinal, all reported correlation coefficients are Spearman's rho as opposed to Pearson's product moment coefficient which is more widely used but assumes interval level data (Glass & Hopkins, 1996). If the aspects represent features of a single latent variable, we should expect moderate to high correlations among the aspects within a scenario. If the protocols outlined herein are reliable, we should also expect high correlations between single aspects across the scenarios. Correlation matrices for both scenarios and correlations of each aspect between scenarios are presented in Table 3.

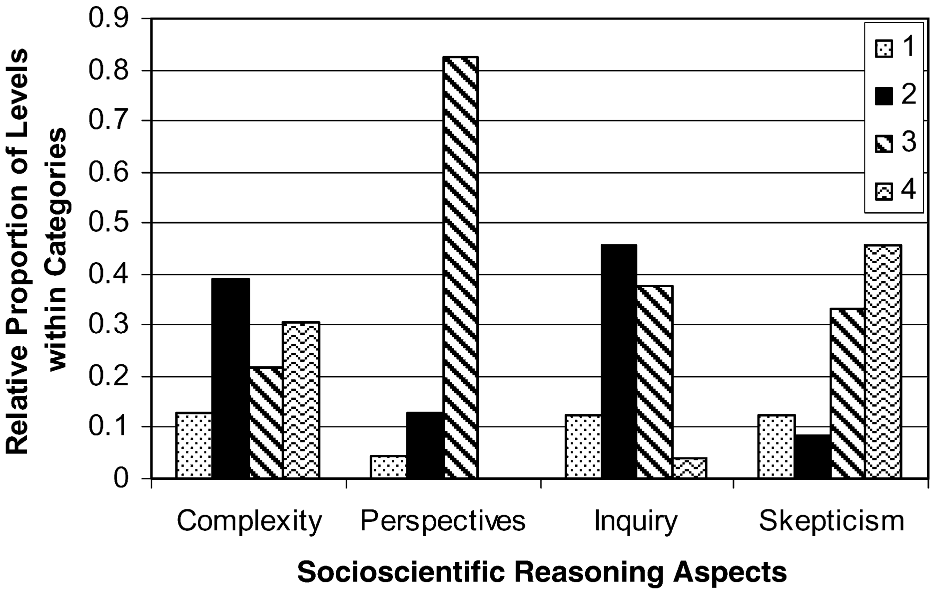


Fig. 1 Histogram for student performances in the Branville scenario. *Note*. The legend to the *right* of the graph indicates rubric levels

Discussion

The within scenario correlations (Table 3) provide an indication of the interdependence of socioscientific reasoning aspects. Whereas the correlations between complexity and inquiry

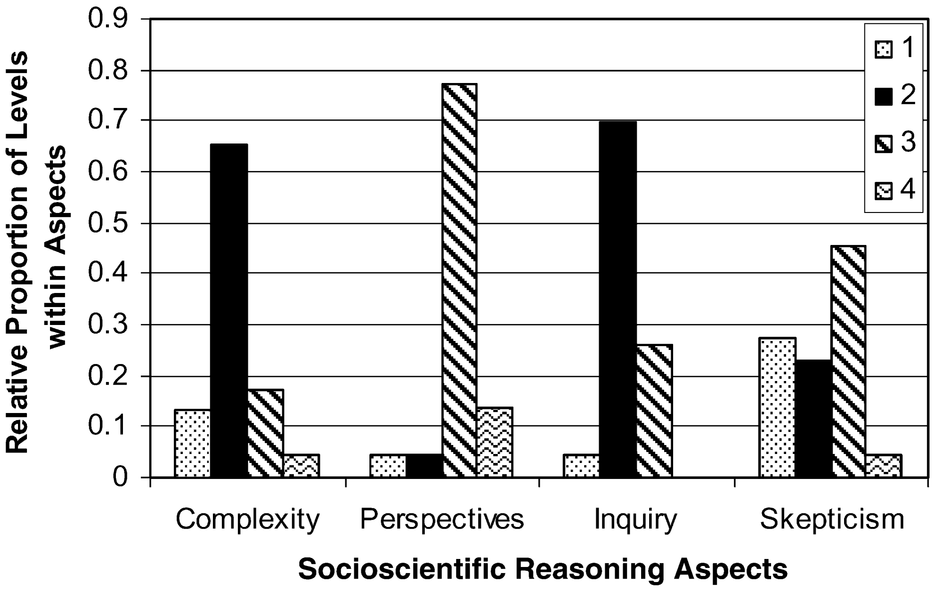


Fig. 2 Histogram for student performances in the Triveca scenario. *Note*. The legend to the *right* of the graph indicates rubric levels

Table 3 Correlation matrices (Spearman's rho) for socioscientific reasoning aspects within each scenario and correlation coefficients (Spearman's rho) for socioscientific reasoning aspects between scenarios

	Branville				Triveca				Between scenarios
	Com	Per	Inq	Ske	Com	Per	Inq	Ske	
Com	1	.220 (.312)	.779 (<.001)	.232 (.276)	1	.326 (.138)	.674 (<.001)	.140 (.533)	.756 (<.001)
Per		1	.228 (.295)	.187 (.392)		1	.333 (.130)	.084 (.717)	.417 (.060)
Inq			1	.298 (.157)			1	.088 (.695)	.728 (<.001)
Ske				1				1	.365 (.095)

Note. Significance estimates (2-tailed) are provided in parentheses below each correlation coefficient.
Com=complexity; Per=perspectives; Inq=inquiry; Ske=skepticism

are fairly high (.779 and .674), correlations between the other aspects are low (ranging from .084 to .333). The across scenario correlations (Table 3) provide an indication of assessment reliability. The correlations associated with complexity and inquiry were relatively high (.756 and .728, respectively,) supporting the reliability of these measures. The calculated relationships for perspectives and skepticism were much lower (.417 and .365, respectively).

All of the correlations associated with perspectives and skepticism are relatively low. One factor which may contribute to this result is the restricted variability of perspectives: over 75% of participants provided Level 3 responses in both scenarios. We still contend that the ability to examine issues from multiple perspectives is a theoretically significant aspect of socioscientific reasoning, but these results suggest that perspectives assessment, at least for this sample, requires a more nuanced approach to yield data that can help document variation in practice.

The low correlation for skepticism between scenarios highlights potential problems in the strategies used to assess this variable. Although the rubric level descriptions differed for the two scenarios, we still expected a significant relationship. The result could be indicative of contextual dependence for skepticism assessment. It might be the case that the extent to which an individual exhibits skepticism depends largely on the context of the issue under consideration. This conclusion makes sense conceptually in that specific knowledge of the context would likely influence how individuals recognise potential bias, but contextual dependence does not explain the low correlation results between skepticism and other aspects within a scenario. Here again, we maintain that individuals need to demonstrate a level of skepticism when dealing with SSI and the claims provided by parties with vested interests. However, skepticism may represent a dimension of socioscientific reasoning relatively unrelated to complexity, perspectives, and inquiry. Unfortunately, the data from this study alone do not rule out either of these interpretations. Therefore, as in the case of perspectives, additional work is required to establish a useful assessment scheme for skepticism.

The relatively strong relationship between complexity and inquiry supports the notion that these aspects are interdependent and could be combined to provide a composite measure of socioscientific reasoning. Such a composite measure would be desirable if it could be shown to be a robust metric with the potential to inform what students learn through socioscientific inquiry. However, because the levels of practice within both aspects

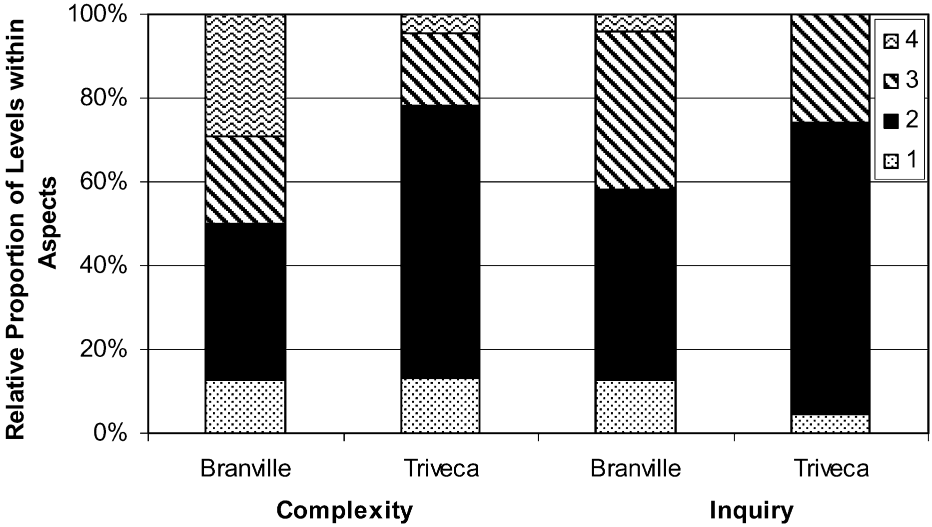


Fig. 3 Comparison of participant performances for complexity and inquiry. *Note*. The legend to the *right* of the graph indicates rubric levels

are based on an ordinal scale, creating a composite measure which could be used in statistical analyses requires data transformation in order to attend to the ambiguous intervals among levels within aspects as well as between aspects. This transformation could be accomplished through Rasch analysis (Boone & Scantlebury, 2006), but the current sample is prohibitively small.

An ultimate goal for this line of research is development of a valid and reliable assessment scheme with the ability to describe changes in socioscientific reasoning. Such a scheme would likely include a composite measure like the one suggested above for complexity and inquiry. If the assessment of perspectives can be improved, it too may contribute to a composite measure. As alluded to earlier, skepticism is important for socioscientific reasoning, but it may be unrelated to the other aspects. If this is the case, then it should not be included in the proposed composite measure. Given the complex nature of negotiating SSI, socioscientific reasoning undoubtedly represents a multi-dimensional construct that cannot be fully captured by a single metric.

Our work leaves open the possibility for identification of other socioscientific reasoning aspects. For example, some work in the area of SSI has focused on the extent to which individuals use content knowledge in negotiating controversial issues (e.g., Sadler & Donnelly, 2006; Tytler, Duggan, & Gott, 2001; Zohar & Nemet, 2002). Most science educators would agree that appropriate use of scientific content knowledge is a very important aspect of socioscientific reasoning. In discussing skepticism, we raised the possibility of practice being dependent on the contextual details of a specific scenario. The extent and manner in which individuals employ content knowledge would certainly be context dependent. An individual with expertise in environmental science and little knowledge of genetics would experience very different opportunities for applications of content knowledge in response to environmental science versus genetic engineering SSI. Actually, consistent with our views on the situatedness of knowledge, we are confident that practice relative to all aspects of socioscientific reasoning will necessary be shaped by context. However, fundamental to our view of SSI and science education is the idea that learners can come to recognise and leverage invariant features of socioscientific inquiries in ways that transfer to other contexts.

At least one interpretation of the data collected as a part of this study lends limited support for this assertion. Careful examination of the complexity and inquiry aspects of socioscientific reasoning, aspects with the strongest reliability data, between the two scenarios reveals that students generally performed better in response to the Branville scenario than the Triveca scenario. Small expected cell sizes (i.e., multiple cells less than five) preclude chi-square analyses for comparing relative performance levels between the two scenarios so any implications drawn must be conservative. Figure 3 presents relative proportions of student responses (the same data presented in Figs. 1 and 2) graphically to facilitate comparisons between scenarios. As discussed in the Materials and methods section, data collection took place following a 10 day SSI unit which focused on issues paralleled in the Branville scenario. One possible explanation for more sophisticated performance in the Branville scenario is that it was easier for the participants to recognise invariant features of the near-transfer context as opposed to the more distant transfer context, Triveca. We realise that our data can not rule out alternative interpretations such as the Triveca scenario was simply more inherently challenging, but the scenarios were designed to offer relatively equivalent challenges.

Another possible aspect of socioscientific reasoning involves the ethical dimensions of SSI. Several authors have argued that ethical sensitivity ought to be central in the negotiation of SSI (e.g., Clarkburn, 2002; Fowler & Tabone, 2006; Sadler & Zeidler, 2005). Explicit attention to ethical considerations was not evident in the reasoning practices observed as a part of this study, but other SSI such as proposals for human cloning would likely elicit immediate ethical concerns. We contend that most, if not all, SSI including the scenarios considered as a part of this study, possess features that could be subject to ethical analyses (Sadler & Zeidler, 2004); however, the prominence of ethical dimensions which emerge from SSI may vary by context. In this way, ethical sensitivity may not be as central to socioscientific reasoning as complexity, perspectives, inquiry, and skepticism with respect to certain issues.

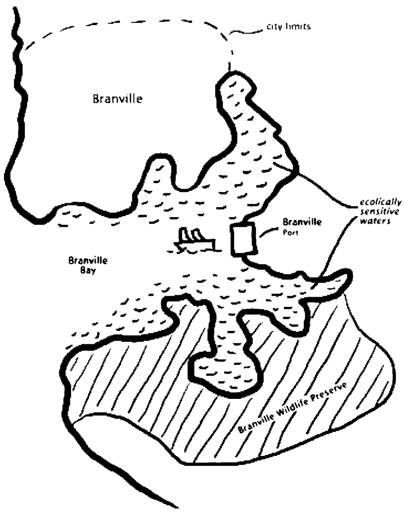
Conclusions

This paper begins with a question to which the advocates of SSI curricula must devote careful attention: What do students gain by engaging in socioscientific inquiry? If the SSI movement is going to make an impact on science education in an era dominated by political accountability, advocates must be able to document positive outcomes associated with student explorations of SSI. Research investigating SSI as learning contexts for science content knowledge and nature of science understandings has provided some evidential support for the use of SSI in science education. However, the acquisition of traditional science teaching goals (i.e., knowledge development) offers only one dimension of SSI curricula. These kinds of learning experiences can also enhance student participation in social practices beyond the classroom. While this paper is certainly not the first to argue that SSI education can enhance citizenship (see, Davies, 2004; Kolstø, 2001a; Zeidler et al., 2005), we extend the claim by operationalising socioscientific reasoning as a construct which captures specific practices associated with the negotiation of SSI. The paper theoretically situates four aspects of socioscientific reasoning: recognising the inherent *complexity* of SSI, examining issues from multiple *perspectives*, appreciating that SSI are subject to ongoing *inquiry*, and exhibiting *skepticism* when presented potentially biased information. We then use data collected with middle school students to offer a means of assessing socioscientific reasoning aspects. The results suggest that the complexity and inquiry aspects could be used to develop a composite measure of socioscientific reasoning, but such a measure is unlikely to capture the full range of practices associated with the negotiation of SSI. We present this paper as an initial framework for investigating the question of why science learning should feature SSI and as a tool for continued work in the area.

Appendix

Scenario 1: THE HEALTH OF BRANVILLE BAY

Branville is a growing town on the Gulf of Mexico. It is located on the edge of Branville Bay. The Branville area was the ancestral home for several tribes of Native Americans.

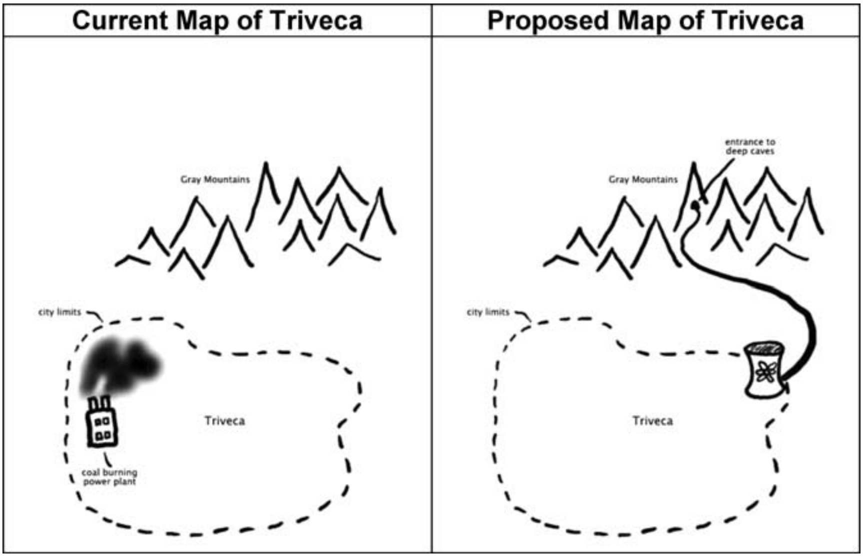


More recently Branville has become a major shipping port. Ships from all over the world dock at Branville Port delivering products like oil, clothing, toys, and fruit. These products are then distributed throughout the United States. Businesses in the US also use the port to send their products around the world.

Branville Bay is a sensitive ecological area serving as the breeding grounds for many fish, birds and other wildlife. There are strict laws that govern fishing in the most sensitive areas of the bay. However, these laws do not apply to the Native Americans still living in the area because they've claimed ancestral fishing rights in the area.

Managers of the Branville Wildlife Preserve (located south of the city) have started reporting declines in fish counts, bird counts, and water quality measures. These managers have concluded that the ships docking in the Port are damaging the Branville Bay ecosystem. Port Authorities claim that their ships stay in specially designated shipping lanes and do not travel into the most sensitive waters of the bay. They argue that the Native

American fishers are the most likely culprits because they overfish and use motor boats in the bay's most sensitive waters. A group of Branville citizens is now trying to make recommendations to the city and state on what should be done about this situation.



Scenario 2: ENERGY FOR TRIVECA

Triveca is a large city (about the size of Indianapolis) located next to the Gray Mountains. Triveca receives all of its electricity from a coal-burning power plant. Burning coal is relatively inexpensive because there are a lot of coal mines close to Triveca, but burning coal produces a lot of air pollution. The city has been fined by the Environmental Protection Agency (EPA) for air pollution violations. Because of this continuing problem, Triveca's mayor has suggested that the city build a nuclear power plant. The nuclear plant would supply all the energy needed by the growing city and would eliminate all of the coal-burning air pollution. One of the problems for nuclear power plants is the production of radioactive waste products. The mayor's plan calls for the nuclear waste products to be stored in deep caves under the Gray Mountains.

A local citizens group opposes the nuclear power plant because of the risk of accidents and the storage of radioactive waste products. The citizens group is concerned about the health of Triveca residents and the surrounding ecosystem. City leaders are now trying to decide what they should do.

Interview questions to follow each scenario.

1. Explain the situation in your own words.
2. Is this a difficult problem to solve? Why or why not?
3. Based on the information you have, what decision/recommendation do you think the city should make? Why?
4. How do you know that is the right decision?

5a. Can you think of a reason why someone would disagree with your solution?

b. How would you respond to that criticism? (*If student doesn't come up with a reasonable response to 4a, interviewer will provide a counter-position.)*

6a. What could be done to better understand the situation?

b. Why would that be useful?

7. What additional information would you like to have before making a final decision?

8. (*For Branville)* Why do you think the wildlife managers and the port authorities have different opinions about the situation?

8. (*For Triveca*) At a town meeting, a group of scientists employed by the mayor and another group of scientists employed by the concerned citizens group provided expert opinions on the power plant issue. What do you think each group said?

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