Students' Use of Scientific Knowledge and Practices When Making Decisions in Citizens' Roles

Beth A. Covitt, Edna Tan, Blakely K. Tsurusaki and Charles W. Anderson

Paper presented at the Annual Conference of the National Association for Research in Science Teaching, Garden Grove, April 17-21, 2009

This research is supported in part by grants from the National Science Foundation: Developing a Research-based Learning Progression for the Role of Carbon in Environmental Systems (REC 0529636), the Center for Curriculum Materials in Science (ESI-0227557), Learning Progression on Carbon-Transforming Processes in Socio-Ecological Systems (NSF 0815993), and Targeted Partnership: Culturally relevant ecology, learning progressions and environmental literacy (NSF-0832173). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Students' Use of Scientific Knowledge and Practice When Making Decisions in Citizens' Roles

Table of Contents

Students' Use of Scientific Knowledge and Practice When Making Decisions in Citizens' Roles

Abstract

A fundamental challenge for science education in a democratic country is preparing its citizens to make informed socio-environmental decisions. The authors offer a framework for analyzing how students approach public and private environmental decisions. The research questions explored within the framework include 1) when presented with a socio-environmental issue, how did students investigate and explain the issue and what consequences did they predict for their possible actions?, 2) what decisions did the students make and how did they justify those decisions?, and 3) given their understanding, what values and other resources did they draw on as they made their decisions? The authors developed two interview scenarios to address the research questions, one about purchasing strawberries and one about a proposed water bottling business, and subsequently interviewed 22 elementary, middle and high school students. The findings of this work show the prominent role that factors other than school science played in students' decision-making practices. The students who had outside-of-school identities and practices, such as being a fisherman or an athlete, had an interest in the scenarios and usually drew on knowledge and values from these out-of-school resources more than school science. These interview results emphasize that decision-making is guided by students' Discourses, and that students come to school with primary Discourses that reflect their communities of practice, identities, values and funds of knowledge. This work raises questions for science education instruction, prominently, how can school science be designed and implemented to help students connect their in and out of school experiences in order to become more informed and engaged socio-environmental decision-makers?

Introduction and Research Questions

Young people who are in school today will be asked to change their lifestyles and agree to restrictions on their freedoms on the basis of scientific arguments about the environmental effects of human actions. Most people who have studied the scientific evidence are convinced that if we do not undertake voluntary changes in policies and lifestyles on a massive scale, our children will endure involuntary changes on a much more massive scale, as we encounter the consequences of global warming, loss of biodiversity, and degradation of water resources.

This is a fundamental challenge for science education in a democratic country. We must prepare our children to make the decisions that confront them in responsible and well-informed ways. Some of these decisions will have to do with their private conduct as consumers, workers, and owners. Other decisions will concern public policy when students become voters, volunteers, and advocates.

In this paper we propose a framework for analyzing how students approach both public and private environmental decisions. We then use this framework to analyze the decision-making practices of students who we interviewed about specific socio-ecological issues. Finally we consider the implications of our results for the school science curriculum. We explore the following questions:

1. When presented with a socio-ecological issue, how did the students investigate and explain the socio-ecological issue? What consequences did they predict for their possible actions?
2. What decisions did the students make and how did they justify those decisions?
3. Given their understanding of the issue, what values and other resources did they draw on as they made their decisions?

Framework and Literature Review

We make dozens of socio-ecological decisions every day. When we decide to buy a bottle of water, or decide whether to buy organically grown strawberries, or drive a car to work in the morning, we make decisions with environmental consequences. We also participate in decisions about public policies when we vote for a candidate or a ballot initiative, or decide whether to accept rezoning of a parcel of land, or choose to volunteer for a political organization. Most of these decisions we make quickly and with little thought, relying on heuristics that frame and limit our choices (Tversky & Kahneman, 2000).

In this paper we are concerned about the reasoning that underlies the heuristics. Some of our decisions are indeed as quick and careless as they appear. In other cases, we are aware that not everyone would approve of our decisions and we have considered different points of view about the proper courses of action before deciding how to act. Thus our daily choices, made quickly on the basis of habits and heuristics, are guided by lifestyle and policy choices that we may have made more carefully and deliberately.

These lifestyle and policy choices are political in nature. That is, they involve reconciling different values and points of view. We normally think of politics as a social process, occurring among different people and groups, in a Vygotskian sense, though, we also internalize those political debates, so the reasoning of individual students that we describe in this paper is the "internal politics" through which they arrive at their decisions.

We are especially interested in the role that scientific knowledge and practices play in students' internal politics—their socio-ecological decision-making. It is apparent from our data, though, that the students' reasoning is not solely or even primarily scientific. Many other factors—students' family and personal values, their common family practices, their identities, economic and social considerations, etc.—also affect their decisions. We will begin exploring the interplay between science and these other factors with a different example—abortion—which we choose because the arguments in this debate are familiar and clearly articulated.

The Role of Science in Political Decision-making: Abortion as an Example

Abortion is both a public and, for some women, a private issue. Some women face personal choices about whether to terminate a dangerous or problematic pregnancy; for them, abortion is a private issue. All citizens have the opportunity to vote on ballot initiatives or to elect public officials on the basis of their positions on laws and policies designed to control the behavior of pregnant women; these laws and policies make abortion a public issue as well. People's public and private decisions may not be the same. For example, women who would never have an abortion themselves may still advocate giving other women that choice.

In this section we will focus on positions that people take on abortion as a public issue: What laws and policies should govern women's choices about whether to terminate a pregnancy? There are two extreme positions on this issue:

- An extreme pro-life position. People holding this position believe that abortion is the murder of unborn human beings, and therefore never justified, any more than the murder of innocent children after their births.
- An extreme pro-choice position. People holding this position believe that women should have the right to make decisions about their own bodies in all cases.

Both of these extreme positions render science irrelevant. They advocate laws that defend an absolute right, of the woman or of the fetus. Many people, however, find both of these extreme positions untenable; they feel that some balance needs to be found that considers the well being of both women and unborn children. At this point, many questions arise that science might help us to answer: What are the dangers to the mother of having an abortion? What are the dangers of carrying the fetus to term? Does the mother or the fetus have a condition that affects quality of life? Is the pregnancy far enough advanced so that the fetus is viable outside the womb? Some of these questions concern our understanding of human pregnancies in general. Other questions are about the conditions of specific cases. Science can contribute to our answers to all of them.

The different positions on abortion policies are associated with different Discourses (Gee, 1990; Gee, 1991) and different communities of practice (Wenger, 1998). The people holding each position are likely to associate with other people who share knowledge, practices, and values that frame the issue for them and make their position seem clearly correct to them.

Our actual laws must emerge from a political process that involves arguments among advocates for the different positions. For some people, these arguments are governed by utilitarian principles; they seek to find metrics that allow for rational comparison of the risks and benefits to all the parties involved and to arrive at solutions that provide the greatest good for the greatest number. For other people, our laws are the outcomes of a tawdry political process that compromises fundamental moral principles. In a democracy, though, we are committed to a political process that allows all parties to make their arguments and arrives at laws and policies that bind us all.

Our personal positions on abortion may or may not involve a similar kind of internal political process. Some of us frame the issue in ways that require no internal debate while others consider all of the arguments about the issue before reaching a decision. Our decisions about socio-ecological issues are similar to our decisions about abortion in that they also may require us to resolve conflicts associated with different discourses and values, and in that our framing of the issues can render science more or less relevant.

A Framework for Analyzing Socio-ecological Decision-making: Discourses, Practices, and Knowledge

In this paper we present results from interviews with students about two different socio-ecological issues, each involving public and private decisions. In the water-related interviews, we asked students about whether and when they drank bottled water (a private decision) and about how they would vote on a decision to allow a bottled water company to drill a well in the watershed of a northern Michigan trout stream (a public decision). In the strawberry-related interviews, we asked students about the health benefits (private) and environmental impact (public) of different strawberry products.

In our data analysis we endeavored to understand the reasoning—the internal politics—of students as they arrived at their decisions. In particular, we were interested in analyzing the role that scientific knowledge and practices played in that reasoning. The framework we used to guide our data analysis is represented by Figure 1, below.

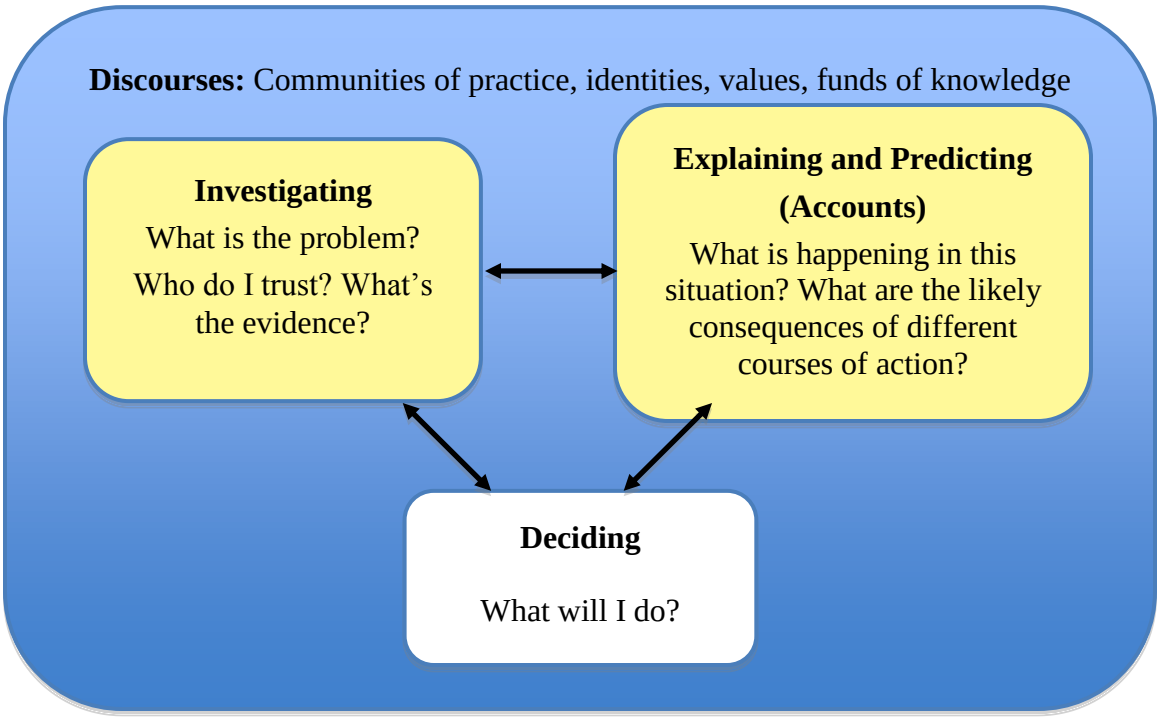

Figure 1: Framework for analyzing students' decision-making Discourses and practices

Figure 1 shows four *practices*—investigating, explaining, predicting, and deciding—embedded within *Discourses*, which are associated with communities of practice and which

frame the practices. The practices all require *knowledge.* These categories—Discourse, practice, and knowledge—provide a conceptual framework for our analysis. We discuss each below.

Discourses: Communities of practice, identities, values, and funds of knowledge

In our interviews we asked students to take on *conventional roles* that are defined for citizens of our society, including a private role (consumer) and a public role (voter). Playing these roles is in part a matter of learning general social conventions—how to pay for food in a grocery store checkout line, for example, or how to cast a vote in a polling place. As noted above we commonly play these roles without a lot of conscious thought, relying on heuristics or habits (e.g., "I usually vote Democratic." "I buy some bottles of water every week."). Thus deciding (the white practice in Figure 1) often does not rely on a lot of investigating, explaining, or predicting (the yellow practices).

But there are times that we are asked to justify our habitual decisions ("Why do you vote Democratic?" "Why do you buy bottled water instead of just getting it from the tap?"), for example when we discuss issues with others or when we encounter new issues in our roles. In those cases, our ability to investigate, explain, and predict possible outcomes for an issue becomes important. These are the kinds of problems we presented students with in this study.

As noted in the discussion of abortion above, our responses to complex issues are generally framed by communities of practice with which we identify and their associated Discourses. Gee (1990) defines a Discourse as "a socially accepted association among ways of using language, of thinking, and of acting that can be used to identify oneself as a member of a socially meaningful group" (p. 143).

Gee further distinguishes between primary Discourses that we acquire in our homes and secondary Discourses that we learn in other social settings:

> All humans … get one form of discourse free, so to speak... This is our socio-culturally determined way of using language in face-to-face communication with intimates…
>
> Beyond the primary discourse, however, there are other discourses which crucially involve institutions beyond the family…. Let us refer to these institutions as secondary institutions (such as schools, workplaces, stores, government offices, businesses, or churches)…. Thus we will refer to them as "secondary discourses". (Gee, 1991, pp. 7-8)

Thus citizens in our society participate in multiple communities of practice, each with its own Discourse, and Discourses provide us with perspectives that we use to define issues and develop funds of knowledge, practices, values, and identities that we can use to decide our courses of action. Although we did not explicitly ask students about their Discourses in the interviews, they gave us a lot of information about their Discourses through their choices of perspectives and values, the funds of knowledge that they drew on, and stories that they told about their home and family practices.

Our knowledge is embedded within practices, which are embedded within Discourses. We hold knowledge gained from participating in everyday family, community, and labor practices, or funds of knowledge (Calabrese Barton & Tan, 2009; (Gonzalez, Moll, & Amanti, 2005; Moje et al., 2004; Moll, Amanti, Neff, & Gonzalez, 1992). In the interviews, students provided us with insight into the funds of knowledge that they used to guide their investigation, explaining, predicting and deciding practices. Just as students have funds of knowledge related to

science from everyday practices, they also have knowledge learned from school science. It is important to recognize the origin of student knowledge, as it gives insight into the values and Discourses students use when making decisions.

One secondary Discourse that is especially important to us is *scientific Discourse*. We discuss the values and knowledge associated with scientific Discourse below. We note one important characteristic here: *Scientific Discourse is about investigating, explaining, and predicting, but not deciding.* Scientific communities of practice have developed values and standards for judging the quality of investigations, explanations, and predictions, and we hold that these standards and values are critically important for those practices. Scientific values, however, do not tell us what to do about socio-ecological issues. For this purpose we must rely on other Discourses.

Thus our students' interview responses were determined in part by their (generally unconscious) choices of Discourses, including their primary Discourse and possibly some secondary Discourses, including scientific Discourse. They acquired these Discourses through association with communities of practice and used these Discourses to frame the problems and their responses. These Discourses also provided them with values and funds of knowledge that determined their responses. Our data analyses are devoted in part to discovering the nature and roles of students' Discourses.

Practices: Investigating, explaining, predicting, and deciding

Some aspects of students' Discourses that were evident in the interviews were their practices associated with investigating, explaining, predicting and deciding. The students in our interviews made decisions, supported to a greater or lesser extent by investigations, explanations, and predictions. In this section we briefly discuss each practice and its possible roles in an overall decision-making process.

Investigating: Learning about the facts of the case. Informed decision-making requires knowledge that can come from various sources, including funds of knowledge from primary and secondary Discourses. When we judge that we don't already know enough to make an informed decision, we investigate the problem, either by inquiring directly into a situation or by relying on inquiry conducted by others. In the course of our investigations, we must decide what the problem is all about, who to trust and how to judge the strength of the evidence we encounter.

What is the problem? (Defining the problem space)

The way we define the problem space when confronted with a socio-ecological issue will consequently impact all other aspects of decision-making (Arvai, Campbell, Baird & Rivers, 2004). The definition of the problem space can influence the questions we ask to learn more about an issue, the sources we go to for answers, the courses of action we consider, and the extent to which we can envision potential environmental and social consequences of different courses of action.

Although decisions about all socioscientific issues can be informed by a combination of scientific and social understandings and values, individuals may not always include all possible factors when they frame their problem spaces. Individuals may define their problem spaces in narrow ways due to personal values, lack of awareness of all factors, and/or an acknowledgment of how overwhelming it would be to process all relevant information for any given socio-ecological issue. As discussed in the abortion example above, some choices of problem spaces and values render scientific knowledge irrelevant to a decision. Research concerning how

students investigate socioscientific issues suggests that they are more likely to consider social rather than scientific information (Fleming, 1986) and immediate factual claims rather than scientific theories and content knowledge learned in school (Kolstø, 2006).

Who do you trust? (Reasoning about sources of information).

Because citizens are not able to carry out independent scientific investigations every time they confront a socio-ecological issue, they realistically need guidelines for deciding who to trust if they are to competently use science as a tool in decision-making. The practice of deciding who to trust is addressed in more and less explicit ways in various science education documents and articles. The National Science Education Standards only obliquely addresses this practice, for instance, by suggesting that scientifically literate individuals have, "the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately" (National Research Council, 1996, p. 22). Similarly, the Atlas of Science Literacy (American Association for the Advancement of Science, 2001) includes "avoiding bias in science" as a strand within the scientific inquiry cluster. Reform science education documents often focus on students' abilities to evaluate arguments and evidence, rather than their abilities to judge the trustworthiness of the sources themselves.

Science education researchers who have an interest in students' capacities to deal with socioscientific issues, however, tend to emphasize the practice of deciding who to trust to a greater extent (e.g., Elliot, 2006; Kolstø 2001; Korpan, Bisanz, Bisanz, & Henderson, 1997; Sadler, Barab & Scott, 2007). Sadler and colleagues (2007), for example, include, "exhibiting skepticism when presented potentially biased information" as one of four significant practices for decision-making about socioscientific issues. Kolstø (2001, p. 877) investigated how students judge the trustworthiness of information they encounter when considering a socioscientific issue. He found that students use four strategies for deciding who and what to trust including, "1) Acceptance of knowledge claim, 2) Evaluation of statements using 'reliability indicators' and through explicitly 'thinking for themselves', 3) Acceptance of researchers or other sources of information as authoritative, 4) Evaluation of sources of information in terms of 'interests', 'neutrality' or 'competence'." Kolstø found that students used one or more of these strategies to judge sources, and that overall, while students were sometimes concerned about empirical evidence provided by sources, they were more often swayed by sources' "superficial contextual information."

What's the evidence? (Reasoning about arguments and supporting evidence).

Arguments may be grounded in scientific data that were collected, analyzed and interpreted in ways that correspond to the scientific Discourse, or they may be grounded in non-scientific ways of knowing such as theological beliefs, social norms, or subterfuge. It is important for people to be able to distinguish between knowledge claims grounded in scientific evidence, and knowledge claims grounded in non-scientific ways of knowing, when engaged in decision-making with respect to socioscientific issues (Bell & Lederman, 2003; Sadler, 2004).

Research on individuals' epistemological stances informs our understanding of how people adopt different perspectives when deciding what they believe. Studies by Perry (1970) and Belenky, et al. (1986), suggest some of these varied perspectives. For example, Perry found that over time, male college students moved from seeing the world in absolutist terms, to acknowledging a diversity of perspectives, through identifying personal commitments among relativistic possibilities. Working with women, Belenky, et al. (1986) found perspectives including silent obedience to authority, valuing personal intuitive understanding, and integration

of personal understanding with knowledge gained from others. The stance that an individual adopts influences the way she/he interacts with arguments and evidence of a socioscientific issue.

Other factors also impact individuals' ways of dealing with arguments and evidence. For example, whereas scientists place high value on arguments accompanied by statistical evidence, non-scientists are often more swayed by arguments accompanied by graphic or personalized information (Arvai et al., 2004; Slovic, 2007). Heuristic biases are human tendencies to rely on simplified versions of information to reduce the complexity of processing (Tversky & Kahneman, 2000). The reliance on heuristic biases is well documented in human information processing and decision-making.

Education related to socioscientific issues could help individuals understand both their own strategies for assessing evidence (their epistemological stance) as well as the epistemological strategies that communities of scientists use to develop shared understanding of the material world. Although scientific Discourse provides one approach to framing investigations and making judgments about sources and evidence, there is abundant research to show that individuals commonly rely on problem definitions and epistemologies associated with other primary and secondary Discourses.

Explaining: Combining Discourses, models, and data. Informed decision-making requires some explanation of the situation; we must figure out what is happening in the socio-ecological systems we live in, and how those systems can be affected by our actions. Much of our current work on environmental science literacy focuses on how students explain socio-ecological processes (e.g., Covitt, Gunckel, & Anderson, 2009; Mohan, Chen, & Anderson, in press). More generally the large body of work on conceptual change (e.g., American Association for the Advancement of Science, 1993, Chapter 15; Driver, Guesne, & Tiberghien, 1985) documents the many ways in which students' explanations generally differ from scientific explanations of natural processes.

In our research (e.g., Covitt, Gunckel, & Anderson, in press; Mohan, Chen, & Anderson, in press), we have found that students' explanations about socio-ecological systems often reflect primary Discourses and funds of knowledge including family experiences, popular media, and popular culture. As such, their explanations often conflict with scientific explanations. We believe that decisions about socio-ecological issues are generally better informed when individuals' explanations correspond with scientific explanations, which combine general knowledge—theories and models—with specific data about the case at hand. The nature of the scientific models and data that inform socio-ecological decision-making is discussed in the section on knowledge, below.

Predicting: Consequences of different courses of action. Informed decision-making involves a concern for the likely consequences of our actions. As with investigations and explanations, scientific Discourse can inform problem definitions and provide values that lead toward accurate predictions, but in our everyday lives we commonly rely on approaches based on other Discourses and their problem frames and values.

The process of predicting outcomes to inform decision-making is always complicated by limited information and uncertainty. This is true for all Discourses including formal (e.g., scientific and economic Discourses) and informal Discourses. For the most part though, as individuals try to reason about the likely outcomes of actions related to socioscientific issues, they do so in informal ways. Few people consciously engage in the weighing of probability,

expectancy, value, risk or uncertainty as they decide what to do (Arvai, et al., 2004). Instead, people generally rely on simplified understanding constructed through the use of heuristic principles (Tversky & Kahneman, 2000). One example is availability bias, where people judge the probability of an event based on the ease with which such an event can be brought to mind. An instance of availability bias would be a person thinking that traffic accidents are more likely to occur for a time after driving past a car that is overturned on the side of the road (Tversky & Kahneman, 2000). Such biases can impact individuals' predictions, and consequently, their socioscientific decisions. For example, a person who drove by an accident might decide to buy an SUV because they perceive that accidents are common and that SUVs are safer for passengers in an accident.

Awareness of the weaknesses of lay ways of predicting outcomes related to socioscientific and health issues have led some researchers and educators to propose educational models for teaching students to deal with risks (e.g., Briscoe, 1992; Gregory, 1991; Zint, 2001) and environmental decisions (e.g., Arvai, et al., 2004). Some decision educators even recommend teaching students to use structured decision-making processes (e.g., Hammond, et al. 1999). In our view, while education strategies that help students consider and understand the strengths and weaknesses of their predictions are desirable, approaches that teach specific, cookbook strategies for making decisions are probably too dissimilar from peoples' intuitive decision-making practices to be useful. Structured approaches, especially those that encourage computation in decision-making, may feel very unnatural to students if they are incompatible with their primary Discourses.

Deciding: Applying values and knowledge in a problem space. Individuals commonly rely on habits and heuristics, lay ways of making decisions that are useful and necessary in everyday life. Without these decision-making shortcuts, we would get bogged down in information processing and have little time left for actually doing anything. Research related to socioscientific decision-making also suggests that personal values often play a more central role in individuals' decisions than does consideration of scientific evidence (Bell & Lederman, 2003; Kolstø, 2006). Still, as science educators, we are interested in exploring what can be done to support people in making decisions about socioscientific issues that are well-reasoned and informed by scientific knowledge and practice.

The internal politics of socioscientific decisions can be utilitarian in nature, seeking to enumerate and quantify risks, costs, and benefits of different courses of action, but utilitarian values are not necessarily "scientific." For example, many scientists endorse some version of the precautionary principle, which states that if an action or policy might cause severe or irreversible harm to the public or to the environment, in the absence of a scientific consensus that harm would not ensue, the burden of proof falls on those who would advocate taking the action (Barrett & Raffensperger, 1999). While science can provide us with some guidance concerning how to calculate some risks and uncertainties associated with different courses of action, it cannot provide definitive suggestions concerning which actions to pursue, given any set of scientific facts. Decisions related to socioscientific issues always depend not just on facts but also, and ultimately, on values (Kolstø, 2006).

So scientific values cannot determine our decisions, but our decisions can be informed by scientific knowledge and practice. Informed decision-making thus involves all of the practices in Figure 1: investigating, explaining, predicting, and deciding.

Summary: The practices of informed decision-making. This paper reports on a study of students' decision-making practices about socio-ecological issues. These practices can never be purely "scientific;" they inevitably rely on problem frames, knowledge and values influenced by other primary and secondary Discourses. Some students may rely on problem frames and values that include no place for scientific knowledge and practice.

We hold, however, that informed decisions about socio-ecological issues require more than use of simple slogans or heuristics. Informed and responsible citizens also engage in other practices, including investigating, explaining, and predicting. These practices, too, rely at least partly on problem frames and values from non-scientific Discourses. For example, scientific communities have constructed a vast network of interconnected explanations, and science alone cannot determine which explanations are relevant to a particular decision. Science provides an invaluable set of tools for these supporting practices, though, and we wish to understand when and how students use those tools.

Knowledge: Funds of knowledge, models, and data

Knowledge is the third part of our conceptual framework for analyzing students' socio-ecological decision-making. We often make decisions in ways that require little specific knowledge, but informed decision-making is a knowledge-intensive activity. Thus we are interested in the nature and origins of the knowledge that students brought to bear while they engaged in decision-making practices. We discussed above how funds of knowledge are associated with all Discourses. So we all rely on funds of knowledge from primary and secondary Discourses when we make socio-ecological decisions.

We are particularly interested in the funds of knowledge related to scientific knowledge and school science knowledge that students drew on in the decision-making process. Figure 2 is an adaptation of the "Loop Diagram" developed by the Long-Term Ecological Research (LTER) Network to describe their ongoing research agenda (U.S. Long Term Ecological Research Network, 2007). The Loop Diagram suggests a way to understand the relationships between our societies and the environmental systems upon which we depend. Figure 2 depicts the key relationships in terms of two boxes, representing human and environmental systems, and two arrows, representing the environmental impacts of our actions and essential environmental services.

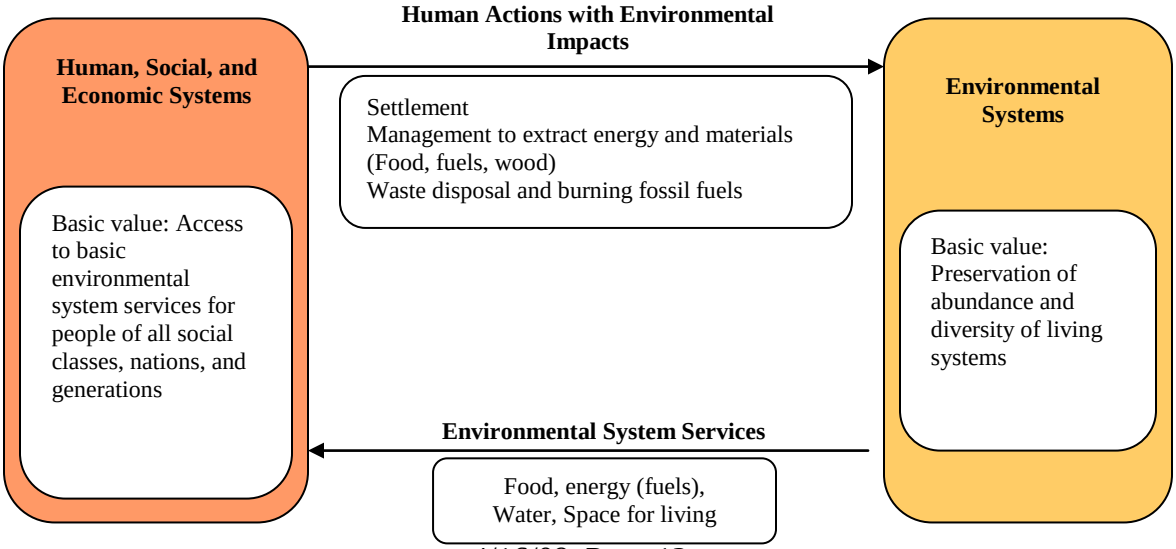

Figure 2: Structures and Processes of Socio-ecological Systems (Loop Diagram)

Figure 2 suggests a general model, within which there are more specific models of processes in environmental and human systems. In addition to these models, scientific explanations and predictions require data that are specific to the scenario. Students who combine models and data according to scientific standards can "locate themselves within the loop." In our study we investigate when and how students were successful in developing explanations that connected their scenarios to other parts of the loop diagram, and the limitations in their attempts to do so.

Methods

Descriptions of Interviews

Thinking and Making Decisions about Purchasing Strawberries (Strawberry Interview)

For this interview, students were asked to complete two ordering tasks of eight different strawberry products. First they were asked to order various food products from what they deemed most nutritious to least nutritious. This task positioned students as consumers. Next, they were asked to order the same food products from what they thought was most environmentally friendly to least environmentally friendly. In both ordering tasks, they were asked to explain why they ordered each product as more or less nutritious/environmentally friendly than other products.

Informed decision-making for the strawberry scenario. Students were asked to examine the given strawberry products and to arrange them in decreasing order, using two different criteria – which is most nutritious, followed by which product is most friendly to the environment. The products had labels with specific information listed on them, as shown in the Appendix.

1. Nutritional Criteria – which product is the most nutritious to eat? Ordering the products according to nutritional criteria is more straightforward. When considering nutritional benefits, students need only concern themselves with what is desirable for a healthy diet. Other components relating to the products in terms of packaging and transportation are not relevant in this regard. Students should consider the following perspectives: 1) Degree of food processing; and, 2) Nutritional content of the products. The nutritional labels on the products are a source of information that can inform these perspectives.

2. Environmentally – friendly criteria. The idea of environmental-friendliness requires the student to make a value judgment based on certain criteria that the student considers salient to her/his judgment. In constructing a scientific account, the student should draw from scientific perspectives that highlight different perspectives, but which are in themselves value-neutral. How the students then prioritize these perspectives in making the decision is reflective of the student's personal values in this issue of environmental friendliness.

Typically this would mean which product has the smallest carbon footprint, from farm to store. The products can be ordered in different ways for this criterion, depending on what one prioritizes when considering the different ways a product can impact the environment. A more

sophisticated account assumes that the student will be able to articulate all the different aspects of a product's life-cycle that can impact the environment and to discuss how the ordering of environmental friendliness may differ based on which aspects are fore grounded as more exigent. Hence, a sophisticated account recognizes that the concept of environmental friendliness can be analyzed from various perspectives, all of which are legitimate and important, and that there is more than one way of ordering the products.

A more sophisticated account would include the following perspectives: 1) How the food is grown; 2) How the food is processed; 3) Transportation of the food product, and 4) How the food is packaged. This last point includes considering both the type of packaging material, and the amount of packaging for each product. In short, a more sophisticated account requires the student to articulate an understanding of the connections between human, social and economic systems and environmental systems, and how each is affected by human actions

Thinking and Making Decisions about a Proposed Water Bottling Venture (Water Interview)

The water citizenship interviews had several parts. First, students were asked some general questions about their knowledge and use of water. Then, students were introduced to a true scenario about a company that would like to drill a new well to enlarge their water bottling business. The well would affect water flow in a trout stream in the same watershed; the students were asked to consider whether the company should be allowed to drill the well. After being introduced to the scenario the students were asked questions to find out how they understood the science around the scenario. Next, students were asked questions about how, as citizens, they would respond to the water bottling issue. During the interviews, the students were presented with some additional information from stakeholders including the Nestle Company, West Michigan Trout Unlimited, Michigan Citizens for Water Conservation, and Michigan Department of Environmental Quality. The students could use the additional information to inform their positions and decisions with regard to the issue. Two interview protocols were used, a high school protocol and an elementary/middle school protocol in which the additional information was abridged.

Informed decision-making for the water scenario. In considering whether or not to support the building of a commercial well to provide water to a water bottling venture, a citizen making an informed decision should consider some of the following general ideas. First, a general understanding of how watersheds and groundwater function in relation to one another is important. A watershed is an area of land where water that falls as precipitation drains downhill into a body of water such as a river, lake or ocean. An individual considering this case should understand that water to be tapped in the proposed well will have arrived underground after first falling as precipitation within a given watershed. Some water that falls as precipitation infiltrates into the ground and enters the groundwater system. Groundwater can also discharge from an underground system back to the surface water system through contiguity with a body of water such as a river or a lake.

When water is removed from the groundwater system through a well, there will be an impact on the amount of water in contiguous water systems such as rivers and lakes. In general, the impact of well water removal on a contiguous surface water system such as a river or stream will depend on the amount of water that is removed relative to the total amount of water in the water system. The greater proportion of overall water in the system that is removed, the larger the impact will be on the system. Taking a small proportion of water out of the system through a

well may have very little impact on a river or stream. It can be noted though that if a set amount of water is approved for removal, the impact of removal would be higher during a dry period of time as compared with a normal or wet period of time.

An informed citizen would also have a general knowledge of other issues related to bottled water such as the fact that there are monetary costs and environmental impacts associated with producing plastic bottles, bottling water, transporting water and disposing of bottles. An informed person should also understand that in the United States, municipal water is generally of high quality and is often subject to greater regulation and safety standards than bottled water is (National Resources Defense Council, 1999). In general in the United States, monetary costs and environmental impacts associated with tap water are likely to be less than those associated with bottled water.

In addition, a knowledgeable citizen should also have some understanding of how scientists develop accounts and make predictions, including, for example, an understanding of validity in scientific studies, uncertainty, and risk. Similarly, a knowledgeable citizen will have a basic understanding of what may be involved in an environmental regulatory process.

In the local case of Ice Mountain Water building a well near Evart, Michigan, a well-informed citizen would likely want to access some of the following types of information to help her or him develop an account and make a decision. How much water flows through this watershed (with a margin for dry, normal and wet years) and groundwater system? How much water is proposed to be removed? What species live in the potentially affected streams and how much water flow do they need to maintain a healthy population? How many people live in this water system and how might the well impact their water supplies? What other impacts associated with building the well and the water bottling plant are likely? What other water systems may be dependent on this system (e.g., the Muskegon River) and what potential impacts may occur?

There is no one ideal decision for the Ice Mountain Water scenario. Rather, an informed citizen would be able to integrate his or her understanding of the general science of water systems, the specific science and data associated with this case, and personal values relevant to the case. Thus, two well-informed citizens may construct similar factual understandings of this case, and yet come to different decisions based on differing values – such as valuing recreational opportunities, valuing local economic growth, or valuing conservation of natural areas. Different decisions can all fit criteria for responsible environmental decision-making.

Design and Procedure

We developed two Think-Aloud scenarios, each presented to students in an interview setting to help us ascertain how students understand and engage in citizenship issues. The interviews focused mostly on issues that we defined in advance. We presented students with tasks or issues and investigated how the students reasoned about their choices.

We conducted 30 to 45-minute interviews with a total of 22 students. 6 students were interviewed for the strawberry scenario: 3 high school and 3 middle school students. For the water interview, we interviewed 16 students: 8 high school, 4 middle school, and 4 upper elementary school students. Interviewed students attended schools in rural, suburban and urban districts, all in one Midwestern state.

Interviews were transcribed and analyzed primarily through a grounded theory approach (Corbin & Strauss, 1997; Glaser & Strauss, 1967). Data were coded by the first three authors and

all four authors met weekly to discuss the data. We took an iterative approach between data analysis and creating the decision-making framework (Figure 1).

In the results section, we first present cases of 6 students (3 strawberry interviews and 3 water interviews). In each case, we provide:

1. A brief description of the student participant;
2. A description of his/her a) investigating, b) explaining and predicting, and c) deciding practices (Fig. 1); and
3. A description the Discourses and values the students drew on in the decision-making process.

Finally, we conduct a cross case analysis of the students where we discuss the Discourses students use as resources for their decision-making practices, including family funds of knowledge and salient identities; peer, popular culture, and media; and school science. We also explore the nature of the student decision-making practices.

Results

Case Studies of Individual Students

James, the eco-conscious guy

James was a 6th grade, male middle school student who participated in the strawberry citizenship think-aloud interview. The strawberry scenario required the students to order the strawberry products in two ways – items that are most nutritious for human consumption, and then items that are most environmentally friendly. There was coherence in what James talked about with regard to making environmentally conscious decisions that ran through the interview and across interview questions. James seemed to be someone who had a consistent belief or principle of operation with regard to the environmental issues related to food consumption. He was aware of issues related to product life-cycle costs, and appeared committed to being an eco-conscious consumer.

Investigating: Who do I trust? What is the evidence?

James trusted the labels on the food products, and where we told him they were from, if there were no labels. He also drew largely from the knowledge he accrued from being an active member of his family's organic gardening practices and energy conservation principles. He trusted the authority of his family with regard to this issue because they engage in these relevant practices. Both his immediate family and his grandmother engaged in organic farming practices, growing strawberries, beans and tomatoes. They also composted and used natural fertilizers. To James, growing their own food was beneficial to the environment because then *"we get that [canned produce and strawberries from grandma] instead of the non-organic or organic ones… from California…"* This family practice grounded James's understanding that it is beneficial to both human health and the environment to grow one's own food (minimal transportation and processing) without pesticides.

Explaining & Predicting: What is happening in this situation? What are the likely consequences of different courses of action?

Nutritional ordering task

With regards to the Strawberry scenario, James ordered the products from most nutritious to least nutritious as follows: Organic strawberries, locally grown strawberries, industrial California strawberries, both large and small containers of yogurt, local jam, California jam, Pop tarts

James based his nutrition decision on three different heuristics: The degree of food processing, how the food was grown and how fresh the food was. His three heuristics were all drawn from scientific accounts. First, he ordered the produce from the least processed to the most processed. He thought that a pop tart was the worst because "*it has all the sugar in the filling… and the chocolate on top is probably not healthy either."* Whole strawberries were more nutritious than the strawberry based products. The jam had a lot more sugar, so was deemed less nutritious than yogurt. He also considered how the produce was grown. He thought that the organic produce was more nutritious than non-organic produce because "*pesticides will be bad for you.*" Freshness of the produce was yet another consideration. As such, James favored the locally grown strawberries and jam over their non-local counterparts, since "they don't have to travel as long from where they were picked."

Environmental ordering task

Most environmentally friendly to least environmentally friendly: Organic strawberries, local jam, small container of yogurt, big container of yogurt, California jam, pop tarts, local strawberries, industrial California strawberries

There was more evidence of James "predicting" from his environmental friendliness decision. He viewed his ordering from a few different angles, all drawn from scientific accounts: How the food was grown, how the food was processed and how the food was transported. He considered plausible scenarios based on these factors.

His first criterion was the use of pesticides being harmful to the environment. Hence, both the industrial California strawberries and the local strawberries (he assumed pesticides were used on the local produce since there was no information provided to indicate otherwise) were at the end of his list. James reasoned that "*the pesticides are polluting water, which are killing the fish, just polluting the land 'cause they get sprayed on… it might make the bugs go away but it hurts a lot of other animals.*"

His second criterion was the degree of food processing since increased processing demands more resources, which in turn taxes the environment. James described how the pop tart was wasteful because "*a lot of stuff goes into it and it's not very big so it takes a lot to make something really little.*" He substantiated his claim by suggesting how the provenance of the various ingredients that goes into a pop tart would be a concern:

> *…the flour, it's in California so you have to take the wheat from let's say… oh I don't know, let's say Michigan. And cocoa beans from some tropical area, South America or Mexico… and it does take a lot of stuff to go into one plant in California, to make that.*

…then the pop tart the flour can come from a flour mill and the chocolate from … all the ingredients of the chocolate come from different spots and then the stuff that's on the inside come from a whole bunch of different factories… they just mix it all up into one thing…

James also considered how far the food had to be transported with regard to both the final destination of the food – a shelf on a Michigan store – and each ingredient's journey during food processing. The California jam was therefore less harmful to the environment compared to the pop tart because *"it's in California and strawberries grow in California so you don't need to transport a whole bunch of stuff to California, then to Michigan."* The local jam was second best because "*It was closer to Michigan… like, all the CO_2 that's coming from the trucks."* James was therefore cognizant of the carbon footprint tied to the production and transportation of food products. He could predict the carbon footprint of a food product.

To a lesser extent James considered the packaging of the products. While deciding between the yogurt samples, James initially placed the smaller container as being more friendly to the environment since "*there can be a lot more of these [small ones] in a truck than these [big ones]."* Therefore, although packaging was invoked as a scientific account, James applied his own personal opinion with regard to packaging in his decision-making. He used numbers as a criterion. When probed further about which sample would save on packaging, James acknowledged that the bigger carton would. He then concluded that both big and small containers are "kind of even" because of "what they save." To him, the bigger carton saved on packaging, but the smaller ones saved on numbers – you could transport more of the smaller cartons in a truck to get more cartons to a store.

James was methodical in listing the different factors he considered that led to how he ordered the products. With each factor, James could articulate well-substantiated elaborations that align well with the canonical account. With the multiple perspectives he took, James could situate himself within the human systems box of the loop diagram and articulate how his decisions contribute to the human impact arrow (Figure 2). James also showed concern for maintaining a robust environmental system and could identify the services provided by the environmental system in this scenario.

Deciding: What will I do?

James also talked about the general shopping habits of his family. With regard to snacks and junk food, James (and his family) relied predominantly on family conventions related to brand (Jiff versus Skippy for peanut butter; Pepsi brands for pop) and economy (whatever chips are on sale). Perhaps nutritional information did not feature in their decisions here since it was junk food ("*all chips taste the same*") anyway. Nutrition did feature in the "proper food" category for his family. James talked about how they buy organic vegetables and try to get eggs that are "*farm grown*," presumably alluding to humanely treated hens.

Discourses and values

James clearly valued the environment and engaged in practices that he thought would help sustain the environment instead of depleting it of its resources. There was coherence in what he said and did (i.e., family practices), and he seemed to be able to trace the loop diagram quite thoroughly and identify actions he could take with regard to the loop diagram.

He drew from scenario-specific knowledge, reading the products' labels which revealed such information as the ingredients of each product and how the product was grown either with pesticides or without. James also drew from his personal knowledge. He understood that pesticides could be harmful to health and that transportation added to time in which a food was held in storage before reaching the consumer, which may adversely affect the nutritional quality of the product. Additionally, James invoked the concept of fresh food versus processed food, correctly choosing the former as being more nutritionally desirable than the latter.

James's reasoning about the environmental-friendliness ordering was quite sophisticated in that he considers the problem from different perspectives and could trace the origins of the product and its ingredients along various routes. James identified all four key scientific threads: How food was grown, degree of food processing, transportation and packaging. In making his decision, James was able to apply his personal knowledge to the scenario-specific knowledge that was mainly presented in the form of labels on each product.

In his ordering decision, James was greatly concerned with the consequences of pesticide run-off. He seemed particularly concerned with the run-off adversely affecting other ecosystems and harming other animals far away from the farm where the strawberries are grown using pesticides. Since there was no information about how the local strawberries were produced on its container, James assumed these were also grown with pesticides along with the industrial strawberries and ordered these two products as being least environmentally friendly. This concern seemed to stem from James's personal values with regard to biodiversity and ecosystems.

Mark, the athlete

Mark was a 10th grade high school student who participated in the strawberry citizenship think-aloud interview. Mark identified himself as an athlete, specifically a wrestler. His identity as a wrestler, along with family practices, played a prominent role in his decisions about ordering the strawberry products according to nutrition. While he drew on these identifies and family funds of knowledge in the nutritional ordering, they did not appear to play a role in how he ordered the products from more to less environmentally friendly.

Investigating: Who do I trust? What's the evidence?

Mark said that he would trust someone based on his feelings and if he felt like what a person said made sense. When ordering the food products, he looked at and trusted the food labels, which told him information such as the amount of sugar and carbohydrates and whether the products were local, organic, etc.

Mark also trusted his family and friends. His mother shopped at organic food stores and made healthy smoothies for his family to drink. She and Mark both took the calories of food and drinks into account when making food decisions. Mark also listened to his friends when he went out to eat with them and they told him to eat certain foods because they were healthier for him. Mark drew on knowledge from family practices, interactions with friends, and his knowledge gained from his experience as a wrestler, trying to make weight.

Explaining and Predicting: What is happening in this situation? What are the likely consequences of different courses of action?

Nutritional ordering task

With regards to the Strawberry scenario, Mark ordered the products from most nutritious to least nutritious as follows: Organic strawberries, yogurt (both large and small containers given equal weight), local strawberries, industrial California strawberries, local jam, California jam, pop tarts

Mark used the labels to help him in the nutritional ordering task. He used three criteria: whether or not the product was organic, the number of ingredients, and the amount of processing. The first criterion Mark used to order the products in terms of nutrition was whether or not they were organic. Mark believed that organic products, such as the strawberries were healthy for you because they did not contain pesticides. He ranked the organically grown strawberries as most nutritious, because they were grown without pesticides. He ranked the local strawberries as third because he assumed that they were grown using pesticides.

A second criterion he used was the number of ingredients. He said, "Ah, pretty much because it's just purely made and you know, fruits is always good for you" as a rationale for ranking the organic strawberries as most nutritious. Thus, the strawberries were ranked higher than the jams that contained sugar and other ingredients.

Along with having more ingredients that could be unhealthy, Mark considered the amount of processing involved in the jam products. He thought that the local jam was more nutritious than the jam made in California because it was less processed. He said:

> *And I put this one before this [local before CA jam] cause I think this is a brand [touching CA jam] so they probably make it at a factory. And this [touching local jam] is probably healthier because they probably are doing it themselves without a machine.*

Mark ranked both sized containers of yogurts as second most nutritious because they were non-fat and contained dairy and protein, which he deemed as good characteristics. With the exception of considering whether or not the products were organic or non-organic, Mark did not seem to take into account how the provenance of the products affected nutrition. He seemed to have a superficial, slogan based understanding that organic products were better than non-organic products. He believed that products with more ingredients were less healthy because they had the potential to contain more sugar and also recognized that processing that could be unhealthy.

Environmental ordering task

Most environmentally friendly to least environmentally friendly: Organic strawberries, yogurt (both sized containers given equal weight), local and California jam (given equal weight), pop tarts, and local strawberries and industrial California strawberries (given equal weight)

Mark did not mention the impact of transportation or packaging of the products in the environmental ordering task. While few students took the packaging of the products into

account, most students mentioned pollution related to the transportation and processing of the products as a factor for the environmental ordering of the products.

Mark used two criteria in the environmentally friendly ordering task: whether the product was organic or not and the amount of processing of each ingredient. Similar to his nutritional ordering, the first criterion Mark applied when ordering the products from most to least environmentally friendly was whether or not the food product was organic or non-organic. He immediately placed the industrially grown strawberries from California as least environmentally friendly and the organically grown strawberries as most environmentally friend. He said, *"So it's [pesticide] also affecting bugs, it's also probably affecting plants and the soil."*

The second criterion Mark used in making his decisions was the ingredients in each product. This is another key scientific thread – the degree of processing. For the yogurt, he considered the impact of milk and strawberries. He believed that because the milk came from cows, there was not a negative environmental impact related to obtaining milk. He stated, *"…cause all you're doing is milking the cows to get the milk and you probably have strawberries so they probably just factorize that and I guess it's not really polluting anything making yogurt."* While Mark mentioned that the yogurt products were processed in a factory, he did not consider any environmental impact of the "factorize" process.

When Mark discussed the negative environmental impact of pesticides, he recognized that the pesticides affected not only insects, but also potentially plants and soil. He presented a partial understanding of the connection between the human impact arrow *(top arrow in loop diagram)* and the environmental systems box (Figure 2). As Mark considered the environmental impact of yogurt ingredients, milk and strawberries, he did not show a deep understanding of the supply and waste disposal chains of milk. For example, he did not consider the environmental impact of raising milk cows, such as the food the cows eat, treatments with growth hormones, or the waste cows produce.

Mark presented an incomplete understanding of the connections between the arrows connecting environmental and social systems. He traced the supply chain of the food products back only as far as the ingredient. For example, he did not think that producing jam products hurt the environment, *"Just because once they've already got the strawberries, they make the jam, that's not really gonna hurt anything bad for that."* Additionally, he said, *"Since the pop tart is industrial and you already have the materials then it's not really affecting anything too."* Thus, Mark placed the pop tarts as more environmentally friendly than the locally grown and industrially grown strawberries from California that used pesticides even though they contained more ingredients and underwent more processing than the strawberries. Mark did not trace the ingredients back to their origin; he only took into account the environmental impact of creating the products once the ingredients were available. When probed about tracing the ingredients back further in the supply chain, the following conversation ensued.

Mark:	*I know strawberry and bread is in pop tarts but I'm not sure where they get it or how they're making the bread or not.*
Interviewer:	*Are you concerned at all about where they're getting it or like where they're getting the strawberry or bread?*
Mark:	*Um, I may be concerned if I knew how they were getting it but I'm not really, I'm not really like oh, no pop tarts are doing something bad. Like it's not really on my mind right now.*

Interviewer: *So do you think it's important to know where they came from? Or where they're getting the strawberries from or where they're getting the sugar or whatnot that they're using in it?*

Mark: *Um, well, yeah, I guess it's important. But I never really ask myself that question when I, when I'm eating a pop tart. I'm gonna be like, oh where's this from.*

Deciding: What will I do?

When Mark discussed the general shopping habits of his family, he said that his mother shops at organic food stores. She usually looked at the calories of products first. She also looked for products that would help her lower her high cholesterol. Mark's family also took price into consideration. For example, if there were differences in prices for peanuts, he would buy the cheaper product. He did not pay attention to brand names.

Discourses and values

Mark valued foods that were nutritious and was knowledgeable about reading nutrition labels present on food items. Mark talked about how eating healthy food was important to him because he's an athlete. During his interview Mark also said that he thought science was important because you learn about how your body works. He also said that protecting the environment was important, but this did not seem to be as important to him as nutrition. He did not talk about pollution when talking about the environmental impact of food production, as some of the other students did. When asked about the provenance of food, he was not able to trace the supply chain well. He did not tell a very detailed account of how food production could impact the environment during the environmental ordering task. As mentioned, he did not talk about transportation; he was mainly interested in pesticides but never detailed why the use of pesticides is bad.

Tom, the germ-centered guy

Tom was a male high school student who participated in the strawberry citizenship think-aloud protocol. He based his decisions and centered his explanations around "germs" – how quickly the strawberry products would spoil, and when they did, how secure the packaging of each product was in order to prevent the germs from contaminating the environment. He examined each package carefully to determine if it was easily breached, and deemed those items with "flimsy" packaging to be environmentally unfriendly. Tom based his germ-centered theory on a school science experiment he had conducted.

Investigating: Who do you trust? What is the evidence?

Tom focused solely on the packaging of the strawberry products while investigating the scenario. We had packed the fresh strawberries into plastic tubs with lids and indicated with labels that they were "organic", "industrial" and "local". The rest of the products came in their original packaging.

He also relied on a region's reputation to guide his decisions. For example, he had a higher opinion of California than of Michigan, so by extension Californian food products were superior to local ones. He also drew significantly from his experiences with a science experiment where he looked for "germs" in his school compound, for example on the faucet of the water fountain.

Explaining & Predicting: What is happening? ? What are the likely consequences of different courses of action?

Nutritional ordering task

With regards to the Strawberry scenario, Tom ordered the products from most nutritious to least nutritious as follows: Organic strawberries, industrial California strawberries, pop tarts, California jam, local strawberries, yogurt (both sizes), local jam

Tom presented a "germ centered theory" in his description and explanation of his decisions. His first criterion was the reputation of the geographical location in which the produce was grown. Tom associated other states with a "better system", and hence food products from those states are likely to be of a higher quality compared to local produce. According to Tom, the organic and industrial strawberries were ranked high because, "*it's grown in LA or California or whatever… and like since California is BIGGER than Michigan and like probably has a better health system team whatever.*" Between the organic and industrial strawberries, Tom deemed the organic better nutritionally but the industrial strawberries were ranked second best in spite of pesticides because they are grown in a "better" state. As he explains, California was "*probably more advanced … [next best- industrial California strawberries] well this one, it has pesticides but it's still grown in California, they know what they're doing*."

Tom also cited the recent spinach recall as evidence of not trusting local produce, even though the recall was for Californian spinach.

> *"…there has a been a couple of, a couple of recalls on I think it was spinach or lettuce or something…and like they said that spinach you could eat it and get sick so I guess like Michigan has like, certain people or certain companies who don't take care of the stuff as well as California*"

The concept of association seemed to resonate strongly for Tom, so much so that he immediately and inaccurately linked the recall to Michigan (local) spinach since California, being what he deemed a more progressive state, would "take care of stuff".

Tom's next criterion was how long the food item could keep before spoiling. He thought that a longer shelf life meant better nutrition since one was less apt to eat something that has gone bad. Therefore, whatever that was "liquidy" or looked most likely to spoil was the least healthy, hence his ordering of pop tart before yogurt and jam. The Californian jam was superior by association to California, local strawberries were worse for being locally produced but did not yet appear "liquidy" and so were better than the yogurt and local jam. The yogurt looked more robust in appearance than the local jam, which was the last in his ordering, being both locally produced and therefore inferior, and also "liquidy." As he explained,

These [pop tarts] can last a long time without being rotten…because its bread, grain… and this [jam] is just like a little liquidy and if you leave it there [with lid open] tomorrow it will get rotten. Yoghurt is like milk type based… like if you let this sit for more than three weeks [checks expiry date] it will start to get rotten. This [local jam is last because] he just looks like he'll get rotten easily.

Environmental ordering task

Most environmentally friendly to least environmentally friendly: Three strawberry samples together (all in Glad plastic containers), both glass jam jars (local and California), large yogurt, small yogurt, pop tart

Tom's only criterion for environmental-friendliness was that food must not release germs into the environment to qualify as being environmentally friendly. His prediction centered solely on "germ- transfer" between the food product and the environment around the product.

Thus, he ordered the products according to how robust he deemed their containers to be in preventing germs from being released should the food products turn bad. As he explained,

These [all three types of strawberries in identical Glad air-tight containers] are first because of the containers and there's some air in there, to me, friendly to the environment is you don't let bacteria out. So these are all packaged up good, they're all like sealed tight. So are these [glass jams], these have lids, and then these [plastic yogurt tubs], but if you like poke a hole through this [foil of pop tart] this will get moldy. So is better to keep them like that [in airtight containers] than in these [pop tart foil] when you poke a hole in it bacteria will be IN and come out.

The plastic airtight containers of the strawberries seemed to inspire more confidence in Tom compared to the glass jam jars, even as he explained that the jam jars are secure containers because the lids are "tightened by machines".

When probed to compare the local and Californian strawberries, Tom suggested that the local ones would be better for the environment versus the Californian strawberries but not for reasons of a smaller carbon footprint. Tom stayed focused on his germ-centered theory and postulated that the Californian strawberries, having been grown in a different climate, have to be transported long distances and that being exposed to the local climate would result in the Californian strawberries losing their quality and therefore "they will die faster" and not keep as long, and therefore they will be more prone to release germs into the environment compared with the local strawberries.

When asked to compare the different sized yogurt containers, Tom again operated from his germ-centered theory and explained that the larger container, which has a plastic lid, was probably more environmentally friendly than the smaller container which has a foil top, because it was easier to penetrate a foil top than a plastic lid, thus the latter works better at preventing germs from escaping from the yogurt (when it spoiled) into the environment.

Deciding: What should I do?

In his everyday life, Tom told us he usually buys "chips and pop" from the store. He prefers "Doritos or Cheetos", because that was what his friends ate as well, and he was more comfortable with these "well known" brands. He liked Pepsi, and sometimes orange juice.

Discourses and values

Tom gave an account based largely on one school science experience focused on looking for "germs" in the school compound. This experience led to Tom's germ-centered theory, which informed his decisions in both nutritional and environmental ordering of the strawberry products. Tom's account also reflected informal perceptions when he associates another state other than his home state to be more progressive and have better "systems," therefore food from those states will be better in quality. Tom bought into this perspective so much so that he alluded to the spinach recall occurring with local spinach rather than Californian spinach when it was in fact, Californian spinach that was recalled.

Tom also had his own perspective about nutritional value. He invoked the organic versus pesticide grown produce partially, since he still deemed the industrial strawberries as being second only to the organic strawberries in being nutritionally superior, because of its being grown in another state. Hence, although Tom constructed his account with an accurate scientific thread – pesticides can be harmful for health - he still prioritized his informal thread – reputation of state - over the scientific thread, reflecting that he highly valued the reputation of the state where the food comes from in making his decisions regarding the quality of the food. Where the food product was grown or made was very important to Tom. He thought that states with a better reputation, as he personally defined them, tended to be more trustworthy in producing nutritionally beneficial food products. This was not unreasonable since consumer confidence is an integral issue in marketing commodities.

Another of Tom's criteria that was unique to him was the shelf life of the food items, which, although a factor considered in canonical nutrition science, is not regarded in the same way as Tom regards it. Tom did not distinguish between the different categories of food – fresh and perishables versus processed foods. He did not discuss the pros and cons of fresh versus processed foods (i.e., fresh foods are usually more nutritious but have the disadvantage of spoiling quickly, processed foods can keep for a longer period but are not as nutritious as fresh food after processing) and seemed to regard all the strawberry products as one category of food items. Therefore, even as he rightly pointed out that milk-type products like yogurt would spoil faster than pop tarts, he did not consider how yogurt was a less processed food item than pop tarts and because of that, could be argued to be more nutritious than pop tarts. Tom also did not make use of the nutritional labels that were on the products in making his decisions. In his decision and explanation, Tom drew largely from his personal perspectives and did not utilize any scenario-specific knowledge apart from the labels on the strawberries citing which is organic and which is industrial. One could argue that his shelf life reasoning would make sense in particular contexts, such as famine, or going on a long expedition where food needs to have a long shelf life, but we don't know if that was what he had in mind.

In short, Tom drew from a few scientific threads in building his account but he relied heavily on his own informal perceptions and embodied experiences to make decisions about the strawberry think-aloud. Tom's values were tightly bound to these informal perceptions since they were the basis of his decisions. When the scientific threads were antagonistic to his informal perceptions, Tom chose to prioritize his perceptions (e.g. reputation of California versus usage of

pesticides). There were many scientific threads missing from his account compared to a more complex reasoning. He operated completely from his personal set of criteria and his germ-centered account. Tom did not allude to any factors that are related to a product's carbon footprint or life cycle cost. From his account, Tom seemed to be largely confined within the human systems box of the loop diagram.

He seemed to value product reputation (i.e. California products better than Michigan) over any other evidence, such that he did not seek out other evidence. He maintained that California produce must be superior to local produce. This appeared to be a common trait among consumers who are loyal to a particular brand because they are convinced of its reputation. He was brand conscious. Tom also placed an emphasis on preventing food spoilage and contamination of the environment from spoiled foods.

Michael, the fisherman

Michael was an 11th grade, male, high school student who participated in the water interview. Michael exhibited coherence in his understanding of the loop diagram. He demonstrated an understanding of watersheds and also considered how social and economic systems might be affected by the construction of a water bottling plant in a small town. Michael had family practices associated with water that were important to him and guided his thinking through the water scenario.

Investigating: Who do I trust? What's the evidence?

Michael used several criteria to decide who he trusted and what made for a good scientific study. Michael trusted sources that had evidence to back up their information.

> *Yeah, I trust the Dept. of Environmental Quality more than I would the Citizens [group] because they actually do all the tests and they evaluate what happens over a period of time. With the Citizens they're just, I don't know if they research their information or not but if they didn't that would influence what I think about them and if they actually had like a bibliography on where they got their information from I would trust them more.*

Michael also trusted sources that provide references for their information. Michael trusted sources that he has heard of, like the Department of Natural Resources. He did not trust sources that he thought had motives that would influence the information they provided the public with, such as the water bottling company.

Explaining and Predicting: What is happening in this situation? What are the likely consequences of different courses of action?

Michael's account demonstrated awareness of all parts of the loop diagram. As he talked about the scenario and answered questions, he brought in ideas about different segments of the loop including human systems, economies and values, impacts humans have on environmental systems, processes that take place within environmental systems, and ecosystem services. There were some weak places in his understanding. For example, Michael believed the bottled water he drank came from glaciers, which was unlikely. In many respects though, Michael had a solid

understanding of water systems that he could apply to his account of the Ice Mountain Water well proposal.

Michael understood what a watershed was and he knew that water that falls within a watershed can run over the surface of the land or infiltrate into the groundwater system. Michael also understood that removing water from the well could impact the flow of water in a stream.

As the interview continued, Michael tried to carefully construct his account of the situation by drawing on scientific information provided in the interview. When asked if there was other information he would like to know to help him make a decision, he was able to list multiple pieces of information, including relevant scientific information that would help him decide. He was interested in quantitative as well as qualitative information that could inform his ideas about what was happening and what was likely to happen. He asked questions of the interviewer to clarify his interpretation of what he had heard and read about the scenario.

Michael used three criteria as he considered the consequences of building a water bottling plant in a small town: the amount of water that would be taken from the creek, the impact that building a water plant would have on the fish in the creek, and the impact of the plant on the people.

The first criterion Michael considered was the amount of water that would be taken from the creek. He said his decision, *"…depends on how much water they take out and how much water is in the creek."* Michael explained how removing water through the well could impact flow of water in the creek. *"It would take the water going that would seep in and go to the creek and it would take it in and they would take most of it and push it back out, or somethin."*

Second, Michael was concerned with the amount of water taken from the creek because it could affect the trout that live in the creek. He did not want to harm the fish that live in the creek. He had experience fishing with his father and was worried that the fish might not survive if the water level got too low.

Finally, along with scientific and personal considerations, Michael evaluated the impact of a water bottling plant on the social and economic systems. Michael considered whether or not the water would be used for the people in the local state or transported to other states or Canada. He also considered how the well would affect individuals and local businesses.

> *It could affect people because maybe they fish for trout. Some people have businesses where they go out and take people fishing and they might get less business because of water going down and maybe they'd go out of business and go bankrupt or something.*

Deciding: What will I do?

Michael would not support building the well. He stated, *"I would vote against it because I don't know where all the information came from and I wouldn't want to affect the environment in a bad way even if I don't live there because I believe fresh water is a great resource in Michigan so I'd vote against it."*

Discourses and values

Michael expressed a fairly diverse set of values through the course of the interview. For example during the initial questions about water and water use, Michael expressed a personal willingness to invest time in preserving water quality. When asked if he took any actions to

protect water quality, Michael talked about what his family does, including, *"we don't, like some people if they don't have enough money they just dump their oil in the yard, but we don't do that, we take it to the recycling center."*

During the interview, Michael expressed related values for maintaining water quality and environmental quality. Michael did not like the idea of removing water from the Great Lakes water system. Michael believed that, *"fresh water is a great resource in Michigan."* On a more personal level, Michael was a fisherman (often fishing with his father) who valued the recreational water resources in Michigan. Talking about the information provided in the scenario, Michael stated that, *"We've been there [the Muskegon River] before; it's a great river. Has a lot of fish. We actually had a lot of fun. I wouldn't like to see anything happen to it."*

Michael also expressed human social and economic types of values. When considering the scenario, he thought about the potential effects on people who may be affected by the well being built. He considered the positive effects on people – it might create job opportunities - and the potential negative impacts on people.

Michael brought up potential impacts on people (both his own family and other Michigan citizens) several times during the interviews, suggesting that he was taking the positive and negative social impacts of the scenario into consideration as values to think about as he decided. For example, when asked if thought he had enough information to make a decision, Michael stated, *"If they had like smokestacks and stuff to make air pollution that could make it so that we wouldn't go down there. I know it takes in a lot of jobs but it also has a negative effect on the citizens."*

Michael expressed a fairly diverse set of values through the interview, including valuing water quality and quantity in Michigan, conservation of recreation areas, social goods such as access to water and jobs, and scientific information needed to inform decisions.

Valery, Who Values Fairness

Valery was a seventh grade student attending an urban middle school. Throughout the interview, Valery emphasized a personal interest in fairness and openness to using scientific evidence to help her make decisions. This interest in science and fairness may relate to Valery's stated career goal of becoming a doctor. However, also during the interview, Valery revealed a mixture of understanding reflecting some scientific understanding and some naïve ideas. She used largely informal understanding to explain the situation and predict outcomes of possible actions. Thus, though Valery was in some ways well prepared to evaluate and consider possible choices about the scenario, her ultimate decision, which sought to balance positive outcomes for various stakeholders, was based on a faulty scientific premise.

Investigating: Who do you trust? What is the evidence?

During the interview, Valery was an information seeker who wanted to learn more about the facts of the case and who actively considered evidence and trustworthiness of sources. When Valery was introduced to the scenario and asked if she felt she had enough information to decide how to vote, she responded, *"I think I would want a little bit more, like to see how exactly it would affect the trout and see how many trout will leave, but right now I will say no from the information I have."*

Valery applied a few criteria in deciding who to trust. For example, she placed some trust in "scientific studies" but did not talk about what it means for a study to be scientific or valid. Valery felt that, *"it says scientific studies… so it's not like a lie."*

Valery also looked at how the different stakeholders talked about themselves, others and the scenario. She appreciated that Trout Unlimited, instead of writing an attack message directed at Nestle, wrote a report indicating some issues that Nestle may have missed in their own report. She describes the Trout Unlimited information by saying, *"it's not like saying Nestle is bad, so it's not trying to call them out. But it's saying what it might do to the trout in a very hot and dry season."* Valery appreciated that Trout Unlimited was focusing on the relevant issues rather than personal attacks.

Valery asked reasonable questions to learn more about the water scenario. When asked what else she would like to know to help her decide, Valery stated, *"How it would affect the water and the citizens. Like would it take away water from the citizens and the people? And would it pollute the water and make our rivers smaller?"* In order to answer these questions, Valery said that she would do an internet search using Google or Yahoo, and that she would look up information about terms and questions such as, *"Deprive water from fishes. If I was to take water away from the river how would that affect the fish? How much water people need. How much water the citizens of Evart use every year."*

Explaining and Predicting: What is happening in this situation? What are predicted consequences for possible actions related to the scenario?

Valery had some relevant understandings and some naïve ideas and tendencies toward misapplication that were evident when she sought to explain the scenario, and particularly the science involved in the scenario. Valery did demonstrate some basic water system understandings. She described how water that fell would run to Twin Creek because water *"likes to run down and you know just find somewhere and grab on."* Valery knew that, *"a river is usually lower than the land that's above it."* Valery could also show and describe which direction the water would flow in a tributary, and she believed that a well could affect the flow of water in a stream because, *"they're pulling the water from here and it might change the current and the water might flow lower because there's not a lot of water anymore."*

However, some of Valery's scientific accounts were more informal in nature. At one point in the interview, Valery indicated that she would not support building the well because of potential impacts on the fish. However, she still thought the idea of building the well was a good one and that the problem could be solved by building the well further from the creek. She would instead put the well, *"not so close to the trout and they could still build the factory so people could have jobs. I mean there's still a lot of water there because the river's still there."* Here, Valery predicted that the well would have a greater effect on the stream and the trout depending on how close the well was to the creek. She appears to consider the well's impact on the river as based on proximity, rather than considering the surface and groundwater systems as connected systems, where removing a given amount of water from the system – independently of the distance from the surface water, would still have a similar effect.

When talking about which information she believed, Valery stated that she believed the DEQ a little bit less than the other sources when the DEQ indicated how many gallons would be removed because, *"say people started buying the water more and then they would have to increase their production so that statement is not always right."* Valery predicted that demand would influence how much water Nestle will remove regardless of the regulations or agreements

that Nestle would have made with a government agency. Valery inferred forces acting in relationships (both within natural systems and human economic/regulatory systems) based on her personal experiences (perhaps primary Discourse) and ideas about how the world works.

Valery also applied some local scientific information inappropriately. When asked how deep she thought the well should be drilled near Evart to get the groundwater, Valery responded, *"Sixty feet. Somewhere between sixty and ninety."* When asked where those numbers came from, Valery indicated, *"We did a project and Mr. S asked how low would we have to get enough water for all year long and I picked sixty feet because it wasn't in the confining layer of sand, but it was above so I could get some water."* Here, Valery applied information from one specific example in class to another case where the circumstances may be different.

Overall, Valery was quite willing to reason about and make predictions related to possible consequences of installing the well. When she was asked if there was anything more that she'd like to know to make a decision, the following comments ensued:

Valery:	*How it will affect the land because it might stop the crops from growing. And like, the land might get very, very dry because they are taking away groundwater instead of just river water. If they take the water from the river it will only affect the river but if they take it from the ground that will make the ground dry.*
Interviewer:	*Anything else?*
Valery:	*How it will affect the river, and the temperature. Because it might get hotter because the river blows cooler air and if there's not as much water it might get hotter.*
Interviewer:	*Why would that be important?*
Valery:	*Some people might not like heat. As you can see it's very hot right now. So that might affect peoples' position like where they live at right now, they might want to move.*

While her predictions are not always aligned with canonical science, Valery did consider the scenario in terms of possible causes and effects, using both formal and informal reasoning to consider consequences of installing the well.

Deciding: What will I do?

Even though Valery was interested in learning more about the scenario, she actually made her initial decision very quickly, before she was even asked to do so by the interviewer. After providing a short, initial introduction to the scenario, the interviewer paused to ask Valery, *"Does that debate make sense?"* Valery responded with an initial weighing of the facts, *"It has its pros and cons, because it takes away water from the fish and also from people in the town of Evart, but it'll create jobs so people can feed their families and they won't starve to death."* She also provides an initial decision, *"They could like build one here [indicating another spot on the map] so it wouldn't take water away from the trout and it could still give people jobs."*

Later, after looking at additional information, Valery again indicated that she would not support building the well, *"Because if it doesn't harm the fish as much, but it'll still harm them enough and it will take the water from the people of Evart and they still don't know how it will affect the river."* Although Valery did not support building the well in the location preferred by

Nestle, she still thought that building the well was a good idea and that it should be relocated to avoid the problems identified in the scenario. The following excerpt shows her reasoning:

Valery: *It's good that they built the company but they should have built the well in a different place. I mean the overall idea is great but it's the positioning they put it in.*

Interviewer: *So what do you think a better position would be?*

Valery: *Right here. Not so close to the trout and they could still build the factory so people could have jobs. I mean there's still a lot of water there because the rivers still there. It's not a lot of fish, so you won't kill the trout.*

Valery's decision represented an effort to balance the potential risks and benefits to several entities, including people who might work at the water bottling factory and the fish in the trout stream. Though she sought and considered information from various sources, her initial decision, provided before she was even asked for one, matched her final decision, provided toward the end of the interview.

Discourses and values

Valery expressed a variety of values during the interview including those associated with fairness, scientific understanding, animal rights, and protecting the environment. Fairness, in particular, seemed to be an important value for Valery. When considering the scenario, she thought about people in Evart, their need for jobs and for water, and the fish in the stream. The value of fairness also arose when Valery considered which sources she trusted. For example, she talked about how she trusted the Trout Unlimited information because this source was focused on the facts of the issue rather than on trying to demonize the Nestle Company. Valery also valued science and scientific studies, perhaps in part because of her desire to become a doctor when she grows up. She trusted sources that had scientific studies. Valery does not, however, describe further criteria for considering whether something might be a more or less valid scientific study.

We did not directly see a lot about Valery's familial life history in this interview. She mentioned family and family practices very little. She did mention school science learning and worked to apply it, with mixed success. Though she did not emphasize her family, we got a sense of some of her practices and ideas which may be family based – emphasis on sense of fairness, interest in "pure" water – family uses a water purifier on their tap, wants to be a doctor, ideas about environmental issues (e.g., hairspray is bad for the environment – her hairspray says it is not harmful to the ozone layer on it, animals have rights – treat them nicely before you eat them).

In summary, Valery had some interesting strengths including what seemed to be a strong internal compass and high value for fairness, an empathetic perspective of diverse groups, a value for and interest in science. She had mastered some beginning aspects of scientific accounts, but many of her science accounts were informal and not well developed. She tried to think through the issue in a deep way and apply her scientific understanding and values. Valery attempted to reason about the various components of the loop diagram. What limited her reasoning was not a narrow perspective of what was involved in the scenario, but rather, an unsophisticated account of the science in the environmental systems. This led her to the idea of moving the well further away, which fit with many of Valery's criteria for a fair decision.

Selena, Who Knows Enough

Selena was a seventh grade student attending an urban middle school. Overall, Selena was not proactive in many decision-making practices. As soon as she heard an introduction to the scenario, Selena felt like she knew enough to make a decision. She did not seek additional evidence, and when provided with additional information, she decided who to trust based on which sources agreed with her prior ideas. Interestingly, Selena indicated that she would like to be a scientist when she grows up, and she believed that scientists are people who invent things. Rather than seeing science as an investigative lens for learning more about the world, Selena was satisfied with her current understanding and willing to apply what she already knew to make decisions.

Investigating: Who do you trust? What is the evidence?

After hearing an introduction to the scenario, Selena did not see a need to investigate the facts of the case further. However, when offered four excerpts of information from different stakeholders, she read and considered several of them. Selena used the information provided during the interview to confirm beliefs that matched her own ideas. After reading the statement from Trout Unlimited, Selena stated, *"That one, I think that's true because when it's very hot outside it could affect the water sometimes. The trout can get hot."* Further, when asked which information she trusted, the following interchange ensued:

Selena:	*I think these [Trout Unlimited and Michigan Citizens for Water Conservation] are more trustworthy because they have the information that I was talking about mainly.*
Interviewer:	*So they kind of match your own ideas?*
Selena:	*Mhm.*
Interviewer:	*So you think that makes them trustworthy?*
Selena:	*Yes.*

For Selena, trustworthy sources offered information that seemed reasonable or right to her based on her own experiences with the world. It made sense to Selena that if it was very hot outside, then the trout would get hot. Although she was not seeking additional information, when information was offered to her, Selena read it and decided whether or not it matched her ideas.

Explaining and Predicting: What is happening in this situation? What are predicted consequences for possible actions related to the scenario?

While describing her understanding of science related to water and the Ice Mountain scenario, Selena shared some informal accounts. Although she liked to drink bottled water, including Ice Mountain water, Selena was not sure where bottled water came from. Selena also did not know if or how drinking bottled water might affect the environment. She said, *"It might. I have no idea."* Further, when asked what the source of her tap water was, she thought that it came from the ocean or one of the Great Lakes.

Selena also held some informal ideas about protecting water. When asked what kinds of things people can do to protect water, she said:

Selena:	*Stop dumping their wastes in the lakes and rivers.*
Interviewer:	*What kinds of things do people dump that's bad?*
Selena:	*Like chemicals, um food sometimes, 'cause it has a lot of calories in it. And I want to say sugar, but that might be wrong.*

Interviewer: *So why would it be bad to put calories in the water?*
Selena: *Having too much calories can affect your body.*
Interviewer: *So that's bad for the water then?*
Selena: *Mhm.*

Selena revealed a few informal ideas in this exchange. First, she had a vague idea about chemicals being bad for the environment. Chemicals for Selena were not materials with individual identities, but rather, generic bad things that people dump into water. Also, her ideas about calories may reflect inaccurately reconciled learning about nutrient overload in water. If she had heard about nutrients polluting water, but did not understand the full story of where the nutrients came from and how they impacted water quality, she may have drawn on her own ideas to complete the story. Thus, the nutrients, instead of coming from overuse of fertilizers or from insufficient sewage treatment, were transformed by Selena into calories that come from people putting food in the water. Further, Selena interpreted the impact of the nutrients through a lens of having too many calories being bad for peoples' bodies. Selena may have sought to make sense of what she had learned, perhaps in science class, through calling on her past experiences and ideas of how the world works.

Selena also held some naïve ideas about groundwater. For example, when asked if she had ever heard of a well, Selena replied, *"they put the well in, they run the bucket down and get the water."* Selena had an iconic vision of a well, which perhaps she picked up from experiences with stories (i.e., childhood books). While talking with Selena further about groundwater science, Selena revealed additional informal ideas including that direction of water flow is related to the orientation of the paper (flowing down on the paper is how water will flow), and that a watershed is a, *"little shed, like a house."*

One aspect of the loop diagram that Selena did understand when prompted to (like many other students who were interviewed), was that human actions that impact the environment might have tradeoffs. When asked if the debate about Ice Mountain water made sense to her, Selena responded, *"it makes sense because, it will hurt the fish because they need a place to live and they breathe underwater. But at the same time it will give people jobs and make us survive."* Although not a sophisticated analysis, Selena's assessment of the scenario did acknowledge both the arrow representing human impact on environmental systems and the arrow representing ecosystem services in the form of people needing water to survive.

Given her informal idea about an iconic well, and probably a limited sense of how groundwater and surface water are connected, Selena imagined and shared her idea of how the well could affect trout that live in the streams.

Selena: *It will affect them because they need a place to live just like we do. And they breathe underwater. And they could die on land.*
Interviewer: *How would the well change the place they live?*
Selena: *The fish, they like to move around, it might affect them trying to get from one side to the other.*
Interviewer: *How come they couldn't get around anymore?*
Selena: *Because sometimes the well takes up space.*

For Selena, the impact of the well on the fish was not about removing water from the system, but rather about the physical structure of the well blocking the fishes' ability to travel around in their habitat.

Overall, Selena had an unsophisticated and informal understanding of science accounts that she drew on as she reasoned about the issue. She focused on human and visible aspects of the systems (e.g., iconic well, nutrients as sugar and calories, water moving down – as in the direction on a piece of paper, and watershed as a house-like structure) and sometimes on ideas about materials (e.g., chemicals as vague substances which have negative impacts on the environment).

Deciding: What will I do?

Selena was one of very few students who stated that she had enough information to make a decision about the Ice Mountain scenario after hearing the initial description of the scenario. In contrast, almost all other students indicated that they would like additional information to help them decide. Selena said that learning the initial information about the well would not impact her decision about whether or not to buy Ice Mountain water, and when asked how she would vote, she stated, *"I think I might agree with them to build the well … because we need water just like the fish does."* When again asked if there was any more information about the scenario she would like to learn, Selena said no.

Subsequently, the interviewer did offer additional information for Selena, even though she did not request it. Later in the interview, after Selena read and considered some of the additional information, she changed her mind about the issue, and came to believe that the well should not be built.

Interviewer:	*Ok. So you say that you do still think that they should build the well, because before you said that it's a good idea.*
Selena:	*No, I don't think it's a good idea anymore.*
Interviewer:	*How come you changed your mind?*
Selena:	*Ahh, cuz I, the fish is very important because sometimes you have to eat fish to survive too.*
Interviewer:	*So now you think it might hurt the fish?*
Selena:	*Mhm.*

Thus, in the course of the interview, Selena changed her mind on the issue based on reading information that she did not solicit. At first, she thought the well should be built because people need water. Then, she decided that the well should not be built because the well might harm the fish, and people also need fish to survive.

Discourses and values

Selena shared some of her values through the interview, but did not express highly consistent values throughout. For example, when telling the interviewer that she understood the scenario, Selena indicated values related to both the fish, *"they need a place to live and they breath underwater"* and to people*, "it will give people jobs and make us survive."* Selena also told us that she values science, though her reasoning about why suggests a novice level of understanding of the nature of science. She said:

Selena:	*I think everyone should know more about science. Science is important like math is important because you have to. Math is like counting your money and everything. Science is like knowing about the Earth and how many days the world take and other things like that. ... How many days the Earth revolves and how does the Sun move from day to night.*

Interviewer: *How come it's important to know that?*
Selena: *It's important to know that because you want to know how it turns to sunlight and how it turns to night time.*
Interviewer: *So you want to know the reasons why?*
Selena: *Mhm.*

Selena did not talk much about her personal and family experiences, but she did share a few ideas. For example, when asked if she did any things to protect water in her community, she said, *"I try to, cuz my Mom works at a factory. I tell her to tell her people not to dump some of the chemicals in the water. And when they throw food away to make sure that you eat it all sometimes."* In this description, Selena described herself as adopting a familial role where she shared what she knows about protecting the environment with her mother. It's not clear where Selena learned her ideas about chemicals and foods as having negative impacts on water quality. It seems likely that these ideas did not come from her mother because Selena positions herself as the person with knowledge to share when she talks about her mother. Perhaps her ideas came from the popular media, and or from school.

At the end of the interview, when asked if she had studied a lot of science in school, Selena described having a deep interest in science. She stated:

Selena: *A lot of science. I like science. Science is my favorite subject.*
Interviewer: *What have you studied about?*
Selena: *We studied how to make underground water models. We also learned to, we did a science fair project on how crayons can float and how many tablespoons of salt to add to make the crayons float.*
Interviewer: *Are you interested in a career in science?*
Selena: *I want to have a career in science because science just like math is also important. I want to be a science inventor and invent some type of stuff.*
Interviewer: *What kind of stuff would you like to invent?*
Selena: *I don't know.*
Interviewer: *Have to think about it some more?*
Selena: *Mhm.*

Selena suggested that she has an identity as a future scientist, but that she may not have deep knowledge about what it means to do science. She associated science with invention, and found the idea appealing, but could not suggest details beyond the initial idea of inventing stuff.

When considering how Selena may have arrived at her decision about the Ice Mountain scenario, we see that she drew on some informal accounts of how the world works. Selena did actively try to make sense of her world, and put some faith in her ability to understand. Thus, Selena trusted the information from the sources that agreed with her own ideas. She was not eager to seek additional information, perhaps counting her own ideas about the world as sufficient.

Selena initially indicated that the well should be built because people need water to survive. She did not consider tap water. In her science account, Selena indicated that the only way the well would impact the trout would be to prevent them from moving around (i.e., by providing a structural barrier to the fish). She did not see the well as an element that would remove water from a system connecting the groundwater and the surface water in the streams. This understanding may have led her to judge the impact of the well (i.e., just a structural barrier)

as relatively small. Although we do not know much about Selena's particular sources of knowledge, she seemed to have some of the general ideas shared by many others students who participated in our water research (Covitt, Gunckel, & Anderson, 2009). Examples for Selena included the iconic well; the unspecific notion of chemicals as vague, bad substances; and the idea that the source of tap water is the ocean.

It is interesting that Selena had been studying groundwater and building groundwater models in her science class, and yet she retained many of her informal ideas about how the groundwater system works. Perhaps because her particular notions about how water systems work were not addressed during her school experiences, Selena had to try to synthesize her experiences in science class with her previous ideas. The result may have been that many of her informal ideas continued to be strongly held.

Comparing Case Studies

In this section we compare the students in terms of Discourse, practice, and knowledge. First, we discuss Discourses as knowledge resources for decision-making practices. Second, we compare decision-making practices in terms of their complexity and use of scientific knowledge.

Discourses as knowledge resources for decision-making practices

Students drew on multiple Discourses for their decision-making. In particular, we identify their knowledge and values from one primary Discourse—their family funds of knowledge and salient identities—and two secondary Discourses—peer and popular culture and school science. Each of the Discourses afforded students with a range of sufficiency in terms of knowledge that they can utilize in their respective Think-Aloud scenarios. We briefly discuss each of the Discourses and the roles they played below in students' engagements with their Think-Aloud scenarios.

Family funds of knowledge and salient identities. Family funds of knowledge appeared to be an important resource some students drew from. Such funds of knowledge are also grounded in salient identities important to the students. For example, James was influenced by family values of conservation and sustainability, as reflected in family practices of organic farming. Both James's family and his grandmother practice organic farming with composting. This family practice is probably informed by their stance against pesticides, a point James talked about coherently during the Think-Aloud. James's identity as an organic farmer positioned him to discuss with some expertise about issues of nutrition and environmental impact of growing foods. Similarly, Mark and his family buy food that's healthy and organic. This is linked to his family practices (mother's concern about health) and his individual identity as an athlete. His mother shops at organic food stores and looks at the nutritional information on products that she buys. She tries to find products that will help lower her cholesterol because she has high cholesterol. Mark's mother makes healthy shakes/smoothies for the family. Mark stated that his family is most influential in his food choices, but his identity as a wrestler also played a role in the food choices he makes because he needs to maintain a certain weight for wrestling. Michael also has a personal history that seems to have a big impact on his thinking through the Ice Mountain issue. He talked about things he does to protect water quality in terms of his family. "We don't use the laundry detergent with some chemical you're not supposed to use in it. We don't dump our oil." Perhaps more importantly, Michael and his dad are recreational fishermen. When asked about whether the initial information would influence his decision about whether to buy Nestle Water, Michael responded, "Yes, because if that interferes, if the fish in the lake, I'm

a big fisherman, so is my father. If that made the fish population go down we probably wouldn't buy Ice Mountain." Similarly, Michael drew on his family experiences near the location where the well would be built during the interviews, particularly experiences along the river where he has gone fishing with his family.

Peer, Popular Culture and Media. Peer and popular culture also appeared to be resources for students. Mark cited his friends as a source of information on healthy food and what is good nutrition for a wrestler, knowledge he applied to the strawberry scenario. Tom's opinion on California producing higher quality food was related to brand-consciousness, as he also explained how his friends and he make sure to choose reputable snacks like Cheetos and Doritos, whose advertisements feature prominently on television.

James's interest and appreciation of animals and wildlife is also reflected in his knowledge of the polar bears being endangered by global warming, something he had learned from watching the Discovery Channel, which he cited as one of his favorite past times. When asked to picture nature, James also gave rich, descriptive narratives about landscapes with different animals in them, as he had seen "pictures" of such landscapes. Therefore, it seems that James is someone who values the concept of an "unspoilt" natural ecosystem or landscape, and this value could be influenced by these media resources.

School Science. School science was also invoked as a resource by some students. Michael drew on what he learned in science class during the interview, though with less certainty than he drew on his family funds of knowledge. For example, when asked if he knew the source of his tap water, Michael responded, "I know it's an aquifer. We talked about it in science class but I forgot about it." Valery also mentioned school science learning and worked to apply it in the water scenario situation – with mixed success. Tom based his germ-centered theory on a particular science experiment he conducted in school – investigating how clean the drinking fountain in school is by swabbing it with Q-tips. That experiment left a deep impression on Tom, which is evident in his emphasis on food spoilage and cross contamination of germs between food products and the environment.

Students also invoked informal ideas whose sources remain vague. For example, Valery brought up such ideas as hairsprays are bad for the environment, and that animals should be treated nicely before one eats them. Selena held onto the notion of a well as an iconic structure. She indicated that the only way the well would impact the trout would be to prevent them from moving around (i.e., by providing a structural barrier to the fish). She did not see the well as an element that would remove water from a system connecting the groundwater and the surface water in the streams. This understanding may have led her to judge the impact of the well (i.e., just a structural barrier) as relatively small. Selena also held informal ideas such as the unspecific notion of chemicals as vague, bad substances, the notion of scientist as inventor, and the idea that the source of tap water is the ocean.

It appears that some students have access to a combination of Discourses while others drew primarily from a single Discourse. For example, Michael had a firm understanding of scientific knowledge relevant to the Water scenario that was deeply grounded in family funds of knowledge and that was also informed, at least in part, by school science. James drew predominantly from family funds of knowledge that allowed him to engage deeply and thoughtfully with the Strawberry scenario. With the students we interviewed, it appeared that family funds of knowledge associated with their primary Discourse provided students with the most relevant knowledge.

Nature of student decision-making practices

Students' decision-making practices are embedded in Discourses (discussed above) that provide them with the knowledge to engage in these practices. With the "investigating practice' students display their inclination to seek out knowledge relevant to their scenario. Their ability to process and make sense of that knowledge reveals the level of sophistication of their "explaining" and "predicting" practices. The students we interviewed displayed a range of competency across these three practices. The variation in competency appears to be related to the knowledge base students have to draw from. We illustrate this observation with a few of the case study examples below.

Michael and James constructed the most scientifically robust accounts and were the most sophisticated in their decision-making practices. Michael in particular, considered multiple perspectives when he was investigating the situation. He considered the pros and cons of building a water bottling plant for different groups of people as well as the possible consequences to the trout population, and could use his knowledge to pursue the argument along different trajectories. In the end, Michael decided he did not have enough information to make a decision, and expressed a desire to look through the bibliography of the various reports in order to learn more about the situation.

James brought a very particular point of view grounded in an impressive repertoire of knowledge relevant to the strawberry scenario. With a strong knowledge base, James was able to consider many factors that could contribute to the impact a food product has on the environment, displaying a high level of sophistication in his explaining and predicting practices. Compared to Michael who was open to all perspectives before making a decision, James filtered the construction of his account through personal values, resulting sometimes in narrow scientific accounts, where he used personal values to decide which aspects of the situation are important or relevant. For example, while he could articulate the different factors that contribute to a food product's life-cycle cost (such as degree of processing, transportation, and how food is grown), James prioritized how food is grown to be the most important factor. He favors organic farming practices because they eliminate the consequences of chemical pesticide run-off. As a result, James deemed the organic strawberries more environmentally friendly than the locally grown strawberries (which were not labeled organic), even though he did not ask or know about the origin of the organic strawberries (did not consider possible transportation costs). James's prioritizing organic farming is related to his personal value on protecting ecosystems and animals from the harmful effects of pesticide run-off. Nonetheless, both James and Michael showed that they could trace the relationships between the human systems and environmental systems in the loop diagram. Both students also grounded their sophisticated decision-making practices in robust scientific knowledge relevant to their scenarios.

Mark and Valery displayed less sophistication in their decision-making practices. Valery has some interesting strengths including what seems like a strong internal compass and high value for fairness, an empathetic concern for the perspective of diverse groups, and a value for and interest in science. She seemed to try hard to investigate the scenario through multiple perspectives and she was very interested in seeking out information related to her scenario, but she could not elaborate on those ideas in her explaining and predicting due to a limited knowledge base. It seems likely that Valery is trying to reason about the various components of the loop diagram. What is limiting her reasoning is not a narrow perspective on what is involved, but rather, a simplified understanding of the science in the environmental systems. This leads her

to the idea of moving the well further away from the river, which fits with many of Valery's criteria for a good decision, and she believes she is relying on science and values. Mark's interest in the strawberry scenario was limited to his personal identity as an athlete and nutrition concerns stemming from that identity. Mark applied his personal values to the scenario. While he could articulate which strawberry products were more beneficial for health, he could not discuss which strawberry item was more environmentally friendly with the same facility, resulting in a narrow scientific account. Also unlike his interest in the nutrition of the strawberry products, Mark was not inclined to finding more information pertaining to how the strawberry products affect the environment. Mark's identity as an athlete and his more robust knowledge related to nutrition positioned him to be more sophisticated in engaging with the nutrition portion, but not the environmental impact portion, of the strawberry scenario.

Tom and Selena exhibited the least sophisticated decision-making practices. Neither seemed particularly interested in investigating their scenario thoroughly, nor did they construct robust accounts in their explanations and predictions. With his germ-centered theory, Tom seemed to be slogan-based in his decision-making; he applied a shallow understanding of "germs are bad" in his decision-making. While explaining and predicting, he constructed limited scientific accounts. While he understood correctly that food spoilage could contaminate the immediate environment especially if the packaging is compromised, he applied this understanding somewhat rigidly to the strawberry scenario. Tom seemed to limit the notion of "environmental friendliness" to the immediate physical space surrounding the food product, rather than the impact that creating and transporting the food product has on the environment. As he was deeply concerned about contamination by germs, he operated from a "germs are bad" slogan-based premise. Tom seemed to be localized in the human systems box of the loop diagram, mainly concerned about protecting himself, and humans, from food contamination. Selena was satisfied with the information presented and felt that she could make a decision on the water bottling plant. She accepted already provided information that agreed with her own ideas without asking more questions. Her decision-making practices were based on naïve notions she held about the science content relevant to her scenario, even though she was studying groundwater in school science during the period of the interview.

Therefore, it appears that the students who were most successful in engaging deeply with the scenarios were the ones with sophisticated decision-making practices who were able to both investigate the scenario by seeking new information as well as use the information in explaining and predicting. Moreover, students' success in these practices was related to how much they could draw from their knowledge base relevant to the scenario. A lack of either science content knowledge or sophisticated decision-making practices seemed to hinder the students' abilities to trace the loop diagram in a reflexive manner. Michael and James appeared to possess the most robust scientific knowledge as well as sophisticated investigating, explaining and predicting practices. Among the students interviewed, they were the ones who seem to know where they are on the loop diagram (Figure 2), and the consequences on the systems their actions will have. In short, students' knowledge base, the Discourses that provide their knowledge base, their repertoire of decision-making practices and how they leverage on their knowledge are all important issues to be considered when thinking about learning progressions related to socio-environmental literacy and informed decision-making. We hypothesize that the ability to engage in the most sophisticated practices and construct the most scientifically robust accounts involves seeking out multiple perspectives and having a solid scientific framework within which the

student makes sense of different pieces of information while rejecting information that falls outside of the purview of the scientific framework.

Discussion & Implications

We interviewed 22 middle and high school students on two socio-scientific issues and described six representative cases above. While we acknowledge that our data set is limited to these 22 students, we share some pertinent observations of the students we interviewed in this section.

Reliance on out-of-school funds of knowledge and salient identities. Our data shows the prominent role that factors other than school science played in students' decision-making practices. Students' funds of knowledge and identities provided entry points that influenced how the students engaged in a scenario. The students who had every day practices, such has being a fisherman or athlete, had an interest in the scenarios and usually drew on knowledge from these practices more than school science.

For example, James and Michael were the students who came closest to our goal of informed decision-making. They constructed accounts that reflected an understanding of the interactions between the human and environmental systems of the loop diagram. They could identify and articulate the factors relevant to their scenarios that could affect the human impact arrow on environmental systems. Both students were able to weave coherent narratives in explaining their decisions. Both students also drew predominantly from family funds of knowledge and salient identities as an organic farmer and a local fisherman. While Michael invoked school science briefly, it did not play a central role in his account. James did not invoke school science at all. Thus, the two students who displayed the most robust understanding of these socio-environment issues drew not from school science resources, but from family funds of knowledge and salient identities outside of school.

What is the role of school science? This raises a question about the role school science plays in equipping youth to be citizens able to make informed socio-environmental decisions. School science did not seem to take center stage with many of the students.

Water scenario students tended to invoke school science more than the strawberry-scenario students. This may be due partly to the way the two Think-Aloud scenarios were structured. Water students were asked to construct a narrative of watersheds before they were presented with questions, while strawberry students constructed narratives after they have ordered the products as explanations for their decisions.

While we could not confirm if the strawberry scenario students were learning relevant science content at the time we conducted the interviews, we were aware that some of the students interviewed for the water scenario had just completed or were currently engaged in a science unit on groundwater and/or watersheds in school. Even for those students who did not complete a unit on the water cycle immediately prior to the water interviews, the water cycle is typically a part of science curriculum in the United States that is taught more than once throughout the K-12 curriculum. Hence, it is interesting and potentially problematic that the students did not cite school science more often when constructing accounts of the water scenario. For example, Selena had been studying groundwater and building groundwater models in her science class, and yet she retained many of her informal ideas about how the systems work, as evinced in her description of an iconic well.

While students learn about concepts such as food webs and food chains, teaching about food supply chains and waste disposal chains and the impact of these on natural systems is not a common part of the K-12 curriculum. Of all the students who engaged with the Strawberry scenario Think-Aloud, only one student invoked school science directly. Tom, the student who constructed a germ-centered theory, based it primarily on a school science experience where he investigated the presence of germs on surfaces with Q-tips. That science experiment clearly left a strong impression with him. However, his application of this science experiment to the Think-Aloud seemed to act as a constraint; he did not explore other factors when ordering the strawberry products. While it is encouraging that Tom leveraged school science, he did not do so in a way that allowed him more resources to engage with the issue. Tom's invoking of this school science experiment did not seem to position him well to consider the immediately relevant factors he could consider for the scenario, i.e., benefits and disadvantages of organic and pesticide farming, pesticide run-off consequences, transportation and packaging cost of a product in terms of environmental impact, etc.

For the students who engaged most deeply with the issues, school science was less useful as a resource than everyday experiences grounded in a salient identity, as previously described. Thus, our data suggests that school science seems to be playing a minute role in influencing students' decision-making processes with socio-environmental issues.

Our study raises questions for us as to the role school science should play in equipping students to make informed socio-environmental decisions. Future work in this area include investigating the following:

- How can school science help students think critically about socio-environmental issues?
- What sort of science content should be taught in school that is relevant to the everyday socio-environmental decisions students have to make?
- How should the content be taught so that it resonates with students' out-of-school identities and funds of knowledge, as James and Michael's cases have illustrated to be so pertinent?

These questions have implications for the kinds of science curricular materials and pedagogical strategies that will best serve the purposes of teaching science for socio-environmental literacy in K-12 science education.

References

American Association for the Advancement of Science. (1990). *Science for all Americans. Project 2061*. New York: Oxford University Press.

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.

American Association for the Advancement of Science. (2001). *Atlas of Science Literacy*. Washington, DC: NSTA Press.

Arvai, J., Campell, V., Baird, A., & Rivers, L. (2004). Teaching students to make better decisions about the environment: Lessons from the decision sciences. *Journal of Environmental Education, 36*(1), 33-45.

Barrett, K., & Raffensperger, C. (1999). Precautionary Science. In C. Raffensperger & J. Tickner (Eds.), *Protecting Public Health & the Environment: Implementing the Precautionary Principle* (pp. 106-122). Washington: Island Press.

Belenky, M., Clinchy, B., Goldberger, N., Tarule, J. (1986). *Women's Ways of Knowing*. New York: Basic Books.

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

Briscoe, G. (1992). Need for risk standards and education. *Risk Analysis, 12,* 331.

Calabrese Barton, A. & Tan, E. (2009). Funds of knowledge and Discourses in hybrid space. *Journal of Research in Science Teaching, 46*(1), 50-73.

Covitt, B., Gunckel, K., & Anderson, C. (2009). Students' developing understanding of water in environmental systems. *Journal of Environmental Education, 40*(3), 37-51.

Corbin, J., & Strauss, A. C. (1997). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage Publications, Inc.

Driver, R., Guesne, E., & Tiberghien, A. (1985). Some features of children's ideas and their implications for teaching. In R. Driver, E. Guesne, & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 193-201). Milton Keynes, UK: Open University Press.

Elliott, P. (2006). Reading newspaper articles as a technique for enhancing the scientific literacy of student-teachers. *International Journal of Science Education, 28*(11), 1245-1265.

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

Gee, J. P. (1990). *Social linguistics and literacies: Ideology in Discourse.* London: Falmer.

Gee, J. P. (1991). What is literacy? In C. Mitchell & K. Weiler (Eds.), *Rewriting literacy: Culture and Discourse of the other* (pp. 3-11). Westport, CT: Bergin & Garvey.

Glaser, B. G., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine Transaction.

Gonzalez, N., Moll, L. C., & Amanti, C. (Eds.). (2005). *Funds of knowledge: Theorizing practices in households, communities, and classrooms*. Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Gregory, R. (1991). Critical thinking for environmental health risk education. *Health Education Quarterly, 18*, 273-284.

Gonzalez, N., Moll, L. C., & Amanti, C. (Eds.). (2005). *Funds of knowledge: Theorizing practices in households, communities, and classrooms*. Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Gregory, R. (1991). Critical thinking for environmental health risk education. *Health Education Quarterly, 18*, 273-284.

Hammond, J., Keeney, R., & Raiffa, H. (1999). *Smart choices: A practical guide to making better decisions.* Cambridge, MA: Harvard Business School Press.
Kolstø, S. (2001). "To trust or not to trust,…" - pupils' ways of judging information encountered in a socio-scientific issue. *International Journal of Science Education, 23*, 877-901.
Kolstø, S. (2006). Patterns in students' argumentation confronted with a risk-focused socio-scientific issue. *International Journal of Science Education, 28*(14), 1689-1716.
Korpan, C. Bisanz, G. Bisanz, J., & Henderson, J. (1997). Assessing literacy in science: Evaluation of scientific news briefs. *Science Education, 81*, 515-532.
Mohan, L., Chen, J. & Anderson, C. (In press). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. *Journal of Research in Science Teaching.*
Moje, E., Ciechanowski, K. M., Kramer, K., Ellis, L., Carrillo, R., & Collazo, T. (2004). Working toward third space in content area literacy: An examination of everday funds of knowledge and Discourse. *Reading Research Quarterly,* 39(1), 38-70.
Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into Practice,* 31(2), 132-141.
National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.
National Resources Defense Council. (1999, March). *Bottled Water. Pure Drink or Pure Hype?* Retrieved March 15, 2009, from http://www.nrdc.org/water/drinking/bw/bwinx.asp
Perry, W. 1970. Forms *of Intellectual and Ethical Development in the College Years*. New York: Holt, Rinehart and Winston, Inc.
Sadler, T. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*(5), 513-536.
Sadler, T. Barab, S., & Scott, B. (2007.) What do students gain by engaging in socioscientific inquiry? *Research in Science Education, 37*, 371-391.
Slovic, P. (2007). "If I look at the mass I will never act": Psychic numbing and genocide. *Judgment and Decision Making, 2*(2), 79-95.
Tversky, A., & Kahneman, D. (2000). Judgment under uncertainty: Heuristics and biases. In T. Connolly, H. Arkes & K. Hammond (Eds.), *Judgment and Decision Making: An Interdisciplinary Reader* (pp. 35-52). Cambridge: Cambridge University Press.
U.S. Long Term Ecological Research Network, Research Initiatives Subcommittee. (2007). *Integrative science for society and environment: A strategic plan.* Albuquerque, NM: Author.
Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity.* Cambridge: Cambridge University Press.
Zint, M. (2001). Advancing Environmental Risk Education. *Risk Analysis, 21*(3), 417-426.