DOCUMENT RESUME

ED 474 454 SE 067 613

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TITLE	Students' Understanding of the Nature of Science and Their Reasoning on Socioscientific Issues: A Web-based Learning Inquiry.
PUB DATE	2003-03-24
NOTE	34p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (Philadelphia, PA, March 23-26, 2003).
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE	EDRS Price MF01/PC02 Plus Postage.
DESCRIPTORS	*Computer Uses in Education; Concept Formation; Elementary Secondary Education; *Inquiry; *Internet; Science Education; Scientific Principles; Teaching Methods; Thinking Skills; *Web Based Instruction; *World Wide Web

ABSTRACT

This study was designed to determine how students' engagement in a learning and debate activity on a current scientific controversy influences their understanding of the nature of science and, in turn, informs their decision-making on the issue. Two high school science classrooms, totaling 38 students from 9th through 12th grade, participated in the Internet-Based unit on the topic of genetically modified foods. The unit, including introductory discussions on the nature of science, a video on the controversy of genetically modified foods, a series of online activities that presented multiple perspectives of the controversy, and follow-up interviews, took place over seven consecutive 1.5 hour period blocks. The study utilized qualitative procedures to analyze students' views on the nature of science as expressed through their answers to online and interview questions and a final classroom debate. Each student conversational turn in the debate was analyzed for references to supporting evidence and instances of moral and fallacious reasoning. While students did not make explicit reference to conceptual understandings of the nature of science in the classroom debate, the issue-based activity was successful as a pedagogical approach to facilitate and reveal students' conceptions of science. The students' answers to online questions reflected conceptions of the tentative, creative, subjective, and social aspects of science. Their high level of engagement throughout the unit supported the students' positive affective verbal response to the Internet-based, scaffolded learning environment and subject matter content. Findings from the analysis of students' mastery of the subject matter of genetic engineering and their reference to subject matter knowledge and evidence in the classroom debate suggest that NOS (nature of science) entered discussions should coincide with in-depth learning activities on the subject matter content of the controversy. Taxonomic categories and samples of thought are presented and discussed, and implications for science education are addressed. (Author)

Students' Understanding of the Nature of Science and Their Reasoning on Socioscientific Issues: A Web-based Learning Inquiry

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Paper presented at the
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March 23-26, 2003, Philadelphia, PA

Abstract

This study was designed to determine how students' engagement in a learning and debate activity on a current scientific controversy influences their understanding of the nature of science and, in turn, informs their decision-making on the issue. Two high school science classrooms, totaling 38 students from 9th through 12th grade, participated in the Internet-based unit on the topic of genetically modified foods. The unit, including introductory discussions on the nature of science, a video on the controversy of genetically modified foods, a series of online activities that presented multiple perspectives of the controversy, and follow-up interviews, took place over seven consecutive 1.5 hour period blocks. The study utilized qualitative procedures to analyze students' views on the nature of science as expressed through their answers to online and interview questions and a final classroom debate. Each student conversational turn in the debate was analyzed for references to supporting evidence and instances of moral and fallacious reasoning. While students did not make explicit reference to conceptual understandings of the nature of science in the classroom debate, the issue-based activity was successful as a pedagogical approach to facilitate and reveal students' conceptions of science. The students' answers to online questions reflected conceptions of the tentative, creative, subjective, and social aspects of science. Their high level of engagement throughout the unit supported the students' positive affective verbal response to the Internet-based, scaffolded learning environment and subject matter content. Findings from the analysis of students' mastery of the subject matter of genetic engineering and their reference to subject matter knowledge and evidence in the classroom debate suggest that NOS centered discussions should coincide with in-depth learning activities on the subject matter content of the controversy. Taxonomic categories and samples of thought are presented and discussed, and implications for science education are addressed.

Introduction and Theoretical Framework

This study attempts to unite the philosophical, theoretical, empirical, and practical underpinnings from many years of research in the fields of science education and instructional technology. The purpose of this exploratory case study was to assess how a learning and debate activity on the current scientific controversy of genetically modified foods (GMF) might elicit, reveal, and develop students' understanding of the nature of science and, in turn, inform their decision-making on the issue. As a study of curriculum development, the pedagogical aspects and instructional design features of the Internet-based learning environment were evaluated in terms of its effectiveness to promote students' discourse related to socioscientific issues and the nature of science. As a study of student learning, it was an exploratory investigation concerned with the epistemological factors surrounding students' understanding of the nature of science and how this understanding might influence their decision-making on a socioscientific dilemma. Following is a review of the three interconnected areas of research issues that this study explored.

Students' Views of Science in Decision-making on Socioscientific Issues

The preliminary findings from recent studies exploring the connection between ones' understanding of the nature of science and their decision-making on socioscientific issues, while useful in suggesting possible patterns of relationships, have been limited and inconclusive (Bell, 1999; Zeidler, Walker, Ackett, & Simmons, 2002; Zohar & Nemet, 2001). If we, as science educators, are going to argue for the inclusion of the nature of science (NOS) in the curriculum on the grounds that it will develop scientifically literate and active communities, then it is imperative that we begin to understand how this knowledge might impact one's decision-making behavior with personally relevant, real-world problems.

The learning treatment developed for this study was primarily geared towards the exploration of students' understanding of the nature of science. Yet, their general understanding of the process and product of genetic engineering as a learning outcome was also of importance. This prerequisite knowledge enables the students to critically evaluate and comprehend the various articles of evidence they read supporting the contending viewpoints. As described by Beyer (1988), critical thinking operations include, but are not limited to, the ability to: distinguish relevant from irrelevant information, determine the factual accuracy of a statement and credibility of a source, identify ambiguous claims, and detect bias. The students' ability to perform these operations are, therefore, somewhat dependent upon their mastery of the scientific content knowledge involved in the controversy. Without this basic conceptual understanding of the science behind genetic engineering, the students' ability as an "informed decision maker" would be undermined by their inability as a "critical thinker" (Zeidler, Lederman, & Taylor, 1992).

Discourse and Debate in the Science Classroom

Unfortunately, research has shown "that there is a general lack of pedagogical expertise among science teachers in organizing activities in which students are given a voice" (Driver, Newton, & Osborne, 2000, p.308). In a study conducted by Goodlad (1984) of more than 1000 elementary and secondary classrooms across the United States, student discussion occupied only four to seven percent of total class time. The majority of class time was spent listening to lectures or doing written work. If science teachers are going to break free of the shackles that continue to hold them to a lecture-textbook driven approach that emphasizes factual recall and confirmatory experiments, then a great deal of time needs to be spent by educators developing and researching pedagogical approaches that include student discourse and debate. Exploring scientific controversies is one approach that lends itself easily to discursive activities that allow students to critically evaluate and debate competing scientific claims. As students gather, interpret, and consider evidence of multiple defensible positions, they might begin to understand science as the dynamic and complex enterprise that it is (Geddis, 1991).

One popular and widely used model for assessing student discourse is Toulmin's (1958) argument pattern. In several recent investigations, Toulmin's model was used to help identify and quantify the characteristics of students' arguments related to controversial issues in science (Bell & Linn, 2000; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Osborne, Erduran, Simon, & Monk, 2001). While characteristics of arguments can be categorized and measured in terms of the number of claims, warrants, data, and backings, many researchers feel they must move beyond the Toulmin model to fully grasp the quality, strengths, and weaknesses of student arguments. In actuality, many young people and adults have difficulty constructing valid arguments (Kuhn, 1991). Zeidler (1997) suggests that educators should become "better acquainted with fallacies common to argumentation and the sources of those errors" (p.487). He identifies some areas of concern including: naïve conceptions of argument structure resulting in problems of validity, effects of core beliefs on argumentation, and inadequate sampling of evidence.

The inclusion of argumentation and debate in the science classroom is a fairly recent and emerging area of interest among educators. Although there are a number of useful approaches to assessing student discourse, much work needs to be done in developing effective pedagogical approaches.

Designing Learning Environments to Explore Socioscientific Issues

With the ever-increasing capabilities of multimedia in creating a multi-sensory instructional environment, computer-aided instruction has the potential of being a highly engaging and meaningful learning experience. The plethora of information now available through the Internet can provide a learning forum rich in information on current socioscientific issues. If effective Internet-based learning environments are developed to engage students in current socioscientific controversies, then students would not only learn about the science content knowledge of a given topic, but could learn it within the context of how it is being applied by scientists to solve or research the issue. This issues-based approach to instruction is being explored in many disciplines as an instructional strategy to develop professional knowledge. In science education, an issues-based approach to instruction could create a forum to explore aspects of the nature of the science as a human endeavor while taking an active, problem-solving role in applying their scientific knowledge to a given situation. As suggested by Driver et al. (1996), further research and development of curricular interventions to develop students' conceptions of the nature of science should include learning activities that engage students in current scientific controversies. Students would be expected to engage in the inquiry process by exploring background information provided by the conflicting viewpoints, using evidence to support their own viewpoint, debating and discussing the issues, and coming to an informed decision. An issues-based approach to learning about the interconnectedness of science, technology, and society would be supported by activities that promote critical thinking, decision-making, and moral reasoning (Pedretti, 1997; Pedretti, 1999).

Consistent with the ongoing research (Linn, 2000) of the web-based Knowledge Integration Environment (KIE; http://wise.Berkeley.edu), this study utilized the KIE Curriculum development tools. For over ten years, partnerships between scientists, educational researchers, curriculum developers, classroom teachers and their students, have allowed for comprehensive design studies aimed at creating computer based activities that can support lifelong science learning. One of the claimed strengths of the KIE design is its use of scaffolding.
The use of the term "scaffolding," in this case, refers to how well the online unit sustains student interest in the task, organizes and simplifies the steps required to solve the problem, and maintains the student's pursuit of the goal (Bransford, Brown, & Cocking, 2000). The scaffolding in a web-based environment is provided in the form of a series of steps in a navigation frame of the web browser window. Each step in the navigation frame brings up a new activity in the main frame window, whether it was an article to read or a question to answer (see Figure 1). An additional form of scaffolding in this study was provided to the student through workbook questions that coincided with the online activities. The workbook guided students with questions that probed their epistemological understanding of the articles of evidence as they progressed through the unit. The purpose of the workbook was two-fold. First, it provided additional navigation support and guided the students in reading the supporting evidence articles (SEA) by prompting them with questions about the articles. Secondly, since the students were working in pairs, the workbook ensured that each student remained active in the learning process. One student would work the mouse, navigate online, and answer the questions online while the other student read through the supporting workbook information and answered questions in the workbook.

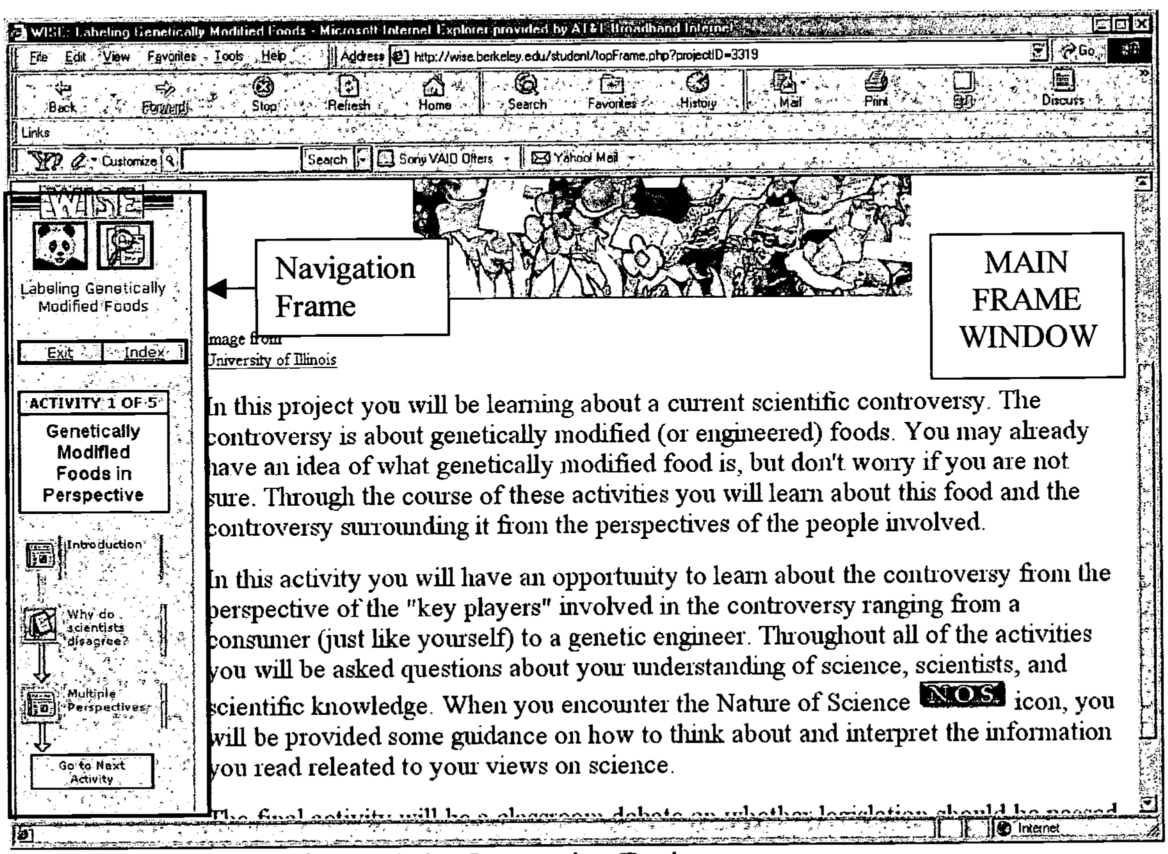

Figure 1. Screenshot of Knowledge Integration Environment

Research Questions

In light of these distinct, yet integrated areas of research in science education and instructional technology, the following research questions were posed:

Research Question 1: What features of a web-based learning environment are effective for engaging students in learning and debate activities on the nature of science and current socioscientific controversies? There were three sub-questions guiding this portion of the data analysis, focusing on instructional design attributes, subject matter content, and the pedagogical structure of the debate activity. They are as follows:

Research Question 1A: Were the instructional design attributes (e.g. scaffolding tools, navigation, and user interface) effective in scaffolding students through the learning treatment?

Research Question 1B: How did students' understanding of the subject matter of genetically modified foods develop or change through the course of the learning treatment?

Research Question 1C: How did students utilize evidence claims or GMF subject matter knowledge (SMK) in formulating and presenting their arguments for the classroom debate?

Research Question 2: How does students' engagement in a web-based learning environment on a current socioscientific controversy elicit, reveal, and develop their conceptual understanding of the nature of science?

Research Question 3: What is the nature of the relationships that exist, if any, between students' understanding of the nature of science and their reasoning used to make decisions on a current socioscientific controversy?

Research Design

This exploratory case study, in its entirety, occurred in six phases as subsequently described.

Phase 1: Identifying the Topic of Study and Developing the Learning Treatment

The first phase included a preliminary survey of students' interests in current socioscientific issues to determine the content that would be used for the design of the curriculum. A survey was conducted with 50 high school age science students to assess their level of concern related to three current controversial issues in science: global warming, water fluoridation, and genetically modified foods. Overall, the controversy of most interest was genetically modified foods, followed by water fluoridation and global warming. In addition, student comments related to GMF supported the notion of personal relevancy (i.e. everyone at some point will unknowingly eat GMF) more than global warming.

Since issues regarding recombinant DNA technologies, including GMF, are prevalent in the news today and students seemed to be most interested in this topic, it was decided that GMF would be used as the context for the science controversy. Additional information culled from the students' written justifications was also used to inform the development of related science content of the learning treatment.

Phase 2: Context of Study and Selection of Subjects

After the development of the initial Internet-based unit was complete, the second phase of the study was the selection and observations of two high science classrooms to participate in the study. Maximum variation and convenience sampling were the two criteria used in selecting the classes to partake in the study (Merriam, 1998). As a case study with a fairly small sample, a heterogeneous group of students was desirable to explore the diversity of students' understandings of NOS and to increase external validity. Convenience sampling was necessary to the extent that the teacher and classroom had access to enough networked computers to support the implementation of the web-based portion of the learning treatment.

In total, 36 students from two classes of 9th through 12th grade science students at a large suburban vocational education school in the southeast United States area were purposefully selected to take part in the study. There were ten student-pairs (20 students) that participated in the first classroom trial (Period 1). The classroom topic was Environmental Horticulture. The pilot study was initially focused on instructional design issues related to the web-based unit, perfecting data collection and analysis techniques. Yet after completing the pilot study, it was determined that the data was valuable and rich enough to include in the data analysis. Eight student-pairs (16 students) participated in the second classroom trial (Period 2). The classroom subject was Environmental Resource Management.

The two classes that participated in the study were unique and diverse in nature. Each class was comprised of students coming from three surrounding high schools in addition to full-time dropout prevention students at the vocational education school. Student learning abilities in each classroom ranged from learning disabled to honors.

Table 1 provides an overview of the number of students in each grade level and learning abilities as reported by the teacher. Since the students involved in the study ranged from 9th through 12th grade, their initial understanding of genetics concepts varied. All of the students had completed an 8th grade course in science that covered basic concepts in genetics, including the concept that variations within a species are the result of genetic information being passed from a parent to offspring and that interactions between the genes may occur in the process. Biology is offered in the 10th grade and includes more in-depth topics on genetics and DNA, hence those students that completed this coursework would possibly hold a greater understanding of genetics concepts.

Table 1
<u>Grade Level and Learning Characteristics of Sample Population</u>

Period Grade	Learning Disabled	Below Average	Average	Above Average	Honors	TOTAL
Period 1						
9	4	0	4	0	0	8
10	2	0	4	0	1	7
11	0	0	1	2	0	3
12	1	0	0	0	1	2
P1 Total	7	0	9	2	2	20
Period 2						
9	0	0	4	2	0	6
10	0	0	2	3	0	5
11	0	0	0	0	1	1
12	1	0	3	0	0	4
P2 Total	1	0	9	5	1	16

The same teacher led the classes that participated in the study. This maximized on the teacher's and researcher's ability and comfort with working together to facilitate the learning treatment and controlled for variation between teachers. The teacher that led the classes has fifteen years of teaching experience at the vocational education school. He is experienced and knowledgeable about nature of science issues and has worked with the researcher on a similar research project. The researcher spent one week observing each classroom prior to the initiation of the study in order to develop a rapport with the individual students so a comfort level in communication would be established prior to their engagement in the web-based unit and classroom debate.

Prior research on utilizing web-based activities in the classroom has found that students' engagement can be optimized if they are paired based on reading ability and learning motivation levels (Bell, 1999). Therefore, the students were paired by the teacher based on their learning abilities; the higher level readers and/or more motivated students were paired with learning disabled and/or lower motivated students who tended to have more difficulty reading and working through learning activities.

Phase 3: First Classroom Trial

In total, the learning treatment took place over seven consecutive 1.5 hour classroom periods. The first day the students were introduced to the controversy through a NOVA/PBS video entitled, "Harvest of Fear." On the second day they joined in a food sampling party of various genetically-engineered and organic products and were led by the teacher in a discussion on the topic of genetically modified foods. In addition, the teacher explicitly discussed aspects of the nature of science that would be explored through the context of the online unit. The students were then paired and began working on the introduction to the controversy. On the third day the students worked on an online animation that was designed to develop their general understanding of genetic engineering. Genetic engineering was contrasted to cross breeding techniques and students were given the opportunity to apply their understanding to three cross breeding versus genetic engineering scenarios. The next two days were then spent on the online unit learning about the GMF controversy through the perspectives of six "key" players. Each key player presented a personal bios, pro/con arguments, and links to current websites with information supporting their position on the issue. These key players included: a consumer, two GMF scientists, an EPA representative, a farmer, and a genetic engineer. (See Appendix A for a more detailed description of the learning treatment). The last two days were spent preparing for and conducting the classroom debate.

Instrumentation

In addition to the descriptive field observations, there were four sources of student-generated artifacts of thought related to the nature of science and the controversy of genetically modified foods. The first was the students' response to the Nature of Scientific Knowledge Scale (Rubba, 1977). The NSKS was administered pre-treatment to provide a baseline measure of students' conceptions of science. The second source of student-generated artifacts was their written answers to embedded questions and "chat-room" discussions within the web-based activities. Some of the questions dealt with the content itself (i.e., questions related to the evidence on genetically modified foods) while other questions focused on the connections students made about their views of science in relation to their decision-making on the controversy. Questions were selected, in part, from the Views on Science-Technology-Society

Survey (Aikenhead & Ryan, 1992). Additional questions were developed by the researchers to fit with the specific content of the activities. Students' work on the classroom debate activity was the third source of data. In order to present their case on whether or not genetically modified foods should be labeled, the students were guided through the process of collecting supporting evidence and organizing it in a manner to present to the class during the debate activity. The classroom debate from the second classroom trial (Period 2) was videotaped for analysis. The fourth source of data came from interviews with the student-pairs at the conclusion of the learning treatment. A semi-structured interview format was used with specific questions from the Views on the Nature of Science Questionnaire (Lederman, Abd-El-Khalick, Bell, Schwartz, & Ackerson, 2001), while other questions and probes emerged from the conversation and/or from the researcher's review of the student-generated artifacts of thought.

Phase 4: Evaluating the Learning Treatment

The purpose of the fourth phase was to perfect the learning treatment and data collection procedures. Preliminary data analysis from the first trial study informed the instructional and methodological changes made by the researcher. In total, there were eleven articles supporting the contending viewpoints on the GMF controversy that the students read through the course of the activity. It was deemed important by the researcher that the articles were authentic and presented real and current perspectives to the students. Therefore, the initial design linked students directly to the websites where the articles resided. Unfortunately, many of the articles were too lengthy or were written for a slightly advanced reading level. Thirty percent of the students in the trial classroom were learning disabled and had an especially difficult time with the content. Although these students were paired with higher level learners, in two noted cases, the learning disabled student was left behind as the other student in the pair did the majority of reading and answering questions without the other student's input. Based upon these observations, the researcher decided to forgo the authenticity of the articles to increase the students' comprehension and interest. Six of the articles were saved to a local directory, reworded, and simplified. The original headings and graphics were saved with the article to maintain an "official" appearance.

The researcher and teacher both decided that the timing of the debate in the sequence of the activities should also be altered for the second classroom study. Since the learning treatment in its entirety took place over seven consecutive school days, the debate ended up occurring after a weekend break. This break seemed to negatively affect the students' level of motivation and enthusiasm. It took some coaxing on the part of the teacher to get the students back into their positions on the controversy in preparation for the debate.

Phase 5: Second Classroom Trial

The implementation of the learning treatment in Phase 5 also occurred over seven consecutive school days in a manner similar to the trial study, but the second classroom trial began with the introductory activities on a Friday. This gave the students five consecutive days to work through the online activities, prepare for and conduct the debate. This change positively impacted the students' enthusiasm and engagement on the day of the debate.

Phase 6: Data Analysis

Both qualitative and quantitative data analysis procedures were employed in the sixth and final phase. With an integrated approach to the evaluation of a case-based learning treatment, the data collection and analysis can be characterized as student-controlled, dynamic, contextualized, and informal (Posner, 1995). Answers to the research questions emerged through the exploration of the researchers and teacher's naturalistic observations, student-generated artifacts of thought, the classroom debate video, and post-treatment student interview transcripts. These varying forms of data were analyzed with the intent of developing classification schemes or typologies representative of students' cognitive processes and understanding of the nature of science related to the learning objectives. Utilizing the constant comparative method (Glaser & Strauss, 1967) all forms of data were compared for instances of similar conceptual categories. Direct quotations from the data are included to support the themes or classifications that emerged through the analysis. The researcher's protocols for establishing trustworthiness (Lincoln & Guba, 1985) of the research findings are subsequently described, followed by the data analysis techniques and findings specific to each research question.

Triangulation between all data sources through the constant comparative method allowed for descriptive categories of students' understanding of the subject matter and nature of science to emerge while increasing internal validity and reliability of the study (Lincoln & Guba, 1985). Although replicability was not a desired outcome of this case study, detailed accounts of how data were collected and how categories were derived are provided as an audit trail to allow authentication of the findings. Direct quotations are used as often as possible to support any emergent categories of students' conceptions and rubric-based analyses. Analyst triangulation (Patton, 1990) was also conducted to reduce any possible research bias and provide additional verification and validation of the findings. In the case where rubrics were used to rate the qualitative data, independent reviews were conducted by one other science educator familiar with, but not involved in the treatment of the current study. The two researchers and an additional evaluator (who has conducted similar qualitative studies on students' views of the NOS) negotiated any initial differences in the ratings until consensus was reached. It is important to note that the participatory nature of this study allowed for modifications and refinement to the learning treatment and the data collection and analysis procedures and provided the greatest level of insight into the overarching research problem.

Due to the qualitative nature of this study, certain procedures for analysis and the subsequent findings for each research question are discussed together in order to provide a more concise and cohesive presentation. To determine what aspects of the learning treatment were effective for engaging the students in learning and debate activities on the nature of science in the context of a current socioscientific controversy (Research Question 1), three sub-questions were posed to focus the inquiry related to: a) instructional design attributes, b) subject matter content, and c) pedagogical structure of the debate activities. These sub-questions are presented along with an overview of the data analysis procedures for each question followed by the presentation and discussion of the findings.

Results

Research Question 1A: Instructional Design Attributes

Were the instructional design attributes (e.g. scaffolding tools, navigation, and user interface) effective in scaffolding students through the learning treatment?

Consistency in Navigation and Activity Structure

In the trial study, the students were initially confused with the navigation as the researcher noted that, "the majority of the students were looking for navigation (i.e. a "forward" or "next" step) in the main frame window even though they had just been instructed on how to advance through the activities using the navigation frame" (Field Notes, October 2, 2001). The navigation process became clear to the students after completing the first activity together, following the researcher's verbal instructions. The navigation for the six key players and related supporting evidence articles (SEAs) was identical in terms of the sequence and type of steps. Only the content of the steps changed. The sequence of steps was as follows: Introduction to key player's position and links to supporting evidence articles, NOS issue and workbook discussion prompt, NOS Chatroom discussion question, NOS Notetaker question. After successfully completing the sequence of activities for the first key player, the researcher observed that in both classrooms the students moved fairly easily through the program and supporting worksheets as the structure and sequence of activities remained the same. Initially the SEAs were a link within the main frame window. This caused confusion for some of the students because it broke the "navigation rule" that all navigation occurred in the navigation frame. As a result of the feedback from the students and teacher, the final design of the unit incorporated a consistent navigation rule: All navigation steps were relocated to the navigation frame. The embedded links were removed from the main frame window and the SEAs became their own "step" in the navigation frame. Consistency in the visual navigation cues and activity sequence diminished students' confusion and lead to a higher level of autonomy as they progressed through the unit.

Student Motivation and Instructional Design Features

Maintaining student interest in the learning task was another aspect of scaffolding that was assessed. In the follow-up interviews, the students were asked to speak about what they viewed as the strengths and weaknesses of the activity. The students were not prompted to discuss any features in particular; instead it was open-ended response in terms of what stood out for them. Numerous students reported that they found it interesting because the nature of the activities was different from the traditional textbook units that they were accustomed to doing. Although they still did a lot of reading and answering of questions online, the novelty of working on the computer seemed to make it more appealing.

> It was a lot better than doing book work. I thought that it was good that we had more freedom going from page to page on the Internet.

> It was kind of visual, and I am better with visual stuff. And since it was on a computer, I use the computer a lot at home.

The students also reported that the current and relevant nature of the socioscientific controversy made it more interesting to them. In response to what they thought about GM foods:

> I mean I found it pretty interesting because I didn't really know what genetically modified foods was. I had never heard of it before and I was curious to know about it and stuff. And frankly I would rather learn about new interesting stuff, than do boring bookwork.

> It was something that we actually experienced. It wasn't something that we don't see or don't care about. It was something that we used all the time. Like we didn't know it, but we picked up bags of Fritos at the grocery store.

In particular, these students noted that they liked the fact that they learned about the issue through the multiple perspectives of the key players.

> I liked it. It was different from anything I've done before and doing my term paper, a lot of the same sources that were used, that I used in my term paper were used there. I liked how there were different views and you went to the different websites, and the different views came from different sources.

> The topic was very interesting because there are so many different points of view of it and you can see it from so many different areas. You can see like that some people don't want it at all and some people want it labeled, so it was a very interesting topic.

Overall the students' affective responses about the learning activity were very positive. Once the navigation was understood, the student-pairs worked independently with the exception of questions that arose about the content. The only negative comments made in the follow up interview were by several students that felt that it was "too much work," but others reported that they thought the workload was fine. Their high level of engagement throughout the activity spoke the loudest in terms of their interest and motivation, but the question now posed is: what did they learn?

Research Question 1B: Subject Matter Content

How did students' understanding of the subject matter of genetically modified foods develop or change through the course of the learning treatment?

Three sources of data were used to assess the students' understanding of the scientific processes involved in and purposes of genetically modified foods. The first source was the students' answers to a pre and post open-ended question that asked them to define genetically modified foods (GMF definition). The second source was the students' answers to three online questions that assessed the application of their knowledge to the cross breeding versus genetic engineering scenarios. Thirdly, an open-ended workbook question asked the student-pairs to describe the differences between genetic engineering and cross breeding.

All of the student-pairs correctly answered the workbook questions on the steps of genetic engineering that coincided with the simulation. Hence, the purpose of the open-ended format of the pre and post question was to assess how well they understood and retained the information that was provided in the simulation.

The researchers and one additional science educator rated the answers independently using the rubric provided in Table 2. In the case where there were discrepancies in the ratings, steps were taken to negotiate the ratings until a consensus was reached. Table 3 presents the outcome of the ratings of students' pre and post rubric-rated definitions of genetically modified foods.

Table 2
Rubric for Assessment of Students' Answers to Subject Matter Questions

Points	Point Scale Definition	Exemplar
0	Student does not attempt to answer or define	I have no idea what that is.
1	Student does not possess correct concept or terminology (expresses incorrect concept)	I'm not really sure what genetically modified food is, but I think it means that food was made in a factory. When the food is done, they put it in cans. This is what I think genetically modified food is.
2	Student possesses a general understanding of the purpose of genetic engineering, but uses incorrect terminology or lacks correct technical understanding (expresses general concept)	Foods that have been modified to do certain things from helping people to growing larger amounts.
3	Answer shows technical understanding of the process OR purpose of genetic engineering (expresses technical concept of process OR purpose)	It is food that has been taken and a certain gene added to it.
4	Answer shows technical understanding of the process AND purpose results of genetic engineering (expresses technical concept of product AND purpose)	Genetically modified foods are foods that have genes added to their DNA in an attempt to improve traits or character of the food.

Table 3
Rating of Students' Answers to Pre and Post GMF Definitions

	0 No attempt to answer	1 Expresses Incorrect Concept	2 Expresses General Concept	3 Expresses Technical Concept of Product OR Purpose	4 Expresses Technical Concept of Product AND Purpose
Pre Period 1 (N)	5	6	7	1	0
Pre Period 2 (N)	0	8	6	1	1
Pre TOTAL (N)	5	14	13	2	1
% of TOTAL	14.3%	40.0%	37.1%	5.7%	2.9%
Post Period 1 (N)	0	3	9	4	3
Post Period 2 (N)	0	4	4	5	3
Post TOTAL (N)	0	7	13	9	6
% of TOTAL	0.0%	20%	37.2%	25.7%	17.1%

In total, 45.7% of the students held some general understanding of the process or purpose of genetic engineering prior to the learning activity compared to 80.0% post-activity. Of those students, 8.6% expressed some technical understanding of the process or purpose of genetic engineering from the pre-activity answer versus 42.8% post-activity. Of concern was the 20% of students that possessed an inaccurate understanding of the subject matter at the culmination of the learning treatment. As discussed earlier, the majority of the students (26 of 36 total) was in either 9th or 10th grade and had not yet completed a course in Biology that would have covered the topic of genetics in more detail. All of the students had completed an 8th grade Life Science course that included general topics on genetics, but perhaps their retained knowledge of genetics was limited such that the concept of genetic engineering was beyond their grasp. In addition, there appeared to be some connection between the students' learning abilities and their level of understanding of the purpose and process of genetic engineering. Five of the seven students who did not express a correct general understanding of genetic engineering were learning disabled (as reported by the teacher). The other two students were of average ability.

As discussed previously, each student-pair was given a workbook that presented questions that were designed to guide them in the reading and comprehension of the online articles of evidence. All of the student-pairs were able to accurately answer the questions within the workbook. This included questions relating to the procedures of genetic engineering (i.e. splicing desired gene trait from donor DNA species and inserting gene sequence into the DNA of the recipient species). Despite the guided inquiry and animation on the process of genetic engineering, the students' comprehension, in some cases, still appeared to be limited. At the culmination of this activity the students were asked to describe the differences between crossing and genetic engineering. Utilizing the same rubric that was used to assess the GMF definitions the students' answers were rated independently by three science educators. Any discrepancies in the initial ratings were discussed and negotiated until a consensus was reached. Table 4 presents a summary of the analysis.

Table 4
Student-pairs' Level of Understanding between Genetic Engineering and Cross Breeding

	0 No attempt to answer	1 Expresses Incorrect Concept	2 Expresses General Concept	3 Expresses Technical Concept of Process OR Purpose	4 Expresses Technical Concept of Process AND Purpose
Period 1 Student-pairs (n)	1	3	2	4	0
Period 2 Student-pairs (n)	0	0	1	6	1
TOTAL (n)	1	3	3	10	1
% of TOTAL	5.6%	16.6%	16.6%	55.6%	5.6%

Four of the student-pairs (out of 18 student-pairs) in Period 1 did not possess an adequate conception of the differences between genetic engineering and cross breeding. Again, the learning level of these students appeared to be of some consequence. These student-pairs were comprised of at least one student that expressed incorrect concepts on the post-activity GMF question analysis and were characterized as learning disabled by the teacher. Obviously the curricular unit did not address the individual learning needs of these students. In one case in particular, the researcher worked with a student who was noticeably dyslexic and had great difficulty reading the articles of evidence and, therefore, answering the related questions. When the researcher helped him through the reading and reworded questions in more simplistic terms, he was able to more thoughtfully and accurately answer the questions.

It is important for students to possess an adequate conceptual understanding of the process and products of science if they are to effectively make decisions and argue in support or against legislation related to socioscientific progress. The students involved in this case study represented a fairly diverse range of learning abilities and interests. All of the student-pairs were able to accurately read and answer questions related to the process of genetic engineering as they were stepped through an animation of genetic engineering and comparison with cross breeding. When presented with the opportunity to express their understanding of genetic engineering, the majority of students held at least a general conceptual understanding of the process and purpose of creating genetically modified foods, but many students were still unable to provide even a general definition.

Research Question 1C: Pedagogical Approach

How did students utilize evidence claims or GMF subject matter knowledge (SMK) in formulating and presenting their arguments for the classroom debate?

The students' arguments were evaluated using Toulmin's (1958) model of argument. Each student turn (i.e. a single student's contribution to the dialogue) was analyzed for their use of claims, grounds, warrants, backings, and rebuttals to support their debate position. The students' grounds for making their claims were then rated for their reference to information obtained from the articles of evidence or factual GMF or general science subject matter knowledge (SMK) using the rubric presented in Table 5.

In total there were 123 student conversational turns in the classroom debate. If a single student turn contained multiple grounds, then each ground was assessed separately within that turn. With this in mind, a total of 132 lines of dialogue were analyzed. In the case where a student turn did not include a formal line of argument (i.e. claim, ground, warrant, backing, or rebuttal), it was not rated (NR). Table 6 presents a summary of the rubric rated dialogue by group. The figures reflect the number of student turns that were rated at each level. The dialogue was rated by the first researcher and was independently re-rated by the second researcher. Discrepancies in the ratings were reviewed and discussed until consensus was reached.

Table 5
Rubric to Assess Students' Use of Evidence Claims and Subject Matter Knowledge in Debate

Rating	Description	Exemplar
0	No evidence claims or SMK are considered	In a way you are acting like God, modifying food.
1	Incorrect consideration of evidence claims or SMK	It can also kill all the people in the third world.
2	Consideration of non-specific evidence claims or SMK	Our food here can stand our weather, but our food that survives here won't be able to survive there.
3	Correct consideration of specific evidence claims or SMK	But it only affects butterflies in the larvae stage.

Table 6
Summary of Students' Rubric-rated Conversational Turns by Group Position

Group	0 No evidence or SMK	1 Incorrect evidence or SMK	2 Nonspecific evidence or SMK	3 Correct evidence or SMK	NR Not Rated	Total (n)
A - Ban GMF	6	6	10	8	33	63
B - Allow GMF w/ Labeling	1	3	10	10	11	35
C - Allow GMF no restrictions	0	0	3	18	13	34
TOTAL	7	9	23	36	57	132

Approximately 52% of the dialogue from the students in Group A were lines of reasoning that fell outside of the formal argument structure as described by Toulmin. Comparably, 34% of Group B's dialogue and 38% of Group C's dialogue did not contain formal lines of argument and was not rubric rated (Note: The analysis of this dialogue with categorical examples will be presented following the discussion on the rated dialogue).

In total, 40% of Group A's and 17% of Group B's grounds were based on either an incorrect consideration of the evidence or subject matter knowledge (rating = 1) or did not include any reference to the information contained within the articles of evidence or their subject matter knowledge (rating = 0). In contrast, all the argument grounds presented by Group C were rated at a level 2 or 3. Interestingly, at the conclusion of the debate, the students agreed that the group with the best argument was the one that provided the most solid evidence: Group C.

Table 7 presents a breakdown of the rated dialogue by student. When the groups for the debate were organized, they were directed to select one or two students to lead their group in organizing and presenting their argument, but were also instructed to work together to collect the evidence and present the argument. Student personalities were taken into consideration when the groups were formed so that the more assertive students were evenly distributed. Unfortunately, the more timid, less motivated students remained on the sidelines while those who were motivated to participate in the debate dialogue took the lead position in presenting for their group. The figures in Table 7 represent the number of times each student turn was rated at a given level. While 13 of the 16 total students contributed to the debate, there were five students (B2, B8, B9, B16, B4) that accounted for the majority (10% or more) of the student dialogue. In the cases of Group B and C, the appointed leaders took the majority of responsibility in presenting the group's position.

It should be noted that none of the students in the class had prior experience in debate or formulating arguments for or against a position. While the paper-based scaffolding tools guided them in selecting articles of evidence to prepare for their argument, counter-arguments, and rebuttals, they did not receive any instruction on the formal structures of argument (i.e. claim, grounds, warrant, backing). At the conclusion of the study, the researcher and teacher agreed that more time should be spent preparing students for the debate, including more explicit discussion and instruction on the nature of arguments and what constitutes suitable evidence.

Table 7
Rubric-rated Dialogue of Argument Grounds by Student Conversational Turn

Student(Group)	0 No evidence or SMK	1 Incorrect evidence or SMK	2 Nonspecific evidence or SMK	3 Correct evidence or SMK	N/R Not Rated	Total	% of Total
B1 (A)	1	1	0	0	2	4	3
B2 (A)	4	2	2	4	8	20	15
B7 (A)	0	0	0	0	1	1	1
B8 (A)	1	3	7	3	9	23	17
B9 (A)	0	0	1	1	11	13	10
B15 (B)	0	0	2	1	1	4	3
B16 (B)	1	3	7	9	11	31	23
B17 (B)	0	0	1	0	0	1	1
B4 (C)	0	0	2	12	5	19	14
B10 (C)	0	0	1	2	2	5	4
B12 (C)	0	0	0	3	0	3	2
B13 (C)	0	0	0	0	1	1	1
B14 (C)	0	0	0	1	6	7	5
TOTAL	7	9	23	36	57	132	100

An analysis of the NR dialogue found multiple examples of hypothetical, moral, and fallacious reasoning. The students' limited and recently acquired knowledge of the claims surrounding the controversy obviously impacted their ability to argue their position in depth. Each group's argument would commence on a strong note as they presented their position and two to three grounds that supported their position. Though, once the initial grounds of their position were stated, the students' lack of additional knowledge or evidence to support a cogent argument resulted in instances of fallacious argumentation consistent with those identified by Zeidler, et al (1992). This included the use of hasty generalizations (overemphasizing the frequency of rare events for its shock value), ad hominem arguments (attack of a person's character), normative reasoning (reference to personal experience), and altering the representation of the argument with the intent to persuade an emotive response. Table 8 provides a few excerpts from the dialogue that reflect various instances of fallacious reasoning.

Observing the classroom debate on a surface level, one might get the impression that the GMF controversy was an effective context for engaging students in dialogue and debate about a current socioscientific issue. The students, for the most part, were indeed engaged and energetic in voicing their positions and oppositions. Yet, with a closer look at the dialogue that ensued, it became apparent that the students were not overly successful during this process in developing sound, evidence-based arguments.

Table 8
Exemplars of Students' Fallacious Reasoning from Debate Dialogue

ID(GRP)	Transcript	Argument Category
B2(A)	So you think you should kill off some people to help some others?	Ad hominem argument; Altering representation of argument; hasty generalization
B9(A)	How do you know that we all aren't allergic to it? Are there tests out there for it? Have you tested to see if we are allergic to it or not? You don't know.	Altering representation of argument
B1(A)	You are talking about ending starvation in third world countries, but you don't know about tests to see if it is safer for these countries. They eat different stuff than we do. You can't understand the innocent people that will die from this food? And you can do that? Just give it to third world countries like that knowing they could die?	Ad hominem argument; Altering representation of argument; hasty generalization

Research Question 2: Students' Conceptions of Science

How does students' engagement in a web-based learning environment on a current socioscientific controversy elicit, reveal, and develop their conceptual understanding of the nature of science?

The students' introduction to the GMF controversy included a teacher-led discussion about aspects of the nature of science that would be included in the activities. Questions were embedded throughout the online unit that prompted students to think about and discuss various aspects of the nature of science as they related to the GMF controversy. The questions, many of which were drawn and modified from the Science-Technology-Society Survey, focused on the following factors that influence scientific advancements: certainty of scientific claims and tentativeness of science; validity and reliability of scientific claims; objectivity and subjectivity; role of government, corporations, media, and special interest groups in science; and, moral and ethical issues. The questions were posed in three different formats: online chatroom (answers read by all students), online private (answers read only by teacher), and partner discussions (answers written in the accompanying workbook). In addition, questions from the Views of Nature of Science Questionnaire (Lederman et al., 2001) were asked during the post interview. The students' answers to all NOS-related questions were analyzed for emergent conceptions related to the nature of science.

Prior to engaging in the learning treatment, the students completed the Nature of Scientific Knowledge Survey (Rubba & Anderson, 1978). The five-point Likert scale of the NSKS assessed students' conceptions related to the following aspects of science: amoral, creative, developmental, parsimonious, testable, and unified. Table 9 provides descriptive statistics of the students' responses. Each category has a 40-point range with the higher the numbers (i.e. closer to 40) representing more instrumental and dynamic views (versus realist and more static views that would describe scientific knowledge as absolute, lacking in creativity, etc.). The purpose of this instrument was two-fold. First, it provided some baseline description of the students' conceptions of science prior to engaging in the learning treatment. Second, it was used an exercise to initiate students into the metacognitive process of thinking about their conceptions of science.

Table 9
Descriptive Statistics of Nature of Scientific Knowledge Survey

Category	Period 1			Period 2		
	M	SD	Range	M	SD	Range
Amoral	24.5	2.5	21 - 29	24.4	3.3	20 - 28
Creative	25.5	5.4	17 - 39	28.8	2.2	26 - 31
Developmental	25.7	4.4	19 - 33	28.6	4.2	22 - 33
Parsimony	23.7	3.3	18 - 29	21.0	2.0	19 - 24
Testable	27.9	5.8	17 - 37	30.6	4.2	26 - 36
Unified	26.2	5.2	18 - 36	29.2	1.8	27 - 31

Developmental and Tentative Nature of Science

Students' understanding of the tentative and developmental nature of science was explored through several different questions. The first of these questions focused on the role of predictions. Highlighting the predictive nature of the GMF evidence claims supporting the possible benefits and risks, students were asked to agree or disagree with the following statement and to explain their position: "Even when making predictions on accurate knowledge, scientists can only tell us what probably might happen. They cannot tell us what will happen for certain." The majority of the students in both classes agreed with this statement. The most prominent reason students gave for the uncertainty of predictions was the scientists' lack of full control of all possible variables.

> I agree with this because they do this in a controlled lab and they don't really know what will happen in a natural cornfield and they don't have any control.

> Yes because there are outside factors that can affect scientific principals.

When presented with the research findings of a study that assessed Bt corn toxicity to monarch butterfly larvae, the students were asked whether the findings from this study could be fairly translated to predictions on how the monarch butterfly population would be affected by Bt corn. Similarly, the majority of the students recognized the weakness of making predictions from these studies in that the controlled laboratory environment could not account for the unknown variables in nature.

> Not really because the laboratory was controlled and most of the time the natural setting of a cornfield is not controlled.

> The lab is more sterile and precise than nature.

The articles of evidence presented in this learning treatment were similar in nature to what students would most likely encounter on their own: second hand reports of scientific studies and claims related to GMF. The researcher selected the articles based on the trustworthiness of the source (e.g. government and university web sites and established news agencies such as CNN). Although the articles were biased to some extent depending upon the position of the organization or individual presenting the information, they did represent current views or evidence for or against GMF. After reading an article about the research on the effects of Bt corn on the monarch butterflies, the students were asked whether the article they read consisted of valid and reliable information. Their level of trust in the articles varied dependent upon their level of confidence in the perceived source of the information:

> This is an online discussion therefore the information may not be up to date. For an example, with the monarch butterflies, the information that was given to us may have been researched a few years ago. Being that, we don't know if the Bt-corn is still in the fields harming the butterflies or not.
>
> The article we read was a valid and reliable information because it was a government article and the government cannot give false information.

Engaging students in discourse and debate over current socioscientific issues necessitates that the students have an understanding of the empirical nature of the science involved in the debate and a critical eye when evaluating the sources of scientific claims. Overall, the students' conceptions of the developmental and tentative nature of science, as expressed in their answers to the online questions, were consistent with desired learning outcomes in the national standards. The majority of students held some understanding of the tentative nature of predictions and theories. While it would be difficult to assess the extent to which their understanding developed or changed as a result of the learning treatment, it was of more importance that the activity created a forum that allowed students the opportunity to reflect upon and discuss their views. It is through these types of activities that the science teacher can begin guiding students toward a more dynamic view of science.

Social and Political Aspects of Scientific Work

Science is a complex social activity as social values and interests often set priorities for research funding. Throughout the online unit, key players representing a range of perspectives on the issue presented the various articles of evidence both in support of and against GMF technologies. Furthering students' reflection on the social aspects of science, additional questions were posed about the role of government, corporations, and special interest groups in science. The comments from the majority of the students in both classes supported a general understanding that science did not occur in a social vacuum. Two questions in particular asked students whether they felt that a country's politics and government affected and/or controlled the work of the country's scientists. The answers ranged on a continuum from the belief that the government was in total control of all scientific work to the belief that the government had little to no control over the research that occurred behind laboratory doors. Table 10 presents exemplars of the students' conceptions regarding the level of governmental control over what scientists study and develop.

Table 10
Students' Beliefs about Government's Control over Science

Category	Exemplar
Total Control	We agree because the government tells the scientists what to do. Yes because scientists have to listen to the government and do whatever they are told.
Partial Control	Ummm, I think that the scientists are not isolated from the government because the government is where they get there funding to do there research . Not ultimate control but they do have regulations and guidelines for them to follow.
Lack of Control	No because what is done in the lab they can't see so they have no control. No I don't think the govt. has ultimate control over what scientists study and develop. You could study whatever you want in your own lab.

Students' belief about the role of government in science is an important one to explore for several reasons. At some level, it is tied directly to an individual's trust in the products and process of science. Whether or not American consumers seek out the Food and Drug Administration or the Environmental Protection Agency's stamp of approval on the products they purchase, there is an assumption that if a product is available for purchase then it has undergone fairly rigorous testing to ensure its safety. As one student-pair pointed out, "scientists can study and develop biotech as they wish, but the government controls what makes it to the market."

The Subjective and Creative Scientist

Inherent within a socioscientific controversy are many messages about the human, subjective side of science and scientists. Although science strives for complete objectivity, the scientist is never purely objective. Theories, questions, and interpretations are a product of beliefs, previous experience, and expectations. These aspects of the subjective and creative scientist were discussed in both the online unit and the follow up interview. In order to reinforce this concept, the students were asked to explain how scientists could come to different conclusions on an issue. Table 11 provides exemplars for each of the categories that emerged from the analyses of their responses.

Consistent with recent research exploring this same question (Zeidler et al., 2002; Zeidler, In Press) the students' answers reflect both an understanding of the subjective side of science (in their reference to personal motives, opinions, perspectives, and moral values) and an appreciation of the variation in experimental methods or modes of research. This "human" side of science was further explored through discussion questions in the follow up interview. In response to the question of whether or not scientists were creative in their work, all of the students felt that creativity in science was possible to a certain extent. There were no distinct conceptions about creativity that emerged from their answers. Instead, there was a general consensus that while scientists' creativity was sometimes limited by scientific methods it does play a role in the hypotheses, interpretations, and the questions they pursue. Typical of student responses were:

> I: And how would you see them using their creativity and imagination in their work?
> S: The strawberry-flounder cross.
> I: Okay, so coming up with new ways to modify food you have to be creative?
> S: Yeah, like the btCorn and stuff like that. Just to think to do that, you have to have some creativity.

TABLE 11
How Can Scientists Have Conflicting Research Conclusions?

Category	Exemplar
Lack of Data	They don't have all the facts. I guess a lot of it would be their own opinion. There could not be enough data to actually know which theory.
Varying Methods of Data Analysis	It depends on whether they are looking through a telescope or just taking facts down, counting the solar systems, or looking at how many have been created through time and how many have been destroyed. Different analysis. Different scientists have different facts, from different years, different sizes, and different measurements.
Personal Motives	Scientists might have different reasons or motives for doing the project. Some scientist may be doing the research for personal reasons, money, or they could be doing it to benefit other people. Because someone will probably do it to benefit themselves.
Moral Values	Moral values can affect them in the way that they think. Their personal motives and moral values affect the decisions they make.
Personal Opinions/ Perspectives	Their opinions on it on what they see. Maybe they just look at it differently or they use their own opinions.

Overall the students' views of the subjective, creative, social, developmental and tentative aspects of science, as portrayed in their answers to the online questions, reflected a moderately dynamic understanding. For the students involved in this study, the learning treatment and the lines of questioning were a unique experience. The metacognitive exercise of thinking about their thoughts about science and scientists was foreign to the students. They answered the fact-based questions related to the subject matter with ease, but a number of students were perplexed by some of the NOS related questions. Interestingly, only half of the students reported that their views of science changed when asked this question in the follow up interview. When asked to explain how their views changed, the majority of students just discussed their changed understanding of the topic of GMF.

I: Do you feel that your understanding of the field of science has changed through this activity at all?
S1: I don't think my view of science has changed. I learned more about genetically modified foods and stuff like that, but my opinion of science is still the same.
S2: I don't think so. I think it was just basically about genetically modified foods and we weren't really focused on the scientists themselves.

Only a few of the students discussed how their views of scientists changed, resulting in perhaps a more skeptical understanding of the social and human aspects of scientific work.

> Well, I kind of trusted scientists. Now I don't know because they have the profit motive and they might not be actually saying what is true. They might just try to cover stuff up because they want to look out for themselves more.

> Yeah, a little bit. I think before I did this program, I felt that scientists went off on their own, but now it seems like huge corporations have their backs and kind of edging them to do this or that or the other thing, experiment a little more. And they don't have as much freedom as they should have.

While the learning treatment had a positive affective response from the students, it clearly did not invoke huge conceptual shifts in students' understanding of the nature of science. Yet, it is highly unlikely that any single activity devoted to developing students' understanding of the NOS would be the catalyst for major conceptual change. Instead, students' exposure to and discussion about NOS topics needs to be a routine and integrated component in the teaching of science content. Perhaps, through time, students will then become more cognizant of NOS issues as the vital link between society and the scientific endeavor.

Research Question 3: The Relationship between NOS and Decision-making

What is the nature of the relationships that exist, if any, between students' understanding of the nature of science and their reasoning used to make decisions on a current socioscientific controversy?

Although the learning treatment included specific questions about various aspects of the nature of science, the students were not explicitly guided in considering how these aspects might play a role in their decision-making on the issue. Instead, the students were instructed to review their online written work (which included their answers to the NOS questions) and the multiple articles of evidence to gather supporting evidence and arguments for their debate position. This open approach to the students' reflection upon and selection of NOS issues and GMF evidence was chosen in order to avoid forced considerations of NOS issues in their decision-making.

As discussed earlier (Research Question 1C), the students' reference to empirical evidence supporting the various positions in the debate was limited. Yet, through their reflection of the arguments that were presented in the debate, the students came to realize the importance of sound evidence. At the conclusion of the debate when the students were asked to vote on the group that presented the best argument, the majority (75%) of the students chose Group C. As explained by one student why Group C was the most convincing, "They had the most facts and they weren't bringing their mother into it." An informal panel of judges who was assembled to listen to the debate also provided their analysis at the conclusion. The lead judge stated, "Most convincingly was Group C. They seemed to have a wide base, a good background, a lot of input by different people, they quoted statistics and I was convinced by their arguments even though I have a different stance on this (topic)."

The transcribed debate was analyzed independently by the two researchers for any emergent references to aspects of the NOS. While the researchers noted no explicit references to the NOS, several implicit understandings emerged from the analysis. The majority of comments reflected a science-society connection with an understanding of the role of government in the safety testing and controls over the products of science, an issue that was explicitly addressed in the online unit (Table 12).

Table 12
Debate Dialogue Transcript of Implicit References to the Nature of Science

ID(GRP)	Transcript	NOS Conception
B15(B)	Yeah, but some people could care less whether it has a label or not because they see it on the store shelves and they know it is edible. And since it is on the store shelves it is obviously safe enough.	Social impact of science; Consumer safety
B16(B)	All foods that are put on the store shelves are tested by the FDA.	Consumer safety; Government regulations
B8(A)	Did you notice it slipped by them? It slipped by the FDA, they didn't catch it.	Government regulations
B17(B)	It doesn't matter if its labeled, they can still recall it after you eat it.	Government regulations
B12(C)	Actually there are already different regulations in place and biotechnology foods are more scrutinized than regular foods.	Government regulations

In order to further explore any possible relationship between the nature of the students' decision-making and their understanding of the nature of science, an in-depth qualitative analysis was conducted of the three students who contributed to the majority of the dialogue. Table 13 provides a summary from the analysis of their dialogue along with the scores from the NSKS that provide a baseline measurement of their views of science. In review, NSKS scores for each of the six categories (amoral, creative, developmental, parsimonious, testable, and unified) range from 0 to 40 points, with a higher point score descriptive of a more dynamic and accurate view of the nature of science (see research question 2 for a more detailed description of the categories). The respective scores from the six categories for Kristen (21, 23, 27, 25, 31, 28) and Jeff (21, 24, 29, 22, 32, 29) were quite similar whereas Ashley (26, 30, 31, 20, 36, 31) scored slightly higher in all categories except for parsimony. All three students answered similarly to the NOS online and interview questions. They all expressed an understanding of the uncertainty of scientific predictions and the tentativeness of scientific knowledge and felt that creativity drives the work of the scientist. Each student expressed an understanding of the difference between scientific knowledge (based on facts that can be proven) and opinion (one's personal view that can not be proven) and felt that both played a role in the work of scientists. Hence there did not appear to be any qualitative differences in the three students' conceptions of the nature of science and their ability to debate the positions. The debate dialogue analysis supports the students' feeling that Jeff and his Group (C) presented a more cogent argument than the others. The majority of his dialogue included reference to general or specific evidence or subject matter knowledge to support the position that GMF should be allowed with no labeling. Albeit, there are numerous other factors that can be attributed to the qualitative differences in the students' arguments that were not measured in this study's analysis, but their conceptual understanding of the NOS did not appear to be a contributing factor. The lack of students' explicit reference to the NOS in the debate dialogue is consistent with previous research findings from a study conducted by Bell (1999) that investigated the relationship between NOS and socioscientific decision-making by examining the beliefs and opinions of university professors.

Table 13

Summary of Student Conversational Turns (SCT) Ratings and NSKS Results for Three Primary Students in the Classroom Debate

Student Name ID (Group Position)	# of Grounds containing no or incorrect evidence or SMK	# of Grounds containing nonspecific or specific evidence or SMK	# of SCTs Not Rated	% of Total Student Turns	NSKS Range	NSKS Total
Kristen, B8 (A - Ban GMF)	4	10	9	17	21 - 31	155
Ashley, B16 (B-Allow w/ labeling)	4	16	11	23	20 - 36	174
Jeff B4 (C- Allow no labeling)	0	14	5	14	21 - 32	157

Conclusions and Implications for Research and Practice

Science educators agree that the nature of science is a valuable and integral part of any science curriculum that is aimed at developing our students as scientifically literate individuals. There are numerous studies that support an explicit and integrated approach to effectively teaching about NOS issues (Lederman, 1998). Yet, what remains in question is how this understanding might be applied or utilized by the scientifically literate individual. Perhaps our students will be able to articulate the meaning of the "nature of science" and describe its associated characteristics, but if that understanding is not applied as they evaluate and make decisions upon scientific claims then how beneficial is that knowledge? The learning treatment in this study contained explicit NOS questions and discussions to promote the students' reflection and reference to these issues, yet the students were not specifically directed in applying this understanding as they debated on the issue. But if the goal of teaching NOS in the science curriculum is to develop our student's ability to critically evaluate competing scientific claims, then perhaps they should be guided in the process of synthesizing and applying their understanding of the nature of science as they evaluate and decide upon socioscientific issues.

Unlike previous studies that have shown students to possess an inadequate understanding of various aspects of the NOS (Aikenhead, 1973; Lederman and Omalley, 1990; Tamir and Zohar, 1991), it would be hopeful to believe that the findings from this study show a positive shift in the development of students' understanding. As measured by the NSKS and supported by online NOS and interview questions, the majority of the students' answers reflected adequate conceptions of the tentative, creative, subjective, and social aspects of science. It is difficult to know how much, if any, of the conceptual shift occurred as a result of this learning treatment, but the activity itself was successful in terms of creating the forum to bring discussions on NOS issues to a metacognitive level.

As supported by the positive affective response of the students to the learning treatment, utilizing current socioscientific issues that students find relevant to their lives can create an engaging forum for students to explore aspects of NOS alongside discipline-specific science content. Because of the apparent social, tentative and subjective nature of moral or ethical issues, teachers can more readily engage students in discussions that touch upon the many aspects of the nature of science.

Implications for Science Education

This study was conducted as a "stand alone" learning activity with two classrooms of students of diverse age and learning abilities. Findings from the analysis of students' mastery of the subject matter of genetic engineering and their reference to subject matter knowledge and evidence in the classroom debate suggest that NOS centered discussions should be conducted along with in-depth learning activities on the subject matter content of the controversy. An increased understanding of the science content knowledge involved in the controversy will allow students to be more critical of evidence and effectively utilize that evidence in the decision-making and debate process. Students also need to be more explicitly directed in what constitutes scientific data and evidence and how to formulate sound arguments. Like the students that participated in this study, the majority of students today have limited experience engaging in discourse and debate in the science classroom. Therefore, it is recommended that students receive direct instruction on argument structure and fallacious reasoning prior to engaging in debates. It is also suggested that teachers who are interested in using debate-focused activities use a juried trial format that would allow the teacher, as presiding judge, to better direct the debate through various lines of questioning (e.g. epistemological probes, issue-specific probes, role reversal probes, and moral reasoning probes).

The importance of exposing students' to discursive activities in the science classroom cannot be overstated if our goal is to increase science literacy. Of course this cannot be accomplished without the development of teacher training programs that focus on the pedagogical techniques necessary to create content-specific and NOS learning activities that emphasize discourse and debate. This requires teachers become adept at guiding students in the process of applying their understanding of the nature of science as they decide on and evaluate the worthiness of competing scientific claims. In addition, the teacher needs to be familiar with the epistemological factors that come into play including scientific misconceptions, moral reasoning, and fallacious reasoning.

Internet and issues-based learning activities can be an invaluable resource in terms of exposing students to diverse perspectives on current scientific reports and claims. With scaffolded learning interfaces such as the one used in this study, students can spend their time reading and evaluating the multiple perspectives of a given socioscientific issue instead of "surfing" through a plethora of sometimes misleading information. Of course, this requires that the teacher invest the time up front to find valid and reliable sources of scientific data and perspectives. Once the content is developed however, the power of the Internet as a global learning environment allows the curriculum to be easily shared with other classrooms and perfected through continuing research.

Implications for Future Research

Researchers and curriculum developers in instructional technology have been focusing on the development and evaluation of instructional models for Internet-based learning environments (Brucklacher & Gimbert, 1999; Linn, 2000). Yet, the multitude of factors that come into play in designing such learning environments can make assessment a daunting task. The Constructivist Instructional Design model suggests that researchers should allow the people who are destined to use the system to play a role in the design process (Willis, 2000). Such an approach calls for multiple small-scale use and assessment case studies to obtain the students' feedback and assess their mastery of the learning objectives. The developmental research being conducted through the Knowledge Integration Environment is an example of evolving and iterative design. For over ten years, partnerships between scientists, educational researchers, curriculum developers, classroom teachers and their students, have allowed for comprehensive design studies aimed at creating computer based activities that can support lifelong science learning. Further collaborative, partnership-based research should continue to develop, implement, and assess science curriculum that is designed to promote scientific literacy. It is through these types of studies that we can begin to maximize on the power of the Internet to produce curriculum that can connect classrooms of science learners to each other and motivate students through learning and discursive activities about the personal implications of current science controversies.

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APPENDIX A
SCOPE Curriculum Design Approach

Day 1: Introduction to the Controversy of GMF

The students are introduced to the controversy through a NOVA/PBS video entitled, "Harvest of Fear." The video presents numerous perspectives of the controversy from those involved. This is followed by a "food sampling" party of various genetically engineered and organic corn products. The teacher guides a discussion about genetically modified foods and the nature of scientific controversies. The students receive a handout highlighting various aspects of the nature of science that are explored through the activity and the teacher probes them on their current views of science related to these aspects. Are all scientists subjective, objective, or both? Is there more than one way to do science or do all scientists follow a single scientific method. How might cultural and social influences affect and direct scientific research? Are scientists creative? Do theories become laws once proven or are they different forms of knowledge serving different purposes in science? Students are informed that many questions and issues related to the nature of science will be discussed through the series of activities. When the student encounters the NOS icon online, they will know the activity is referencing some aspect of the nature of science.

Days 2 through 5: Internet-based Activities

Students are paired and are guided on how to log on to the web-based unit. The class works together through the first online introductory unit.

Activity 1: "Genetically Modified Foods in Perspective"

Objectives:	Introduce and provide overview of the topic of GMF and the learning objectives. Probe students' understanding of how controversies in science are possible.
Activity:	Step 1: Provides introduction into the debate issue of labeling GMF. Step 2: Notetaker question: When scientists disagree on an issue (for example, whether or not genetically modified foods is harmful), they disagree mostly because they do not have all the facts. Their scientific opinion has NOTHING to do with moral values or personal motives. Students asked to agree or disagree and explain their position on this statement.

Activity 2: "What is a Genetically Engineered Plant?"

Objectives:	Upon completion of activity, students should be able to: • Define genetic engineering. • List and briefly explain the five basic steps in genetic engineering. Describe why each is necessary. • Identify the fundamental differences between genetically engineered crops and non-genetically engineered crops. • Explain the limitations to traditional breeding that are overcome by genetic engineering. • Contrast between genetic engineering and cross breeding technologies as methods to create desired traits in plants

Activity:	Step 1: Discuss main differences between genetic engineering and cross breeding. Step 2: Transgenic Plants Animation (http://croptechnology.unl.edu) details five basic steps in genetic engineering, limitations of traditional breeding, and fundamental differences between genetically engineered and non-genetically engineered crops. Step 3: Compares crossbreeding with genetic engineering methods used to create large-eared corn. Step 4: Notetaker Questions: Students apply understanding to the following three situations: 1. Would you use a cross or genetic engineering to make trees which produce larger fruit? Explain your answer. 2. If many crops were being destroyed by a new virus, which technique would be more useful to solve the problem quickly: a cross or genetic engineering? Explain your answer. 3. If someone wanted to get a gene for "roundness" from a tomato, into a Strawberry plant (so that Strawberries would pack better in containers without being bruised), would you use a cross or genetic engineering? Explain your answer.

Activity 3: "Multiple Perspectives of the GM Controversy"

Objectives:	Provide evidence on the multiple perspectives of the controversy from the key players involved. Develop students' understanding of science as a complex social activity.
Activity:	Students "meet" six key players involved in the controversy representing equal pro and con arguments. There are six activities, one for each key player (consumer, scientist, EPA representative, genetic engineer, farmer, CEO of GMF producer). With each key player bio, students answer questions related to that person's perspective of the controversy. Multiple issues related to the nature of science are addressed in each perspective.The sequence of activities are as follows: Introduce Key Player and their Position on the Controversy Present related aspect of NOS issue Provide first supporting evidence article Student Discussion: related NOS issue Provide second supporting evidence article Chatroom: related NOS issue Notetaker: related NOS issue

Activity 4: "To Label or Not to Label"

Objectives:	Present political, governmental role in monitoring and regulating products of science Develop students' understanding of science as a complex social activity.
Activity:	Provide a history of food labels Supporting Evidence Article: Separating and Tracking GM and Non-GM Crops Chatroom Discussion on Related NOS Issue

Activity 5: "Plan for the Debate"

Objectives:	Students consider and review all evidence presented by key players to present their case on three alternative positions: Group A: Ban GMF until further research proves its safety for consumers and the environment Group B: Allow GMF with tracking and labeling Group C: Allow GMF with no restrictions or labeling Students consider and review their written work related to NOS questions
Activity:	All student-pairs are guided in the process of considering and reviewing the key player's supporting evidence articles and their online notes to NOS questions. The student pairs organize the evidence to support the three alternative positions.

Day 6: Classroom Debate

On the day of the debate the students are organized into three groups supporting the three alternative positions. The groups collectively organize their evidence to support their position in the debate. Each group is given three minutes to present and defend their position. The other two groups are then allowed two minutes to ask questions or offer objecting positions. Then the presenting group has one minute to reiterate their position and provide rebuttals. Group A presents first, followed by Group B, then Group C. Only one person can speak at any time, but each group can have multiple presenters/defenders. A panel of judges is assembled to listen to the debate and provides feedback on the presentations and decides on the most compelling argument. Each student is then given the opportunity to decide on their personal position regardless of the position they defended.

Supporting Evidence Articles:

Taco Shell Recall – A recall notice posted on Kraft's website states that Kraft taco shells are recalled because they were found to have a variety of genetically engineered corn called, Starlink. Starlink had only been approved by the EPA and FDA for use in animal feed.

Can GM Corn Cause Allergic Reactions? – This article reports on the claims from several people that apparently had severe allergic reactions after eating Mexican food that contained Starlink corn. These allegations had not been proven or disproven, so it is unknown whether the Starlink corn was the source of their severe allergic reactions. The EPA did not approve Starlinks use in food products because it contained a certain protein that did not break down in the human digestive system whereby causing possible allergic reactions.

Toxic Pollen from GM Corn can Kill Monarch Butterflies – This article discussed the findings from a Cornell study that found Bt corn can be toxic to monarch butterflies. Bt corn was genetically modified to produce its own pesticide. The toxin naturally occurs in bacteria called *Bacillus thuringiensis* (*Bt*). Scientists took the genes that produces the toxin from the Bt bacteria and put it in the corn, whereby creating "Bt corn."

Monarch Butterflies and Bt Corn – Risk is Limited – When the EPA approved Bt corn in 1995 they determined that exposure of the Monarch larvae to Bt pollen would be limited. This conclusion was based on the fact the majority of pollen moves only a short distance away from cornfields and that exposure of Monarchs would be limited only to larvae developing on milkweeds within the cornfield or very near to cornfields during pollen shed. Since only a portion of the milkweed population is likely to be exposed to Bt pollen and only a portion of those plants would be expected to harbor Monarch larvae, the EPA scientists concluded that Bt corn does not present any "unreasonable adverse effects" to butterflies.

In Defense of Gene-spliced Corn – This article presents the EPA Review Process of genetically modified foods. The author states that the EPA and other government agencies hold gene-spliced foods to a much higher standard than other, similar foods when it comes to regulations and safety testing. The author presents the argument that other natural foods known to cause allergic reactions in people (like peanuts and wheat and foods containing those products) are still allowed to be sold on supermarket shelves.

Safety and Regulations of GM Foods – An overview of the safety and regulation process is given. The FDA looks at a wide range of factors before approving foods, including their safety, nutrition and the potential for allergies and toxins. Manufacturers bear a legal obligation to ensure the safety of food, and they test products extensively to meet it. One strain of biotechnology soybean was subjected to 1,800 analyses. To further address safety concerns, the FDA proposed guidelines in January 2001 that would require biotechnology companies to consult with the FDA before marketing any new biotech food or animal feed. Current law requires biotech foods to be labeled if their composition or nutritional content is significantly different from their conventional counterparts or if they pose any health risk.

Are First World Fears Causing the Third World to Go Hungry? – This article explains that the creation of genetically modified foods — like drought-resistant corn, for example, or super-nutritional rice — holds enormous promise for developing nations. But even as scientists develop GM crops with ever-increasing precision and skill, there is growing concern that first world disquiet over food safety and genetic engineering may slow or even stop the dissemination of bountiful GM crops to the countries where they are most needed.

The Impact of GE Crops on US Farmers - There are a variety of impacts of GE on farmers including loss of markets because countries are banning the import genetically modified foods. Without a market to sell their GM crop to, farmers are going to loose money. Another concern is genetic contamination. In other words, it is very expensive for farmers to keep GM crops totally separate from non-GM crops. If just a little bit of GM crops contaminates non-GM crops, then they cannot sell it. Another concern is the farmer's liability if contamination occurred.

Biotechnology: Helping to Protect the Environment - This article discusses some of the benefits of planting genetically engineered crops, including: Biotech crops can conserve soil and water, Biotechnology can help preserve natural resources, and Biotech crops can reduce the use of crop protection chemicals in agriculture.

Benefits of Genetically Modified Foods – This article states that the benefits of genetic engineering include: biotech foods can make it possible to grow more food on the same land, especially under tough growing conditions, biotech foods can reduce crop losses to pests and disease, and biotech crops can be more nutritious.

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