Students' Epistemologies of Science and Their Influence on Inquiry Practices

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For almost a century, we have heard the importance for students to understand nature of science (DeBoer, 1991; Matthews, 1994; McComas, Clough, & Almazroa, 1998; Lederman, 1992; & Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Nature of science has been defined as the "epistemology of science, science as a way of knowing, or the values and beliefs of scientific knowledge and its development" (Lederman 1992, p. 331). The *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993) clearly describe many aspects of science teaching and evident among these standards is the heavy emphasis on the nature of science. For instance, *The National Science Education Standards* has stated, "students should develop an understanding of what science is, what science is not, and what science can and cannot do" (NRC 1996, p. 21). An essential goal of understanding nature of science is for students to be able to evaluate knowledge claims and make informed decisions about science in the real world. Still today, teachers and students fail to adequately understand how science functions (Abd-El-Khalick & Lederman, 2000).

Most research in this field has examined both teachers' and students' conceptions of nature of science as well as instructional approaches to teaching about it. Science educators have learned that if we want to improve students' understandings about nature of science, then we should teach it explicitly through investigative activities and reflective discussions (Abd-El-Khalick & Lederman, 2000; Bartholomew, Osborne, & Ratcliffe, 2004; Schwartz & Lederman, 2002). Duschl (2000) points out that nature of science is made explicit when students examine, discuss, and argue about good evidence and decide between alternative explanations. He recommends that we should create learning environments where students have opportunities to evaluate the transformation of data to evidence, evidence to patterns/models, and patterns/models to theories and explanations.

Lederman & Abd-El-Khalick (1998) make it clear that there is a general consensus among science educators that certain aspects of authentic science should be integrated into the science curriculum. These aspects concerning nature of science include (1) scientific knowledge is tentative, (2) scientific knowledge has basis in empirical evidence, (3) scientific laws and theories are separate kinds of scientific knowledge, (4) scientific knowledge is based upon observation and inference, (5) scientific knowledge is created from human imagination and logical reasoning, (6) scientific knowledge is inherently subjective and based on interpretation, and (7) science is a human endeavor influenced by society and culture. However, this is not yet a solved problem because we still see that many teachers' primary goal is to focus on content learning objectives, rather than learn about content, inquiry and nature of science concurrently. Unfortunately, understanding nature of science comes in second, sometimes third, or not at all when considering science classroom learning goals.

Our research interest in the nature of science is in supporting learners in complex inquiry practices. From a design perspective, we suggest using an inquiry context to teach about nature of science. We argue that inquiry and nature of science are synergistic and to best support inquiry we need nature of science. In this work we are exploring how to integrate an understanding of nature of science into an inquiry unit. We are already working with an existing inquiry unit to motivate and support learners' inquiry in extended investigations by using project-based science. Our research for this study focuses on finding out how students can use their epistemologies of science to influence their engagement in inquiry practices. For example, do learners' understanding of evidence or ideas about how scientists use evidence support their participation in inquiry? In this paper, we investigated design aspects of integrating reflective discussions about the nature of science into a 7th grade science curriculum. Secondly, we examined how students' understanding about the nature of science affected their inquiry practices. Thus, we studied epistemological understandings in two ways: (1) as a learning objective such as learning about the nature of science and (2) as a mediating factor, examining its potential influence on scientific practices such as argumentation.

Curriculum Context

This study took place in the context of an Investigating and Questioning our World Through Science and Technology (IQWST) biology unit, "What Will Survive?" IQWST is designed as a project-based curriculum where students were involved in meaningful investigations, but without explicit attention to nature of science prior to the current study. Our design work was to incorporate nature of science reflective discussions into the already existing inquiry unit. The "What Will Survive Unit lasts 8-weeks and is divided into two 4-week parts. The first part addresses structure/function, species interaction and food webs in the context of designing solutions to stop a sea lamprey invasion in the Great Lakes. The second part of the unit focuses on understanding competition, environmental change, and differential survival in the context of investigating a crisis in the Galapagos Islands. The study was carried out during part one of the unit, which took approximately 6-weeks to complete.

Design Strategy I

In order to examine student understandings and its influence on their practices, we had to create a context in which nature of science was a focus of their investigations. We developed two different design strategies to incorporate the nature of science within the IQWST biology unit. In our first strategy, we integrated explicit, reflective discussions about a subset of the aspects of nature of science that science educators have agreed upon as important (Schwartz & Lederman, 2002). Our research focused on the following aspects: (1) scientific knowledge has basis in empirical evidence, (2) scientific knowledge is based upon observation and inference, (3) scientific knowledge is created from logical reasoning, and (4) scientific knowledge is inherently subjective and based on interpretation. We selected these particular aspects of nature of science because of the relevancy each had to the investigation sequence and progress.

To provide support for thinking about nature of science, we embedded reflective questions in the discussions where we wanted the teacher to reflect on these ideas with the students. For the design format, these ideas were marked in the materials for the teacher through reflective questions, possible answers, and background teacher support notes. Below is a sample discussion from a lesson about populations and ecosystem. The purpose of the lesson is for students to see the relationships between individuals and the population level. The students are using a computer model called NetLogo to figure out which populations are competing for resources. Since students are using a model to make inferences, we integrated a discussion about observation and inference into this inquiry experience.

Here is an example of a reflective question in the NetLogo lesson. We wanted the students to step back and think about what they were doing with the computer model. Were they doing science? What is an observation and how is it different than an inference? Is using a model scientific?

> *(Sample reflective question in a lesson).* **Reflective Discussion: Based on what you know about observations did you make any scientific observations when you used the NetLogo model? Ask**

students to support their answer with evidence and reasoning. Did you directly see the foxes eat the rabbits and the rabbits eat the grass on the computer screen? Would this be considered a scientific observation? Why or why not?

Below is an example of what we wanted the teacher to be prepared for during this reflective discussion about observation and inference. These are the possible answers that students may give in the discussion. We needed to add enough teacher support so that teachers were prepared for many types of student questions and answers.

(Answer for teacher to look for from asking this reflective question). The purpose of this discussion is for students to learn that scientists use models to make inferences about nature. Models are only representations of the real world. Any part or parts of a model can be made from an actual observation and since a model is depicting the individual parts and how they are inferred to interact, the model itself must be defined as an exercise of inferences. When using a model, scientists cannot make direct observations about a rabbit's behavior, but can only infer about a rabbit's behavior from its interconnection with the rest of the model. By using the NetLogo model, students are "seeing" the foxes eat the rabbits, etc, but these are not considered scientific observations, because no one saw the foxes actually eat the rabbits. For students to make scientific observations they would have to witness and carefully make and record direct observations of the foxes consuming the rabbits in the real world. It stands to follow than that scientific observations would be more scientifically convincing than making inferences from a model. Again, this in no way implies that an inference is any less useful or accurate in deciphering, concluding and presenting data.

Many times teacher background support boxes were designed to accompany a specific reflective discussion. Below is an example of a support box about models. This box provides more detailed information about the topic for the teacher.

Teacher Background Knowledge: Why use models?

- It is important for students to understand that the information scientists use to develop models come from direct observations previously made about the real world. These previously made observations may have taken years and most likely were performed by many different scientists from around the globe. This is also the reason science evolves so slowly.
- Models also allow scientists to manipulate or control different variables within that environment. Since variables are always in constant fluctuation in the natural state, scientists need to accurately represent these fluctuations. The following scenario is a good example. A scientist is trying to determine how different populations of animals (birds) interact within an environment (rainforest ecosystem) over a thirty-year period (time). A model allows the scientist to manipulate the above two variables (number of birds and amount of rain) as well as the third variable, the number of years (time). Model interaction can be paused at any point to provide a highly condensed snapshot of natural state interaction and an informative look at nature.

Another example of situating reflective discussions in the investigation occurred during a sea lamprey dissection. The students dissected sea lamprey and yellow perch and compared their structures and functions. This experience facilitated the opportunity to reflect on whether conducting a dissection was an observation or an experiment. Please see the example of the text materials below.

(Sample reflective question). Remind the students that they are going to use this information to help them develop a scientifically convincing explanation. During the investigation they have been asked to record how they scientifically collected their evidence. Ask the class to think about and discuss the following question. **Reflective Discussion: How did you scientifically go about identifying the structures of the sea lamprey? Did you make any observations or conduct any experiments? How do you know?**

Below is the response that the teacher would be looking for regarding the differences between observation and experiment. The teacher box also supports the teacher by providing more specific information about what scientists do when they are making scientific observations and experiments.

> *(Answer for teacher to look for from asking this reflective question)*. The purpose of this discussion is for students to recognize that they made observations of the fish structures. Students should also discuss the differences between observations and experiments. Many students think that whenever they are doing science that they are doing an experiment, but this is not always the case. Students should learn that by making observations, they are scientifically collecting information. See teacher background knowledge below for the differences between observation and experiment.

Teacher Background Knowledge: What is the difference between observation and experiment?

- *Observation*. Scientists make observations about the natural world by carefully making and recording direct observations using one or more of their five senses: sight, sound, smell, taste, and touch. In lesson 1, students were given an example of when a scientist would make an observation: When scientists wanted to look at how a fish swims in the water, they would make scientific observations.
- *Experiment*. Scientists carry out controlled experiments to test and manipulate scientific ideas while keeping other factors the same. This allows the scientists to determine cause and effect relationships. In lesson 1, the students were given an example of an experiment: What if scientists decided to remove some trout from the Great Lakes and put them in colder Alaskan waters to study the survival difference between the two sites. The trout that have been relocated to the Alaskan waters becomes the experimental group while the trout remaining in the Great Lakes becomes the control group. The scientist is able to test ideas by manipulating one group of trout (experimental) and comparing these results to another group of trout whose conditions remained the same (control). You could make scientific observations during this experiment; however, you don't always have to do an experiment to make scientific observations as in the case above about looking at how a fish swims in the water.

As can be seen in these examples, the students' inquiry context is used as a context for reflective discussion of nature of science. While the teacher discusses the results, the teacher also focuses questions and discussion on explicit particular aspects of the scientific approach such as how science needs to use observation and experiments, what they have in common, and how they differ. Thus, rather than an abstract treatment of these ideas, the distinctions and rationales for science are introduced where students were already engaged in reasoning about the referents for these ideas.

Design Strategy II

For our second design strategy, we emphasized the *utility* of the epistemological understandings in the investigation. In the contrast to other approaches, we wanted to do more than just situate reflective discussions. We wanted these considerations of nature of science to have clear consequences for students' problem solving and the products they were creating. More specifically, we required students to *use* conceptions of nature of science to help them perform inquiry practices. Our research focused on using students' conceptions of evidence, observation and inference, logical reasoning, and subjectivity. In part one of this unit, students were trying to design solutions to stop a sea lamprey invasion in the Great Lakes. For this assignment, students were required to develop a scientific explanation that included claim, evidence and reasoning for their solutions to the problem.

Our goal was for students to use their understandings about nature of science to facilitate this inquiry practice. For example, students developed a KWLS to support the investigation. The fourth component "S" of the standard KWL represents the question, 'how was information scientifically collected?' We designed the "S" column to motivate students that since they were going to scientifically convince the fishery commission of their plan to stop the lamprey, then they would need to record how they scientifically gathered their evidence. They would record observations, experiments, and background information when necessary. Students revisited this "S" column numerous times during the project to record their developing understandings about aspects of the nature of science and then referred to this chart as they worked on new practices such as developing and defending an evidence-based scientific explanation. Below is an example discussion that was designed for students to discuss what is means to scientifically convince someone.

> (Class discussion after reading the letter). Remind the students that the letter also asks them to develop a scientific explanation on how to remove the sea lamprey from the Great Lakes. They are counting on you to scientifically convince them that your removal plan will solve the problem. Ask the students, what should we do to show the Fishery Commission that we solved the problem scientifically? Encourage your students to bring up the idea that they will need to record the scientific processes such as observations, analyzing data etc. that they used to collect their evidence. By showing how they scientifically collected their evidence they will convince others that their solution is better than alternative solutions.
>
> (Putting together the KWLS). Remind your students that they will be required to make a scientifically convincing explanation of their plan. It will help to chart how we scientifically collected information about the sea lamprey. Column "**S**" is not completely independent of the other columns. Each time, information is updated in the "**L**" column there should be an update in the "**S**" column to document the methods used to gather this information.

The next paragraph is from the last lesson of part one where students are putting together their scientific explanation for solving the sea lamprey problem. We wanted the teacher to have the students develop a criteria list for what makes a scientific convincing explanation. The intention was that the students would use this list and their epistemologies of science to help them develop a convincing scientific explanation.

> (Solving their problem) Review Part 2 of the Student Sheet with the class. In this section of the Student Sheet, your students are asked to write a scientific explanation about why they think their plan for getting rid of the sea lamprey would work. Students are also asked to explain how their explanation is scientifically convincing by describing how they scientifically came up with their solutions. Lastly, the students are asked to explain how they would scientifically test their removal plans. For instance, would they design an observational study or experimental study? Would they use models, etc? Before students begin developing their explanations have the entire class develop an itemized checklist that frameworks a convincing scientific explanation. The checklist should include all of the essential elements they learned from the previous lessons on how to make a convincing scientific explanation. Referring to the list will aid the students during both their student sheet explanations and the final document development.

Study Enactment

One of the teachers recruited for the IQWST curriculum pilot was solicited for this particular nature of science study. The teachers for IQWST were solicited through an existing network of teachers who had worked with Northwestern University to pilot test project based curriculum in prior years and had some familiarity with the approach of project based science. The teacher for this study was given the curriculum materials including the integrated nature of science reflective questions a month before she enacted the curriculum. This allowed the teacher time to review the materials and ask questions about nature of science instruction and/or content. Once the curriculum was enacted, the researcher attended the classroom every day over a period of two months to videotape classroom activity and audiotape discussions with the teacher about the materials. In these discussions, the teachers talked about her instructional reasons for skipping discussions as well as moving the reflective questions to different places in the lesson. There were also opportunities to talk about nature of science content, rationale for integrating nature of science within the curriculum, and instructional challenges.

In summary, our design was intended for students to learn about nature of science while at the same time using these understandings to influence inquiry practices. To explore this we examined a middle school classroom using a pilot version of these materials.

Methods

Participants in this study included one 7th grade class, consisting of 23 students and their science teacher from an urban, magnet school in a Midwestern city. To assess students' conceptions of how science functions and scientists carry out their work, each student completed the VNOS-SI written questionnaire (Schwartz, Lederman, & Crawford, 2004) before and after the curriculum enactment. The VNOS-SI consisted of eight open-ended questions about how scientists carry out scientific investigations (Appendix 1). Some of the questions on the VNOS-SI also addressed ideas about the nature of science such as tentativeness, subjectivity, and experiment. Eight students from the class were randomly selected as a focus group to observe and follow during the enactment. The same eight students participated in follow-up interviews to the VNOS-SI to validate their written responses. Throughout the study, we visually and audibly recorded class activity. Other data sources collected from the study included classroom videotapes, field notes, and student artifacts such as the KWLS class poster, student poster presentations with evidence-based scientific explanations, and student worksheets.

Results

The purpose of this study was to (1) design reflective discussions about nature of science into project-based inquiry materials (2) observe how teachers enact these curriculum materials in the classroom, particularly with grounding reflective discussions about nature of science in the investigation (3) assess students' understanding about scientific inquiry and nature of science before and after participating in explicit, reflective discussions about nature of science and (4) evaluate whether students used these understandings about nature of science to influence the practice of developing evidence-based explanations.

Learning About Nature of Science

The VNOS-SI consisted of eight open-ended questions and we related each question to a particular scientific inquiry or nature of science core idea. The following ideas were represented on the VNOS-SI questionnaire: (1) scientific work (2) scientific decisions (3) experiment (4) scientific observations (5) scientific method (6) subjectivity in science (7) data and evidence (8) and scientific explanation. We assessed whether students learned about nature of science by comparing their pre conceptions to their post conceptions after they participated in explicit, reflective discussions about nature of science. We looked for a level of change between pre and post conceptions and divided this "change" into three categories (Schwartz, et al., 2004). A "no change" category was specified if students maintained the same exact views of nature of science before and after the enactment. An "enhanced change" category was given if students had become more articulate in describing the meaning of their conceptions and using the language of nature of science to explain these ideas. An example of an enhanced change follows below in which the student responded to a question about subjectivity. We used this coding approach because we wanted to see if there were variations or degrees in student conceptions about nature of science.

> Question: If several scientists, working independently, ask the *same question* (for example, they all want to find out what Illinois looked like 10,000 years ago), will they necessarily come to the *same conclusions*? Explain why or why not.
>
> Student pretest: Not necessarily because they might have mistakes or they might be doing different experiments
>
> Student posttest: Probably not because they might have an error or they might have interpreted the data differently

A "major change" category was identified if students' post conceptions completely changed or contradicted their initial pre conception of a particular idea. Below is an example of a major change regarding experiment and scientific observation.

> Question: A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed that birds who eat similar types of food, tended to have similar shaped beaks. For example, birds who eat hard shelled nuts have short, strong beaks, and birds who eat insects from tide pools have long, slim beaks. He concluded that there is a relationship between beak shape and the type of food birds eat.
> a. Do you consider this person's investigation to be scientific? Please explain why or why not.
> b. Do you consider this person's investigation to be an experiment? Please explain why or why not.
>
> Student pretest: I think it is scientific because he is doing an experiment. It is an experiment because he is testing something.
>
> Student posttest: It is scientific because he is observing and he is making inferences. It is not an experiment because he is not testing anything. He is only observing.

As shown in Table 1, over a 6-week period, overall most students' conceptions remained unchanged. However, there were occasions of enhanced and major changes in their conceptions of nature of science. For instance, understandings about scientific work, scientific observations, and scientific explanations exhibited shifts from their initial conceptions. In the following, we consider each of the nature of science characteristics in turn and indicate whether there were any conceptual changes after participating in an inquiry unit using explicit, reflective discussions.

Table 1
VNOS-SI Student Conceptions

Scientific inquiry/Nature of Science Concepts	No Change	Enhanced Change	Major Change
Scientific Work	52%	48%	0%
Scientific Decisions	87%	13%	0%
Experiment	83%	17%	0%
Scientific Observation	70%	8%	22%
Scientific Method	87%	4%	9%
Subjectivity in Science	72%	28%	0%
Data and Evidence	73%	27%	0%
Scientific Explanations	5%	75%	0%

<u>Scientific Work</u>

Almost half of the students (48%) exhibited enhanced conceptual changes regarding how scientists go about their work and what type of activities scientists do to learn about the natural world. An example of an enhanced change to this question is below.

> Student pretest: They test plants. They do experiments. They did recent studies and try to improve their studies.
>
> Student posttest: They do experiments to test out problems in the world. Some scientists use models to help them learn about the natural world. Scientists could also learn about the natural world by observing.

A common theme throughout the sea lamprey investigation was to make a scientifically convincing explanation. We designed in the first lesson and throughout the rest of the investigation opportunities for the teacher to address this idea. A brainstorming session in the first lesson tapped into some of the students' early conceptions about what it means to do something scientific. Students' answers included: factual, testable, logical, science information, conclusion, data, experiments, finding something out, discovering, procedure, putting things into categories, internet, identification, and classifications.

<u>Scientific Decisions</u>

Only 13% of the students indicated a shift in change about how scientists decide what and how to investigate. This idea about scientific inquiry was never explicitly discussed in the classroom. Typical student responses to this question included: "they decide by what they have a question about," "scientists look for what is important to the environment," they see what is going on in the world," and "they think about how they should go about their work and "map out what they should do to at least get an idea of how they are going to proceed."

Experiments and Scientific Observations

According to the students' responses on the VNOS-SI questionnaire, few students (17%) changed their understanding about the definition of experiment. However, there were both major (22%) and enhanced changes (8%) in conceptions when students were asked to determine whether an investigation was an experiment or observation. The VNOS-SI question for this topic pertained to a person interested in birds and who had looked at hundreds of different types of birds who eat different types of food. He noticed that birds who eat similar types of food, tended to have similar shaped beaks. Below is an example of a major conceptual change found on the questionnaire.

> Question: Do you consider this person's investigation to be an experiment? Please explain why or why not.
>
> Student Pretest: Yes, he is finding the similar features of birds
>
> Student Posttest: I don't consider this an experiment because it is more of an observation because he just looked at the birds.

Below is an example discussion where the teacher situated reflective discussions about observation and experiment in the investigation. The teacher used the recommended reflective question found in the text materials to facilitate the discussion. The students had just finished dissecting the sea lamprey and were revisiting the KWLS chart to record what they had learned about its structure and function.

> T: Let's talk about **observations** for a second. How would you define observation, I do not want you define it formally. What is an observation? What's an observation? Mary?
> Mary: It's like when you see something and you record it or write it down.
> Bruce: To study something visually,
> T: So there are two things you can say the word **observation** can mean simply a statement of something you have seen or that you know. When you talk about observing it might or might not be something that you saw. But it definitely **involves your senses**. You can talk about something that you heard, or if you eat something you observed that the peanut butter tasted rancid. So you can make an observation which is a statement about your senses have perceived. But in the science sense an observation is what Mary said and many of you echoed her and that is noticing something and writing it down. So that's a scientific observation. **What is an experiment**? LeeAnn?
> LeeAnn: Something you test
> T: **So how is an experiment different than an observation**? **When we were dissecting were we doing an experiment?**
> Ss: [Mixed responses] Yes and no…
> T: What were we testing?
> Ss: [Mixed responses] we were testing, no observing, no testing.
> Emma: We were observing.
> T: We have kind of a conflict of opinion here. When we were doing the dissection, were we testing or observing something?
> Mary: I think we were observing because…
> T: Yeah, we were observing. We were looking at something, smelling something, writing it down and talking about it. We were poking at it and comparing, so we were making observations. And we were doing it in a scientific way, right?
> Ss: Yes
> T: So, when we were talking about an experiment that is like the one that you had as an example awhile back when we talked about some trout from Lake Michigan and transport them in a container to Alaska and put into a lake. And then we would see a year or two later what would happen to the fish. **So that would be an experiment**. Because you **would compare them with the ones in Lake Michigan**, but

when you're doing a dissection and looking at the structures in the sea lamprey and perch that is not an experiment, but it is very scientific.

Scientific Method

There was a slight change, major (9%) and enhanced (4%), in understanding that scientists do not follow one single step-by-step scientific method. We had designed in the first lesson a reflective discussion about this core idea of scientific inquiry. However, the teacher skipped this discussion and never revisited the idea. The teacher did talk about observations, experiments, modeling, and making inferences as different types of methods in science. It is suggested that the slight shift in conceptions regarding the scientific method occurred because the students were thinking of various types of methods, not a single step-by-step method of doing science. It is also important to point out that many typical student responses that did not change mentioned ideas of a single scientific method. Typical student responses included: "purpose/problem, hypothesis, materials, experiment, data, conclusions," and "computer observation we tested and observed, sea lamprey dissection we observed."

Subjectivity in Science

According to the VNOS-SI results, 28% of students exhibited enhanced conceptual changes regarding subjectivity in science. The following is the question and typical student response for the idea of subjectivity.

Question: If several scientists, working independently, ask the *same question* (for example, they all want to find out what Illinois looked like 10,000 years ago), will they necessarily come to the *same conclusions*? Explain why or why not.

Student Pretest: Yes, because information is passed down
Student Posttest: No because people think differently

Below is an example discussion where the teacher situated reflective discussions about evidence and subjectivity in a NetLogo computer lesson about populations and ecosystems. The teacher used the recommended reflective question found in the text materials to facilitate the discussion.

T: So what was the invader eating?
Martin: It is eating grass
T: So this is a **piece of evidence**. The first evidence anyone has actually introduced. When Martin put in just invader and grass it lived for a long time. So that means the invader could eat grass, which means it was eating grass. So that's a **piece of evidence**. Ken what were you going to say?
Ken: I think it is eating rabbits and grass because the foxes wouldn't have anything to eat so then they would die out.
T: So the foxes wouldn't have anything to eat and they would die out cause the foxes could only eat rabbits? Alright, so that's **another piece of evidence**. Sam?
Sam: I think that the invader was competing with the foxes and the rabbits, because they ate grass and I noticed when the rabbits were dying so fast from the foxes, they were dying twice as fast when the invader came.
T: So the rabbits were dying out twice as fast which made you think what?
Sam: That the invader ate the rabbits too.
T: Okay **that is one interpretation**. Fred?
Fred: I say that it eats the rabbits and the foxes because the invader eats the rabbits, the grass dies out, and the foxes have nothing to eat. But then the foxes and invader go back at it and the grass grows back and then the rabbits come back then it does it all over ago, like a cycle.

LeeAnn: They were eating grass and competing with rabbits.
T: Okay, they were eating grass and competing with rabbits.
T: Okay, so lets go to a different question. **Could it be that all of you using the same data could have different interpretations?**
Ss: yeah.
T: Could it be? Sure. Yeah. **You could have different interpretations. Do you think that scientists all looking at the same data are going to have the same interpretation?**
Ss: No, nope
T: No they don't. Absolutely. There are many arguments in science about many things and everybody has data that they are using to support their argument and sometimes they are using the same data, but they just interpret it differently.

Data and Evidence

Only 27% of the students indicated a shift in change about the difference between data and evidence. The meaning of data was not designed into the lesson for the teacher to explicitly talk about. However, the concept of evidence was designed and explicitly taught throughout the investigation. A slight enhanced conceptual change may indicate that students attempted to differentiate between data and evidence, based on what they knew about evidence. Typical student responses to the question, are "data" the same or different from "evidence"?: "different because data in a way leads up to the evidence", "yes because their both what you found out," and "it's the same because when you compare evidence its comparing the results which is also data."

Scientific Explanation

According to the results from the VNOS-SI, most students (75%) showed enhanced conceptions of scientific explanations. An instructional framework of developing scientific explanations was taught throughout the sea lamprey investigation. Students learned how to develop a scientific explanation by putting together claim, evidence, and reasoning. To assess students' conceptions of explanations, we added an additional contextual question to the VNOS-SI to examine what students' thought represented a convincing scientific explanation. The question follows below with examples of student responses.

Question: A scientist is presenting their claim that killer whales attack sperm whales. How do they make a convincing scientific explanation to support this claim?

Student A Pretest: They need to put why they think that.
Student A Posttest: They can give really good evidence to persuade people that he is right. He can give lots of numbers as data.

Student B Pretest: They should show proof and also do a scientific experiment
Student B Posttest: By providing reasonable evidence and reasoning

Student C Pretest: I would have to go back to my data and research to support my scientific explanation
Student C Posttest: First you state your idea, what you think (killer whales attack) then you give your data to give reasoning why you think that. Then give a reasoning that links your claim and evidence together

In summary, we saw that explicit, reflective discussions about nature of science, can affect students' learning about nature of science. We showed both enhanced and major changes of certain aspects of nature of science. We were not surprised that certain nature of science understandings increased more than others because it depended on the explicitness and repetitive nature of the instruction about those ideas.

Utility of Nature of Science

The second part of this study was to evaluate whether students used their epistemologies of science to influence the practice of developing evidence-based explanations. Throughout the investigation the class recorded how they scientifically collected their evidence on the KWLS. The students were told that they would use this information to help them develop a scientifically convincing solution for members of the community. Table 2 is a representation of the KWLS that the class composed for this problem. Most of the students mentioned that they collected evidence from video, maps, pictures, and articles.

Table 2
KWLS for Sea Lamprey Investigation

What do we know about what animals need to survive?	What do we want to find out about how sea lampreys survive?	What do we know so far about lampreys?	How is this scientific?
Water	Kind of food	(1) Eat fish	(1) Evidence from film
Food	Fresh or salt water	(2) Live in salt and freshwater	(2) Map/video/analysis
Habitat/shelter	Who are the enemies?	(3) 2 life stages, blind larvae & filter feeders	(3) From film
Reproduce	What habitat?	(4) Suckers and teeth (mouth)	(4) Picture, video, article, interpretation
Air (O_2)	How do they reproduce?	(5) Enemies don't attack them (lake trout)	(5) Down's article,
Space		(6) Habitat-rocky bottom	(6) Video
		(7) Lay eggs (lots) mate	(7) Showed and said on video dissection, observation
		Filter water	Discussion-reading other research observations, data collection, inference, models
		Lots of eggs/mating No stomach/parasite	

Although the design of the utility was integrated within the materials, classroom observations showed that students were not very interested in revisiting the scientifically collecting column each time. In fact, the challenge of motivating students to contribute to the discussion was very evident in the classroom. Students did not seem convinced that it was important for them to understand the different aspects of scientific inquiry and nature of science to help them solve their problem. For instance, when the teacher asked questions about science content, the students raised their hands and contributed to the discussion. On the other hand, when the teacher asked about collecting information by observation or inference, students did not exhibit the same enthusiasm or participation as they did with science content. This finding suggests the need to revise the curriculum to better support the utility of nature of science. Students need to see the relevance to why they need to know about nature of science. Ideally, we would want students to understand that by knowing what makes good evidence, they can use this understanding to develop and evaluate scientific explanations.

Another observation was that the teacher did not "sell" the utility of the nature of science to the students. The teacher did reflect about nature of science core ideas, but usually at a superficial level with the students. She presented the material of nature of science only as an end in itself and not as a means to learn about something else. There were many spontaneous moments when the teacher could have reflected on a particular aspect of nature of science, but missed the opportunity because of other curriculum/instructional matters. This project-based unit was challenging, and there was a tension between getting through the milestones and reaching the various content learning objectives on the one hand, and having the luxury of time for reflective discussions.

During part one of the unit's last lesson, the students were required to develop a scientific explanation that was both scientific and convincing. It was necessary for them to use what they knew about how science functions to construct these explanations. However, the teacher skipped this essential part of developing their explanations. The students did develop a form of an explanation for their solution. The teacher asked the students to write out their "ideas" for solving the sea lamprey problem, not in an explanation format. The students worked in small groups and presented their "ideas", then the teacher asked them during their presentation if they collected their evidence by observation, inference, and background information. The students did respond to the teacher by giving examples of different ways that they gathered the information, but failed to articulate any understandings about these conceptions. They simply repeated the terminology and agreed with the teacher that they used inferences, etc to make their conclusions. Below are two examples of sea lamprey solution presentations. Both examples show how the students' superficially mentioned the ideas of nature of science and the teacher did not ask more probing questions about these understandings and how those ideas can support the development of the students' proposals.

Group 1:
T: What is your system for removing the sea lamprey?
Emma: Our solution is to destroy the liver of the sea lamprey, thus destroying the population in the great lakes
T: Okay, how are you going to destroy the liver and why do you think that will work?
Emma: Destroying or damaging the liver will work because the liver unlike the human liver will provide the necessary functions to the survival of the organism. We used **inferences and**..
Fred: **analysis**
Emma: **data, data analysis**
T: Okay, so what do you have to say after that?
Carl: By destroying the liver which is very important to the sea lamprey's digestion, reproduction and movement, we will be affecting all three of these negatively.

Group 2:
T: What is your removal plan?
Kathy: Find a predator for the sea lamprey.
T: Okay, find a predator for the sea lamprey. Okay. What else do you have to say?
Kathy: Um, What we would do is investigate ways with the predator and this plan will work because it will stop the sea lampreys from reproducing more or eventually reduce or remove the population of the sea lamprey.

T: Okay, so back to your plan and looking at these words on the board. [students are looking at the "S" column from the KWLS]. **What kind of process did you go through to come up with your plan, in terms of scientific processes.**
Kathy: **In our reading we learned that sea lampreys didn't have any predators so uh we collected data and the uh video the letter. Inferences.**
T: Okay, Laura did you want to add anything? [Laura shakes her head no]
T: Okay, great, you have some good ideas

Conclusions

The outcomes of this study suggest that integrating explicit, reflective discussions about nature of science into an inquiry curriculum shows some success in shifting students' conceptions of nature of science. Our findings are similar to other studies regarding an explicit approach to teaching about nature of science (Abd-El-Khalick & Lederman, 2000; Bartholomew et al., 2004; Schwartz & Lederman, 2000). However, more support is needed for teachers to increase their epistemologies of science as well as guide them toward using more spontaneous reflective discussions about these concepts. After participating in reflective discussions, students increased conceptions of scientific work, subjectivity in science, evidence, and scientific explanations. Thus, by designing reflective discussions about nature of science into a curriculum and grounding these discussions in an investigation, students were able to learn about nature of science.

In the design two approach, we found that we needed to explore a more evaluate measure of using the nature of science. We did not see the teacher facilitate the utility of these understandings at a meaningful level, nor did we see the students' value learning about nature of science in the context of their investigation. The implementation of this design work was very difficult considering what we know about the challenges of inquiry for learners. Having students consider nature of science issues in creating their work products requires thinking about these as real products. The challenge comes from using an audience and thinking about what makes a genuine persuasive scientific product rather than creating things to show the teacher what you have learned.

Our next step is to use a two-pronged approach to support constructing and defending scientific explanations by developing an instructional framework and articulating the role and utility of epistemological understandings. Findings from Kuhn and Reiser (2005) suggest that after using an instructional framework for developing scientific explanations, students were able to communicate or communicate and defend their understandings. They have now targeted the need to focus on the use of audience and highlight the persuasive goal of argumentation. Alternatively, our nature of science findings suggest that we need to further explore the use of nature of science and its influence on evaluating explanations. Both studies have now merged together to form a phase two design approach to support the practice of evidence-based explanations. This design approach is divided into two strategies: (1) motivating and supporting explanation evaluation and (2) reflecting to guide inquiry.

The purpose of strategy one is to use audience as a context for students to debate and evaluate their scientific explanations and use nature of science concepts to guide development and evaluation of explanations. Students will use specific nature of science criteria to evaluate each component, (i.e. claim, evidence, and reasoning) while developing and assessing their scientific explanations. A shortened version of the nature of science rubric is shown below. This is a sample of the ideas that we want students to know regarding each of these components. In the classroom, we are designing the rubric to be student driven and constructed.

1. Claim. What is the answer to your question?
- Is your claim specific enough to answer the question?
- What makes your claim scientific?
- How can your claim be changed or modified?
- Is your claim different than others, how can you convince others that your claim is well supported?

II. Evidence. What scientific evidence did you use to make this claim?
- Is this evidence based on observations, experiments, or historical data?
- Is your evidence specific enough to support the claim?
- Did you select relevant evidence from your pool of data?
- What patterns did you find from your selected data?
- Does your evidence support your claim? Is it valid?
- Can someone get the same evidence if they repeat the observation or experiment?

III. Reasoning. What scientific ideas make your claim believable?
- Does the reasoning gives a scientific principle connecting the claim and evidence? (a scientific principle is predictive and general)
- Does the reasoning connect the claim and evidence?

Duschl (2000) suggests that students should be able to evaluate the transformation of data to evidence, evidence to patterns/models, and patterns/models to theories and explanations. We hope that students will explicitly learn about nature of science through the use of this nature of science rubric and evaluation of student explanations. The purpose of the second strategy is to use nature of science in reflective discussions to motivate construction and revisions of scientific explanations. Below is a sample of types of questions that may be asked concerning these ideas.

Subjectivity Discussion: Do you have the same claims? How is it possible to have different claims if you have the same evidence? If your claim is different than others, how can you convince others that your claim is well supported?

Tentative Discussion: Have your explanations changed through the investigation? Can your new understandings be used to improve your explanation?

Creativity: Were you creative in putting together your evidence to support your claim? What other ideas do you have that would connect to the evidence? Could you look at your data in a different way?

Strategy II involves using nature of science core ideas about subjectivity, creativity, and tentativeness to help motivate the evaluation process of strategy one. As a result of merging these two studies and using the phase two design approach, we hope to increase students' strategic and epistemological understanding of evidence-based explanations.

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Appendix I

1. What types of activities do scientists do to learn about the natural world? Be specific about how they go about their work.

2. How do scientists decide what and how to investigate? Describe all the factors you think influence the work of scientists. Be as specific as possible.

3. (a) Write a definition of a scientific experiment?
   (b) Give an example from something you have done or heard about in science that illustrates your definition of a scientific experiment.
   (c) Explain why you consider your example to be a scientific experiment.

4. A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed that birds who eat similar types of food, tended to have similar shaped beaks. For example, birds who eat hard shelled nuts have short, strong beaks, and birds who eat insects from tide pools have long, slim beaks. He concluded that there is a relationship between beak shape and the type of food birds eat.
   (a) Do you consider this person's investigation to be scientific? Please explain why or why not.
   (b) Do you consider this person's investigation to be an experiment? Please explain why or why not.

5. Some people have claimed that all scientific investigations must follow the same general set of steps or method to be considered science. Others have claimed there are different general methods that scientific investigations can follow.
   (a) What do you think? Is there one scientific method or set of steps that all investigations must follow to be considered science? Circle one answer:
   Yes, there is one scientific method (set of steps) to science.
   No, there is more than one scientific method to science.
   If you answered "yes," go to (b) below.
   If you answered "no," go to (c) below.

   (b) If you think there is one scientific method, what are the steps of this method?

   (c) If you think that scientific investigations can follow more than one general method, describe two investigations that follow different methods. Explain how the methods differ and how they can still be considered scientific.

6. (a) If several scientists, working independently, ask the *same question* (for example, they all want to find out what Illinois looked like 10,000 years ago), will they necessarily come to the *same conclusions*? Explain why or why not.
   (b) If several scientists, working independently, ask the *same question* and follow the *same procedures* to collect data, will they necessarily come to the *same conclusions*? Explain why or why not.

7. (a) What does the word "data" mean in science?
   (b) Is "data" the same or different from "evidence" ? Explain.

8. A scientist is presenting their claim that killer whales attack sperm whales. How do they make a convincing scientific explanation to support this claim?