

# **A Functional Approach to Nature of Science: Using Epistemological Understandings to Construct and Evaluate Explanations**

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## **Abstract**

Understanding nature of science has become a primary focus for preparing students to make informed decisions in the real world (AAAS, 1993, NRC, 1996). We want students to be able to reason about evidence and evaluate knowledge claims (Hogan, 2000; Sandoval, 2005). A challenge for students is finding the relevancy of nature of science and using these ideas to engage in inquiry practices. We see a need to develop a *functional* approach toward nature of science where students use their epistemological understandings to guide their inquiry investigations. In this paper, we discuss two critical design strategies that support students' use of epistemologies in the planning and management of their investigations. This study takes place in a 7th grade project-based ecology unit. We show examples of classroom discourse where students learned to use epistemologies of science to construct and evaluate scientific explanations. We found that using nature of science criteria was supportive for helping students assess the quality of explanations and creating a need to argue about these ideas supported their use in making decisions. We point out the student challenges and where students adopted to use these ideas.

## **Introduction**

Understanding nature of science has become a primary focus for preparing students to make informed decisions in the real world (AAAS, 1993, NRC, 1996). We want students to be able to reason about evidence and evaluate knowledge claims, which requires an understanding of nature of science and inquiry practices (Hogan, 2000; Sandoval, 2005). 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. Empirical research has suggested that students' learn about nature of science through an explicit reflective approach in the classroom (Abd-El-Khalick & Lederman, 2000; Bartholomew, Osborne, & Ratcliffe, 2004; Schwartz & Lederman, 2002). We also see the value in using an explicit approach for teaching about nature of science, but question whether learning nature of science as an end in itself will help students see relevancy and use nature of science understandings to make scientific decisions.

For this reason, we see a need to develop an *instrumental* approach toward nature of science where students use their epistemological understandings to guide their inquiry investigations (Kenyon & Reiser, 2005; Sandoval, 2005). In an earlier study (Kenyon & Reiser, 2005), we attempted to integrate reflective discussions about nature of science into a project based science curriculum. Our strategy was to situate explicit reflective discussions about nature of science within ongoing meaningful investigations and select nature of science core ideas based on their relevance to the investigation. We attempted to contextualize nature of science understandings within the context of the lesson rather than add drop-in activities into lessons about these

understandings. Our design goal was to make these ideas concrete and connect these understandings to the inquiry experience. Our research goal was to determine whether students saw relevance with these epistemological ideas and examine if they used them to guide their investigations.

We found that our design strategies of situating nature of science discussions within the ongoing investigative unit were successful in situating nature of science discussions within the ongoing investigative unit. However, most student discussions were superficial and appeared to be mostly a teacher-guided process with little support for student decision-making. Most importantly, we found that discussions did not support students' need to use their nature of science understandings and students did not find learning about nature of science ideas necessary or relevant to their investigation. These findings motivated new design strategies that focused on creating opportunities that convince students of the utility of epistemological understandings in their decision-making process.

Duschl (2000) suggests that nature of science is made explicit when students examine, discuss, and argue about good evidence and decide between alternative explanations. In this paper, we propose a *functional approach* toward nature of science, consisting of two critical design aspects to guide use of epistemologies in the practice of scientific explanation and argumentation. We describe this functional approach and examine if students use their epistemological ideas of science to help with the practices.

### **Design Approach**

In the past decade, there has been a noticeable shift from looking at epistemological views of science in isolation to how students engage in the practices of explanation and argumentation surrounding these epistemologies (Hogan, 2000; Osborne, Erduran, & Simon, 2004). Having students engage in inquiry practices—developing explanations, arguing about the quality of evidence, and defending explanations all require epistemological understandings to support epistemic decisions. Hogan (2000) supports this notion that epistemology resides in the practice of inquiry. Recently, Sandoval (2005) made an argument for further study of student *practical epistemologies* in which students apply their own scientific knowledge building through inquiry and school science. Sandoval suggests a research agenda in which we document students' epistemic decisions while constructing and evaluating scientific work products. In our design approach, we build on this idea of using epistemological understandings and develop two critical strategies to convince students to use epistemological understandings to construct and critically evaluate scientific explanations.

#### *Creating a Need*

Our first design approach was to use argumentation (in small and whole class settings) to *create a need* for students to use epistemologies of science throughout their interactions with one another – argumentation made the epistemologies of science necessary. By using argumentation as a context, students were able to use their epistemological understandings to construct and critically evaluate one another's scientific explanations. More specifically, it was through activity structures (in small and whole class settings) that they engaged in the practices and applied scientific criteria to construct, evaluate, defend, and revise explanations. These scientific criteria particularly focused on the quality of the claim and evidence components of an

explanation and solve the problem of deciding what to use when making these decisions. Students participated in both small group and whole class settings as they peer critiqued their explanations (Kuhn, Kenyon & Reiser, 2006).

Having students argue about the quality of claims and evidence may not be supported in many traditional science classrooms (Driver, Newton, & Osborne, 2000). Thus, the development of argumentative activity structures both in small and whole class settings should support the need for student discourse about epistemological ideas relative to the quality of the evidence. For example, in a small group setting we use an argument jigsaw activity where students develop potential explanations in pairs, but need to draw from these in larger working groups to present one explanation drawn from their work — this creates a need to apply scientific criteria in evaluating and revising their explanations. Specifically, the student pairs converge on the most convincing explanation (Kuhn & Reiser, 2005). At this point, the now converged group of students defends their explanation in a whole class debate. Students use audience roles as presenters, questioners, and observers to defend and evaluate explanations constructed by student groups (Herrenkohl & Guerra, 1998; Kuhn et al., 2006). Students' epistemological understandings become evident as they structure their questions around their understandings and construct and evaluate the quality of evidence of their peers' explanations.

#### *Providing Scaffolds*

In our second design approach, *providing scaffolds* are used to support students' understandings of the components of an evidence-based explanation. The instructional explanation framework of the project based science units consists of three components, claim, evidence, and reasoning (McNeill & Krajcik, in press) and is based on Toulmin's (1953) argumentation model. In order to support students' use of epistemologies, we took this design approach a step further by enhancing this instructional framework. In the context of the investigative units, students are asked to develop a set of epistemological criteria to construct and evaluate their explanations that they use to help guide their arguments and epistemic decisions (see Table 1). Thus, the criteria support students' engaging in scientific argumentation by providing them with tools on which to base their evaluations of one another's explanations. As a result of this extension, students go beyond checking that they have included evidence for claims, and evaluate whether the explanation incorporates replicable, reliable, and relevant scientific evidence.

Table 1. Enhancing the explanation framework using explicit nature of science aspects to assess the quality of claim, evidence, and reasoning.

	Explanation Framework*	Nature of Science Enhancement Supports
Claim	What or why something happened.	Is your claim specific enough to answer the question? What makes your claim scientific?
Evidence	Information or data that supports the claim.	Is your evidence specific? Does the evidence reflect data or opinion? Is there enough evidence to support the entire explanation and to connect to the big ideas?
Reasoning	A justification showing why the data supports the claim.	Is your explanation believable because of the big ideas you used? Are all the pieces of the explanation connected?

\* (Kuhn & Reiser, 2005; McNeill & Krajcik, in press)

Developing and discussing scientific explanations is challenging for students (Hogan & Corey, 2001; Kuhn & Reiser, 2005; Sandoval & Reiser, 2004). By having students evaluate explanations and communicate their epistemological ideas adds another level of complexity. This need to provide scaffolds is necessary to guide student epistemic decisions and support their peer discussions about their explanations. These supports give students the leverage they need to articulate their understandings and argue about what ‘makes good scientific evidence’ rather than them simply thinking ‘I need evidence’. As part of this design approach, the list of epistemological criteria that students developed within the investigation were refined and turned into a scoring rubric that students used to assess the quality of their explanations during peer interactions. In Table 2, we show an example of a scoring rubric for assessing evidence. The table also illustrates the distinction made between the explanation framework and nature of science enhancements that support the evaluation of explanations.

Table 2. Scoring rubric using epistemological criteria to assess the quality of evidence.

Explanation Framework	Score 1-5
1. Our claim ____	1. The evidence is specific _____
2. Evidence to support our claim ____	2. The evidence came from data and is not opinion _____
	3. There is enough evidence _____

## **Curriculum Context**

This design took place in the context of a 7th grade ecology unit that situates student learning in project-based inquiry investigations (Bruozas, Finn, Tzou, Hug, Kuhn, & Reiser, 2004). The unit is designed for eight-weeks and divided into two parts. In the first part, students learned about a biological invasion in the Great Lakes and designed solutions to stop sea lampreys from destroying an aquatic ecosystem. Their solutions consisted of a scientific explanation where students defended claims with convincing evidence. In part two, students learned about an ecological crisis in the Galapagos Islands where the majority of ground finches have suddenly died during the dry season of 1977. While investigating the mystery about why most finches died but some survived, students use *Galapagos Finches* software and work with a dataset, find mathematical patterns in species survival, and build a scientific explanation that accounts for the differential survival (Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001).

Over the course of these investigations we integrated argument jigsaws and whole class debates to provide students with opportunities to use the epistemological criteria to guide their arguments about their differing solutions to these investigative problems. These investigations provide an opportunity for students to use criteria about claim, evidence and reasoning while arguing about which solutions are most convincing. The existing unit supported the practice of constructing explanation; we extended the explanation supports to foster sophisticated epistemologies of science, by having students argue about their explanations thereby motivating the relevancy of these epistemological understandings.

## **Method**

We collected data from a 7th grade science class in which the cooperating teacher recruited for the study had pilot tested project-based curriculum for our research teams in prior years and had some familiarity with the approach of project-based science. Participants included 64 students divided among three class periods from an urban Midwestern school. The design strategies were developed through weekly design meetings with another researcher and the teacher participating in the study. Researchers acted as participant observers in the third period class, observing and occasionally interacting with the teacher and students throughout the lessons. Eight students from this class were randomly selected as a focus group and were audiotaped and videotaped during the enactment.

## **Learning to Use Epistemologies**

### *Developing a Rubric*

Within the unit, students' participate in benchmark lessons where they learn and apply their science content understandings to construct explanations that help them solve scientific problems. We needed to make students' epistemological ideas of science concrete and relevant to the tasks of the investigation. Our first step was for students to develop a list of epistemological criteria that they could use in the investigation to evaluate what makes a good scientific explanation. From our earlier work (Kenyon & Reiser, 2005), we knew it was important to situate this discussion in a lesson where students collected evidence and argued about different explanations to make it more meaningful to the task.

In part one of the unit, students used a computer model called NetLogo to examine the individual and population levels of an ecosystem and figure out which population of organisms compete for resources. An unknown invader was added to the ecosystem in which it indirectly affected the survival of an organism in the food web. Students tried to solve the problem by using data gathered from the model to figure out the nature of the unknown invader. The teacher used this investigation opportunity to facilitate a whole class discussion about scientific explanation and asked students to think about questions that they could ask of their peers as they evaluated the quality of claim, evidence and reasoning. In the following excerpt the students have just completed talking about their claims for what animal they think represents the unknown invader. Many students thought the invader was a fox, coyote, snake or cow that was either eating or competing with the rabbit in the ecosystem. We see how the teacher was challenged with getting students to explicitly discuss epistemological ideas about explanations. Instead, students are thinking more concretely and specific to the science content ideas in answering the questions.

- Teacher: So, what kinds of questions would you want to ask when the group gets up to present their information, what kinds of questions can we ask them to sort out if they really have the right answer or not? Say the coyote, what kinds of questions would you want to ask them, if you weren't on their team and you wanted to know why they thought that was a good idea?
- John: Do you really think a fox could eat a coyote?
- Michael: No, a coyote, a fox is this big and a coyote is this big.
- Teacher: Let me move back from that. Let's not get specific about do you think that a fox could eat a coyote and lets be real general in terms of the questions that you could ask anybody about any of those things.

In the next clip, we see that this challenge prompted the teacher to give examples to guide student thinking about epistemological ideas as they developed the list together. Next, we see the teacher trying to encourage students to think about asking questions about the quality of evidence.

- Teacher: So I am going to give you an example of the kind of questions you could ask. Do you have an example?
- Sarah: What evidence that you have that shows that.
- Teacher: Alright, yeah.
- Sarah: What evidence do you have?
- Teacher: What do you mean by evidence?
- Sarah: Like a graph, if the grass goes down, what does that tell you?
- Teacher: So, in general what do we use as evidence? What is evidence the same as?
- Sarah: Proof.
- Teacher: Proof. It may or may not be proof, but I would say it could help prove.
- Toby: Information, data.
- Teacher: Okay, good what evidence do you have?
- Sarah: Where does the evidence come from? How do you know that?
- Teacher: Where does the evidence come from? Okay, where does the evidence come from is a slightly different question and that's a good one. So, where does the

evidence come from, is it opinion or where did it come from? Because for you to introduce it as evidence you have to know where it came from.

Throughout the rest of the discussion the teacher continued to support students' thinking of the ideas as the whole class developed their list of criteria to evaluate explanations. Once the criteria were complete, the teacher refined the list and posted it in the room to guide peer questioning during their presentations.

### *Learning to Use the Criteria*

Following the completion of the criteria, we looked at student discourse in the classroom to find out how they were using the criteria to construct and evaluate explanations. Each student pair was given a packet to guide their investigations. The packet included the scoring rubric (see Table 2) for pairs to evaluate one another in small and large group settings. During the first part of the unit the students used the criteria for the first time to evaluate explanations to stop a sea lamprey invasion in the Great Lakes. One of the interesting observations we found with the development of the criteria was that students started to use it to guide their construction as well as evaluation of their sea lamprey explanations. In the following example, we see Toby and Janelle in a small group setting discussing their draft proposal to stop the sea lamprey invasion. Janelle uses the scaffolds and explicitly points out to Toby that quantity and specificity are necessary for good evidence. She then backs up her understandings by suggesting her proposal to Toby, which includes specific evidence to support the draft idea about jamming the Wellen Canal to stop the sea lampreys.

- Toby:        Alright guys, let's work on the first draft of the proposal. First we have to dam the Wellen Canal, right?
- Janelle:     We have to jam it, we should make it very general because we have to add a lot of evidence to it, but still be specific.
- Toby:        We will say, by jamming the Wellen Canal the sea lamprey form the Atlantic Ocean can't get in.
- Janelle:     I would've said something like because the sea lamprey used the Wellen Canal as a route to get to the Great Lakes, blocking it will save more from coming in. Something like that.
- Toby:        Okay, that is good.

Once students had constructed their scientific proposals, the students then defended their explanations in a whole class debate. As mentioned earlier, the class was divided into audience roles to present, question or observe during the presentations. It was evident during these whole class debates that students were relying on the criteria scaffolds to support their questioning. In fact, many times students read a question directly off the list and posed it to the presenting group. Since this was the first time that students were evaluating peer explanations in a whole class setting, we observed that students needed these supports to guide thinking and learning about these epistemological ideas. In the next excerpt, we see Janelle's group defending their sea lamprey explanation. It is also important to notice that students are using the scaffolds and discussing these epistemological ideas at a definitional level. At this point of their learning to use the criteria, students are checking to make sure they have included claim, evidence or reasoning

(big ideas) in their explanations rather than evaluating the quality of these individual components.

Vanessa: What big ideas relate to your plan? You didn't say anything.

Toby: Yes, we did. It was part of the draft plan.

Janelle: We were not explaining the big ideas and evidence, we were giving an idea of our draft plan. So we could show other people.

Vanessa: Well, we need to hear the big ideas and evidence.

Toby: Evidence is our facts.

In the second part of the unit, students were given another investigative opportunity to practice using the rubric to guide development and evaluation of scientific explanations. In part two, students learned about an ecological crisis in the Galapagos Islands and developed an explanation for why most finches died, but some survived on the island. We found that as students practiced using these epistemological ideas they shifted from evaluating whether they had included evidence to instead examining the validity of evidence. In the following clip, Alicia presented an early draft of her finch explanation to the whole class. She did not explicitly discuss the criteria, but presented a careful description of the evidence that was specific and included data. Alicia's presentation of evidence reflects the epistemic criteria we were hoping to foster.

Alicia: Birds, name GF10. It said that once the plant started to decrease, her weight started to decrease and in time when the plant went to zero in the dry season.

Earlier in the unit, we noticed that students relied heavily on using the criteria scaffolds to guide their thinking about the practice of explanations. Interestingly, we noticed that during their second investigation, students began to adopt these epistemological criteria as their own and started using their own words to question one another about the quality of the explanation components. In this next example, when student pairs combined to form an argument jigsaw (Kuhn et al., 2006) to evaluate one another, some students explicitly pointed out criteria they used within their explanations. For example, in the following quote, Janelle presented her explanation to the other student pair and included her claim, evidence, and reasoning. She pointed out that she does have evidence and that she has an appropriate quantity of evidence.

Janelle: Our claim is the rainfall because of an indirect effect because of a drought. Evidence? Okay, we have a lot of evidence. First part of our evidence is rainfall measurement because during the wet season the measurements decreased over time until 1977 and the same thing with the dry season. It went from 200 to 162 to 25...

At this point, Janelle was interrupted by one of the students and tells them that she was not finished giving all of her explanation. She proceeded with giving more data and reasoning for her explanation. Like Alicia, Janelle has presented evidence that is specific and includes numbers, thereby reflecting the criteria for good evidence. There were other instances during evaluation where students clearly questioned the validity of the evidence based on specific criteria and pointed it out to the other students. In the next example, Janelle questions Toby's evidence and explicitly points out that he does not have good evidence because he is not using numerical data.

- Janelle: Our evidence is that we actually have measurements that says the rainfall decreased.
- Toby: Yeah.
- Janelle: But do you actually have numbers that says the rainfall increased, because you can't say it increased without numbers.

We noticed that during these small and whole class activity structures, students' epistemological understandings become evident as they structured their questions around their understandings and constructed and evaluated the quality of claim, evidence and reasoning. We observed a noticeable shift in students asking more specific questions about the quality of these components than before. Some of the questions from the questioners included, "ok, I believe your evidence because it is very specific, its persuasive, it also has numbers to back up your claims", "do you think there are any holes in your claims at all", and "I don't have a question, but ya'll need to have more evidence." Here we see students use a knowledge-in-use approach toward nature of science.

Interestingly, there were also moments when students made explicit their epistemological understandings to make sense of why everyone was looking at the same data but constructing different explanations. In the next example, Rhonda is confused about why so many of her classmates have different explanations. Another student, Michael thinks that maybe they are interpreting the data in different ways. The teacher answers her question, verifying Rhonda and Michaels' ideas to explain the different explanations. Here we see that students have noticed the role of subjectivity in the development of scientific knowledge; they are struggling with the idea that scientists interpret their data in order to solve problems.

- Rhonda: Some ideas say they might have killed the finches, somebody said that it was small or that it was big does that mean that maybe one of us is misinterpreting the graphs?
- Michael: It could be another way to look at it.
- Teacher: It is possible that somebody is misinterpreting the graphs, it is also possible that you can interpret the evidence in more than one way.

We know that talking about epistemologies of science is difficult for students. We found that using epistemological criteria scaffolds were supportive for helping students talk about epistemological ideas and assess the quality of explanations. Initially, students depended on teacher guidance while they used criteria to evaluate explanations. Eventually, students adopted the nature of science criteria as their own and started using their own words to question one another as they engaged in explanation and argumentation practices.

## Summary

A challenge for students is finding the relevancy of epistemologies of science and using these ideas to influence their decision-making in inquiry practices. While epistemological understanding is now of high interest in the field, empirical studies have typically focused on epistemological understanding as an end in itself (e.g., Abd-El-Khalick & Lederman, 2000). We have taken a more *instrumental* or *functional* approach in which we develop the epistemological

understandings that have direct bearing on students' planning and management of their investigations, as they are needed to help the inquiry (McNeill et al., 2006; Schwarz & White, 2005). Thus, we focused on how epistemological knowledge can help learners develop and argue for their scientific explanations, rather than on tasks that stress this knowledge as the learning goals in isolation.

We found that students were using the criteria to guide development of explanation, but we need to know more about why they make certain decisions at particular points in the evaluative process and how these epistemologies influence their explanations. For instance, why did the group choose their particular evidence or feel they did not have enough evidence. We see opportunities to design scaffolds that probe more deeply into students' epistemic decisions and support more thoughtful student questioning and evaluation that guide inquiry practices.

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