Using Students' Epistemologies of Science to Guide the Practice of Argumentation

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Abstract: Understanding students' epistemologies of science have become a primary focus for scientific literacy. We want students to be able to reason about evidence and evaluate knowledge claims. This requires an understanding about the epistemology of science and inquiry practices. In this paper, we propose a functional approach for using students' epistemologies to guide inquiry practices. In our design, students use a set of criteria that reflects epistemologies of science and guides construction and evaluation of explanations in their scientific investigations. We use argumentation to create a need for students to use these criteria to compare and evaluate one another's explanations. This study takes place in a 7th grade project-based ecology unit. Our analysis shows that these criteria guide students as they construct and evaluate explanations. During this process, students enhance their epistemologies of science and the quality of their scientific work products.

Understanding what students know about science has been a long-term goal for scientific literacy (AAAS, 1990; NRC, 1996). We want students to understand epistemology of science, and more importantly, how the scientific community engages in real life decision-making. Ultimately, we want students to be able to reason and evaluate knowledge claims about scientific issues. This requires an understanding of both epistemology of science and inquiry practices. Most empirical research has focused on epistemological understandings as an end in itself relying on explicit instructional approaches and assessments to determine student understandings (Abd-El-Khalick & Lederman, 2000; Bartholomew, Osborne, & Ratcliffe, 2004; Schwartz & Lederman, 2002). We see the value in using an explicit approach, but question whether students will see relevancy and use these understandings in authentic situations.

Duschl (2000) suggests that nature of science is made explicit when students examine, discuss, and argue about good evidence and decide between alternative explanations through their own investigations. 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. He makes the distinction between practical and formal epistemologies, the latter referring to students' expressed beliefs about professional science, and trying to make the bridge between the two understandings. Sandoval suggests a research agenda in which we document students' epistemic decisions while constructing and evaluating scientific work products. It is common to see nature of science and epistemology of science used interchangeably, both expressing the theory of scientific knowledge. For purposes of this paper and examining students' beliefs about scientific knowledge we will use epistemology of science.

In this study, we build on this idea of using epistemological understandings to influence the practice of inquiry. We use design strategies focused on creating opportunities that convince students of the utility of epistemological understandings in their decision-making process. Our first design strategy 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. In the second design strategy, students develop a set of epistemological criteria that they use to help guide their arguments and decision-making. 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. In this paper, we examine ways students learn to use the criteria to construct and evaluate explanations, how the uses of the criteria affect the quality of the work, and what epistemologies of science students learn through this process.

Curriculum Context

This study 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. 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. The design team used Toulmin's argumentation model (1953) to design an instructional framework to support scientific explanations. This framework consists of three components, claim, evidence, and reasoning (McNeill & Krajcik, in press). In order to enable students to use epistemologies to guide their inquiry, we took this design approach a step further by enhancing the instructional framework. In the first part of the unit, students are asked to develop a list of criteria specific to claim, evidence and reasoning during a whole class discussion (see Table 1). This list of explicit criteria was then refined and turned into a scoring rubric that students used to assess the quality of claim, evidence, and reasoning during construction and evaluation of explanations.

Table 1. Students' criteria list of claim, evidence, and reasoning.

Claim	Evidence	Reasoning
The claim answers the question.	The evidence is specific.	The big ideas connect to evidence.
The claim is specific.	The evidence came from data not opinion.	
The claim is based on facts.	There is enough evidence.	
	The evidence supports the claim.	

Although students participated in the entire eight-week unit, for this paper we present research findings from the second part of the unit. In part two, students learn 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 this investigation we designed activities to provide students with opportunities to use the epistemological criteria to guide their arguments about their differing solutions to the finch mystery. This investigation provides an opportunity for students to use criteria about claim, evidence and reasoning while arguing about which solutions to the finch mystery are most convincing.

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. It is important to point out that these students had completed our chemistry unit prior to the enactment of this biology unit. Students were therefore introduced to the scientific explanation framework used in both units. However, students did not use a set of criteria to construct or evaluate their explanations within an argumentation context. Our study focuses on this extension: in what ways did students use the criteria to guide the practices.

Participants included 64 students divided among three class periods from an urban Midwestern school. The design strategies were developed through weekly design meetings with the second author 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 to observe and follow during the enactment. We collected daily videotapes and pre/post interviews from the third period and written artifacts, pre/post epistemological questionnaires from all periods.

We used Conley et al. (2004) epistemological questionnaire to examine students' epistemological beliefs before and after the enactment of the unit. This questionnaire was based upon earlier work by Elder (2002) and divided into four epistemological belief dimensions: knowledge form external authorities (source), science has one right answer (certainty), science as an evolving and changing discipline (development) and how individuals support and justify knowledge (justification). The questionnaire was composed of 26-items and rated on a 5-point Likert scale (1=strongly disagree; 5= strongly agree). We also included a second written part to the questionnaire to examine how the epistemological criteria with which they had practiced throughout the unit affected their evaluations of scientific explanations. In this second part, students were given a fictional scenario followed by four scientific explanations. Students evaluated the claim, evidence, and reasoning for each explanation using a scoring rubric on a 5-point Likert scale (1=poor, 3=average, 5=excellent). We conducted pre/post interviews with the focus students in which they explained their evaluation of the explanations.

Analysis

In this study, we examined how using epistemological criteria about claim, evidence, and reasoning influenced the construction and evaluation of student explanations. These criteria represented students' epistemologies of science, particularly the nature of evidence, and we wanted to see ways that students learned to use these criteria. We analyzed videotape and interview data to examine how students were using their epistemologies to construct and evaluate explanations. We examined the quality of scientific explanations using videotape data and written artifacts. Lastly, we looked at pre/post epistemological questionnaires to investigate changes in students' epistemological beliefs.

Learning to Use 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 of the software. The packet included a scoring rubric for pairs to evaluate one another in small and large group settings. We designed two activities for students to use the criteria to evaluate one another's scientific explanations (Kuhn, Kenyon, & Reiser, 2006). One occurred during an argument jigsaw (and activity in which the student pairs combined to become a group of four that was then asked to converge upon a single answer with which all students agreed) and the other during a whole class debate setting. We noticed that when students constructed scientific explanations they did not always explicitly talk about the criteria. However, we know that they looked for evidence with particular characteristics that may suggest they were using the criteria to guide their decision-making.

For example, when trying to figure out why some finches died, we see Toby and Peter examining and making sense of the available evidence: Toby, "Right, it has something to do with their weight, let's look at this last one. Wow, yeah that was a trend okay." Peter replies, "They pretty much stopped dying." Toby responds, "No, that likes 90, that likes 85. Yeah, they are all dying at about 8 grams. So what kind of trend do we see?" Here, we see Toby examining the data to find trends. His work therefore reflects a key aspect of the criteria: he was using evidence. In another example, Alicia presents an early draft of her finch explanation to the whole class. Like Toby and Peter, she does not explicitly discuss the criteria, but she presents a careful description of the evidence that is specific, one of the criteria on their list: "birds, name GF10 and it said once the plant started to decrease, her weight started to decrease and in time when the plant went to zero in the dry season." Thus, as with Toby's knowledge construction process, Alicia's presentation reflects the epistemic criteria we were hoping to foster.

Interestingly, when the pairs combined to form groups of four (Kuhn et al., 2006) to evaluate one another in an argument jigsaw, some students explicitly pointed out criteria they used within their explanations. For example, in the following quote, Janelle presents her explanation to the other student pair and includes her claim, evidence, and reasoning. She points out that she does have evidence and that she has an appropriate quantity of evidence.

> 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 is interrupted by one of the students and tells them that she is not finished giving all of her explanation. She proceeds 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.

We found that the scoring rubric was helpful in guiding students' evaluation of good evidence. Sometimes, students would use the rubric to give a score without further elaboration about why they gave it a specific score. Continuing from the earlier clip where Janelle presents her evidence for why the finches died, we show Toby's evaluation. It is important to point out that Toby had misinterpreted the scoring rubric and he thought that 1 was excellent and 5 was poor. In this example, Toby interrupts Janelle's presentation of her evidence to give her a score, "you get a 1, 1, you get a 1." Janelle responds, "I'm not done." Toby replies, "Yeah, still get a 1. That is good evidence." We see that Toby gives her a score without any explanation. However, we did notice that his evaluation occurs directly after Janelle gives numbers for her evidence thereby implying that Toby may identify numbers with the criterion that evidence is based on data not opinion and this may be the reason for his evaluative score.

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. During the argument jigsaw, Janelle questions Toby's evidence, "our evidence is that we actually have measurements that says the rainfall decreased." Toby's says, "Yeah." Janelle responds, "But do you actually have numbers that says the rainfall increased, because you can't say it increased without numbers." Janelle is explicit in pointing out to Toby that he does not have good evidence because he is not using numerical data.

The evaluation process was also prominent during whole class debate. For the design we used the idea of audience roles to evaluate and defend explanations (Herrenkohl & Guerra, 1998). These roles included presenters, questioners, and observers and facilitated student-to-student discussion. This evaluation process helped us observe how students used their epistemological understandings to question one another in a whole class setting. Students used the criteria as they questioned the quality of the components of the explanations. 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."

The students' evaluation process was also monitored through pre/post interviews. In the pre/post written component, seven students evaluated four explanations and explained in their interview why they gave specific rubric scores for claim, evidence, and reasoning. Some of the comments included, Toby, "I think the scientist needed to support his evidence with more evidence", Janelle says, "And evidence should be facts, not opinion because it says…and that's not really good evidence", and Vanessa comments, "and eats the same food, I mean that's evidence, but it's not, like specific." Table 2 shows the total frequency of students' evaluative comments for each specific criterion before and after their participation in the study. The most prominent evidence found in Table 2 was the students' emphasis on the volume of evidence and specificity of claim and evidence in both pre- and post-tests.

Table 2. Frequency of Students' Evaluative Comments for Epistemological Criteria. N= 7 participants.

Epistemological Criteria	Pre-Interview	Post-Interview
The claim answers the question.	0	3
The claim is specific.	7	10
The claim is based on facts.	0	2
The evidence is specific.	7	10
The evidence came from data and is not opinion.	4	6
There is enough evidence.	16	16
The evidence supports the claim.	3	1
The big ideas connect to the evidence.	2	5
Total Score	39	53

Influencing the Quality of Scientific Explanations

We examined whether students' used their epistemologies to guide the construction of their scientific work products. We found examples where students used the criteria to guide their written work and other times when they were unsuccessful in this process. Below we follow the learning progression of an early draft written explanation to the final draft after argument jigsaw and whole class debate. Here we see Vanessa and Sarah's initial written explanation for why some finches survived: "the owl population was going up and they were eating the birds. The little ones have bigger wings so they could fly away faster so they survived." The next example is the presentation of their explanation as a group of four in the whole class debate. Jackie says, “the wing length because the food was drying up, they have to fly farther for food and the finches with larger wings were better at flying farther for food.” At this point, they received questions about the quality of their data and evidence. Their final written explanation shows the specificity of their evidence, data rather than inferences, and quantity of evidence.

> The trait that affected the finches’ ability to survive was the wing length because the food was drying up, they had to fly farther to food. We know this information because in our evidence, it shows that during the years of 1976 and 1977, the portulaca seeds went from 450 to 130 to 20 and down to 0. The chamae seeds went from 57 to 21 to 5 and then down to 0. The cactus seeds went from 500 to 230 to 100 then down to 20. The tribulus seeds went from 663 to 500 to 240 then down to 80.

One of the challenges for developing scientific explanations was the consistency between discourse and work products. In instances of student discourse it was evident that students knew specific criteria for good evidence, but when writing or presenting actual explanations this was not always the case. For example, Toby many times referred to good evidence as having numbers and data, but when he presented his explanation he did not always back up his claims with this type of evidence. Mostly, he made inferences to support his claims, Toby says, “Our evidence is, usually when there are harsh rains it kinda pushes you down and you can’t fly to get your food and it kills you…and also sometimes it like floods the plants.” Shortly after, Toby tells his group that they need to make sure they include numerical evidence, “ok, we need to back this up with evidence, the graphs, the data tables and charts.” Again, when he presents his evidence in the whole class debate he gives inferential evidence, “well it wasn’t that heavy, but that it was killing the food that was killing the lighter finches because the heavier finches would eat all the food before the lighter finches could get to it. ” We see again that Toby’s struggles with giving evidence that represents the appropriate criteria.

Changes in Epistemological Beliefs

We used an epistemological questionnaire (Conley et al., 2004) to test for any student epistemological changes after participation in the study. In Table 3, we report results of four separate paired *t*-tests for each of the four epistemological belief dimensions at Time 1 (pre unit) and Time 2 (post unit). We found that students had relatively sophisticated epistemological views when they took the questionnaire before and after their participation in the unit. There were little changes in epistemological beliefs. There is a possibility that the reason for their sophisticated views was because of their prior involvement with our chemistry unit. It was interesting to see that after participation in the biology unit, we found that there was a significant change in epistemological beliefs about science as an evolving and changing subject (see Table 3). This suggests that our extension to the explanation framework – the use of argumentation to foster sophisticated epistemic understandings– helped students develop a more sophisticated understanding about how scientific understandings evolve.

Table 3: Changes in Epistemological Beliefs from Time 1 to Time 2. N=64 participants.

Category	Time 1 *M* (*SD*)	Time 2 *M* (*SD*)	*t*-Value[a]	Effect[b]
Source	2.36 (0.77)	2.27 (0.79)	1.08	0.12
Certainty	1.87 (0.61)	1.97 (0.81)	1.00	0.16
Development	4.33 (0.47)	4.46 (0.41)	3.09***	0.28
Justification	4.48 (0.35)	4.46 (0.44)	0.50	0.06

[a]Two-tailed paired *t*-test, **** p <.01*
[b]Effect Size: Calculated by dividing the difference between posttest and pretest mean scores by the pretest standard deviation.

Students revised their explanations throughout both argument jigsaw and whole class settings. Moreover, there were a couple of times during the investigation in which students learned that they had misinterpreted their data and could no longer use their data as evidence to support their claim. For example, Janelle explains to the class that their interpretation of the evidence was incorrect and that they will have to make a new claim, “first we looked at graphs and believed that the lighter finches were dying, found out that finches reproduce in the wet season and mature in the dry season, we have to go back and change.” Toby supports Janelle’s statement and says, “yeah, we have to go back and change the trait that we believe in and that is probably going to change the whole idea about how the finches are dying and surviving." The experience of continual revision of scientific explanations may have influenced this change in epistemological beliefs about development in science.

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, asking: "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?" Another student, Michael responds, saying: "It could be another way to look at it." In other words, Michael thinks that maybe they are interpreting the data in different ways. The teacher answers her question, verifying Rhonda and Michael's ideas to explain the different explanations, "It is possible that somebody is misinterpreting the graphs, it is also possible that you can interpret the evidence in more than one way." 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. This may have contributed to their beliefs about science as an evolving subject.

Discussion

As consumers of science, we want students' to be able to think and reason about scientific issues. In doing so, they will need the epistemological knowledge and inquiry skills to guide these types of decisions. This study supports the need to further examine using epistemological criteria and its influences on explanation and argumentation practices. Talking about epistemologies of science is difficult for students. We know that students are 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. In whole class debate many students did not take their questions to a higher level or elaborately defend their answers. For instance, the questioners would comment that the presenting group needed more evidence, but failed to question the group about why they chose their particular evidence or why 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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