A Resources Interpretation of Teachers' Epistemologies of Science

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Abstract: Teachers' epistemologies of science are explored as they emerge during the course of an authentic laboratory research experience. Using a resources framework as an interpretive lens, we find that teachers develop epistemological resources for the nature of science while conducting authentic research and participating in conversations in which epistemic discourse about the nature of science is facilitated. However, stability of these epistemological resources and the contexts in which they are activated vary across individuals. Here we describe a sample of the resources along with some contexts in which they are and are not activated.

Teachers' understandings of the nature of science and inquiry are critical to reform. However, many teachers hold relatively naïve conceptions of the nature of science (Abd-El-Khalick & Lederman, 2000). Recent studies have shown that providing teachers with authentic research experiences is not sufficient for developing sophisticated conceptions of the nature of science (Windschitl, 2002; Schwartz, Lederman, & Crawford, 2004; Kang & Wallace, 2005). However, these same studies show that when combined with explicit instruction in the nature of science along with guided journaling, these research experiences can provide a context for developing epistemologies of science. Maintaining perspective at the periphery of the authentic research context may be important in the development of these understandings (Schwartz, Lederman, & Crawford, 2004). Sustaining these improvements may be difficult. A recent study indicates that five months after a one semester methods course where explicit reflective instruction in the nature of science was used, not all teachers sustained improvement seen immediately after the course's completion (Akerson, Morrison, & McDuffie, 2006). Beliefs about the nature of science influence teachers' practices (Brickhouse, 1990; Gallagher, 1991; Gess-Newsome & Lederman, 1994; Lakin & Wellington, 1994; Tobin & McRobbie, 1996). The extent of undergraduate or career research experience appears to be directly related to the likelihood of teachers adopting inquiry teaching practices (Windschitl, 2002). Recent case study interpretations also suggest that teachers' epistemologies may be filtered through their goals for teaching, which in turn get translated into actions that form their modes of implementation in the classroom (Kang & Wallace, 2005).

This study applies a resources framework to teachers' talk about their research and its connections to the nature of science, their students' school science experience and their teaching practices as they emerge during and shortly after an authentic research experience. Facilitated discussions were carried out to explicitly develop epistemological resources for the nature of science and multiple contexts for activating them.

Research Context

During the summer of 2005, 10 high school science teachers participated in 4-week full-time research internships with faculty at an academic bioscience research institution. Teachers were recruited from a single school system using a unified curriculum for ninth grade biology. All had taught at least 3 years. Teachers were matched to one of 11 mentors based on teacher preference for research topic. Although the types of research were diverse (examples include molecular biology, developmental biology, aquaculture, and marine microbiology), teachers were situated in a single department within the same facility.

While actively involved in research, teachers also participated in hour-long facilitated discussions twice per week. These discussions were designed to connect their laboratory experiences with the nature of science and their teaching practices, while guiding teachers in their epistemic discourse on the nature and practice of science in their situated context. In half of the sessions, readings related to the discussion topic were distributed to encourage deeper reflection. The facilitator for these discussions was the first author, a Ph.D.-level molecular biologist with expertise in science education and inquiry teaching practices. On the last day of their internships, teachers presented their research work to mentors, peers and other staff in the departments. Facilitated discussions are continuing on a monthly basis during the school year with 7 of the 10 teachers.

Data Collection

Discussions were initiated in a number of ways: through conversations about progress in research projects, casual reporting on social adjustments to individual labs, or a question (posed by the facilitator) grounded in the nature of science relating to a previous session's discussion. In every discussion session, teachers did greater than 90% of the talking. The facilitator's role was to simply tie the discussion to the nature of science through questions, when possible, to reorient it in that direction, or to offer expertise that would give teachers a footing in the evidence base. These discussions had a high engagement value to teachers. Although scheduled to last one hour, they often lasted 90 minutes or longer. Although it is difficult to place a label on discussion session topics, examples of topics discussed are: how does authentic scientific inquiry differ from school science; what is the value of inquiry to science, to teaching and to students; what is science; how do scientists grapple with uncertainty; and what do scientists do with evidence. All but one of the facilitated discussions were videotaped or audiorecorded and transcribed for the analysis described here. Fieldnotes from discussions and informal conversations with teachers, as well as teachers' unguided journals were also collected for this study.

Findings

In this study, we use the authentic research experience as context and vehicle for talking with teachers about the nature of science. These conversations proved to be rich sources of data relating to how teachers reveal their epistemologies for the nature of science and in what those epistemologies are. The conversations also allowed us to reframe the experience of "doing real science" in the teacher's context of "what we do with students," meaning the student science experience, curriculum and instruction. Indeed, this study finds that teachers were able to generate ideas about the nature of science directly from their research experiences, and connect them to what students experience as science in the classroom.

In these facilitated discussions, we were able not only to discern elements of teachers' epistemologies of science, but also to some extent guide their development. Although "no consensus presently exists among philosophers of science, historians of science, scientists, and science educators on a specific definition for NOS [nature of science]" (Abd-Ed-Khalick & Lederman, 2000), this study is guided by the AAAS Project 2061's *Science for All Americans* (AAAS, 1990) and the *National Science Education Standards* (National Research Council, 1996). Included in them are the scientific world view, scientific inquiry and the scientific enterprise (AAAS, 1990), science as a human endeavor, nature of scientific knowledge, and historical perspectives (NRC, 1996). Therefore, we use these two descriptions and the elaborations of *Inquiry and the National Science Education Standards* (NRC, 2000) as contexts for describing the teacher epistemologies in this study

Our data clearly indicate that most, if not all, teachers in this program developed epistemological resources for notions of the empirical and social construction of science, the tentativeness of science, scientific inquiry and science as a human endeavor. Over the course of the summer, they expressed a further appreciation for the value of skepticism in science and the nature of uncertainty in science. The manner by which authentic scientific inquiry is conducted was contrasted to the misguided linear "scientific method" of most school science. In an extended conversation on the vital importance of careful observation and the unspoken honesty and integrity in recording data and evaluating evidence, they also talked about "making mistakes." When one teacher opened with, "I'm afraid of looking stupid…so many chances to screw it up," another noted "…the mistakes thing is a *huge* part of becoming a scientist and you need to worry about every little thing. But I mean *eventually* you need to get over it to be a scientist" (original emphases). The teacher who made the latter statement was able to immediately translate this to the classroom by making a distinction between two types of mistakes in students' science work: careless mistakes made because students do not care about the quality of their classroom work and mistakes as human or experimental error in design and/or execution of an experiment.

Teachers also observed the utility of disagreement and, hence, argument as a regular mode of operation for scientists. During their short stay, the disagreements they most often witnessed or participated in were in the context of troubleshooting technical details of experimental protocols. In two instances, however, disagreements centered on interpretation of results from data as evidence. They were also acutely aware that scientific findings do not rise from the data on a daily basis. Rather one teacher summed it up this way, "The guy I work for…constantly says that 90% of what we [scientists] do is perfecting technique and 10% is gathering data from it."

Teachers talked about the contrast between how science is represented to students as a big picture, and how large lab groups were merely generating all of the "small pieces" that make up that big picture.

In terms of science as a human endeavor and the importance of communicating results to peers and the public, teachers commented on how busy their scientist mentors were as they witnessed them juggling many duties from writing and reviewing grant proposals and manuscripts, attending meetings, mentoring several students and supervising staff. They also expressed the pressure that scientists were under and how it affected their productivity. In preparing their final research presentations, all teachers were surprised at how invested their mentors were in seeing professional quality presentations, careful attention to detail in the explanation of experimental design and accuracy in the communication of results to others.

The Resources Perspective

We have examined these conversations through the interpretive lens of the resources framework for epistemologies (for a full description, see Louca, Elby, Hammer, & Kagey, 2004). In this framework, epistemologies are viewed as being composed of resources, which are fine-grained cognitive elements that can vary in their stability and mode and context of activation. By contrast, the grain size of resources is much smaller than beliefs. Activation of resources may be passive, i.e. not requiring metacognition, and may or may not be reliably activated in a given context. The attractiveness of the resources framework lies in its ability to account for the context-sensitivity of beliefs, including differences between professed beliefs and their enactments. We examine these properties of epistemological resources in more detail in the context of the examples below. With them, we suggest that the teacher epistemologies that developed in this program have a form consistent with epistemological resources in that they vary in grain size, stability and context dependence for activation among the individual teachers.

Understanding Self as Novice Learner

We use portions of our first discussion with teachers as an example of how they serve as a vehicle for examining a teacher's personal epistemology and for guiding its formation. This discussion began with teachers talking about the difficulties in adjusting to being the new kid on the block and acculturating to laboratory life. Part of this "new kid" phenomenon was their induction into the role of novice learner, a stark contrast to that of expert science teacher. Here we recall a portion of the discussion and the context-broadening opportunity it afforded.

One of the teachers, who was engaged in research involving cloning of DNA, talked about something he called "the gaps." He described these gaps as little missing pieces of the puzzle. For him, the gap was "why we need to clone something [at this point] here [in time]" rather than proceed directly to a different, subsequent step in the investigation. While he understood what cloning was and how it was done, he could not immediately see the utility of cloning as a vital tool in the molecular toolkit for making available a pure copy of a DNA sequence away from the noise of its genome. He talked about the difficulty in getting other scientists in the lab to explain what he was missing in a way that was meaningful to him. In another but somewhat similar incident, a different teacher sought foundational knowledge in microbiology, the discipline in which her project was situated. In a very well intentioned response, her postdoctoral lab mentor gave her a graduate level textbook in microbiology. As she attempted to read this book, she found herself looking up words in the book's glossary so frequently that it distracted from comprehending content. Because we talked about these incidents as a group, not only were we afforded the opportunity to discuss the affective part of these experiences, but also their grounding in our current understanding about expert versus novice knowledge. Teachers were also able to compare themselves as beginning researchers in their experiences with their research mentors to themselves as teachers relating science to their students. In the instance of the teacher who was overwhelmed by vocabulary, we immediately related her experience to what it might be like for English language learners to comprehend a biology textbook. This discussion was supported by the group's reading of the chapter in *How People Learn* (Bransford, Brown, & Cocking, 2000) that compares expert with novice knowledge. We view this conversation as contributing to the development of epistemological resources on learning.

Talking about the Scientific Method

Here we examine the contrast between two teachers' views of the scientific method. Throughout the summer, Amanda was constantly surprised at how different "real science" is from school science. Amanda moved to teaching middle school from her former high school position after the summer intervention. In the first meeting of the school year following her research experience (her first semester teaching middle school), she told the group that she was aghast that the other science teachers at her new school did not teach the scientific method. By "scientific method," she indicated the canonical linear process. She was adamant that if anything should be taught at all, it should be the scientific method. Less than an hour before Amanda's comment, the group had discussed how real science was significantly different than school science. In that earlier segment, another teacher, Terry, explained how non-linear the process of real science is and that this was not at all what we teach students. Because of this inconsistency between Amanda's immediate comments and Terry's earlier ones, the facilitator asked the group how Amanda's frustration related to the way they experienced the scientific method during the summer. Amanda was silent and seemed confused. Terry responded by reiterating that the scientific method of real science is not linear by any means and that teaching students the scientific method as a linear, canonical process is not an accurate portrayal. Using the resources framework, we can interpret Amanda's confusion as demonstrating that her epistemological resources for the scientific process are not stable and activation of resources related to constructing the non-linear scientific method is highly dependent on the context of her research experience. That is to say, outside the frame of her research experience or her discourse about authentic scientific research, Amanda does not activate these resources. We would, therefore, say that Amanda's epistemology remains naïve. By contrast, Terry demonstrates a more sophisticated epistemology. He shows passive activation of his resources for scientific inquiry and appropriately activates them in two contexts: "real science" and teaching science. Although we have not actually observed Amanda or Terry in practice, Amanda's statements lead us to believe that she would teach her students the linear scientific method. Classroom observations would help us examine the connections between what is professed and what is enacted.

Describing What Science Is and What It Is Not

In this next example, we examine the context dependence of teachers' definitions of science and what cognitive processes they might be invoking to activate resources. In discussing their research, teachers universally lamented the tedious repetition involved in day-to-day science, such as "getting experiments to work," "screening tons of plates," and keeping the enormous aquaculture tanks operational. When asked whether they thought this type of activity was science, at least three teachers agreed that it was not science; the others did not state an opinion. In a subsequent discussion session, the facilitator started off the session asking for clarification of what they meant when they said that these types of tasks were not science.

Jim: PCR(1) is a tool of science. So I guess you can say it falls under that. I think of science as seeking questions, answering …that sort of thing. And that's a tool used to get there.

Facilitator: OK.

Jim: But if someone comes in and does the protocol [PCR] without any thought involved along with it, I don't think so.

Facilitator: OK. So you consider, you consider, science as the more higher-order thinking parts.

Jim: Otherwise you could say making a peanut butter and jelly sandwich is science. If I give you instructions on how to do it, you sit down and do it. The only difference is PCR is something that scientist *do*. The average person doesn't do it in their normal life, so they think, 'Oh, wow. He's doing science when it's really just a procedure or tool used by scientists."

Facilitator: OK. So that's how you picture that in your head.

Jim: Just now, right.

Facilitator: [begins laughing] Just now 'cause I asked.

Jim: Yeah. I probably wouldn'ta thought about it. [laughter from the group] You forced me to be metacognitive. [Everyone laughs loudly.] Thinking about my thinking.

Fred: I was thinking that uh these repetitive, tedious tasks are part of science when they're um…part of..um..trying to answer a scientific question…or…when it's part of an experiment. [pause] To me, it's, that's mean um..that's *part* . It takes a lot of time. There's a difference between making a peanut butter and jelly sandwich versus um like if you're trying to make a peanut butter and jelly sandwich to answer some question. How much nutrition is there.um. you know. If you have to study. To *study*. That's part of it. It's part of it.

Facilitator: If it's grounded, the *task* is grounded in a scientific question, it's science. If the question is *not* grounded in a scientific question, then it's not science. That's, that a good description. How about you, Terry?

Terry: Uh…As far as the …routine work aspect of science, when I said 'not science,' I'm referring more to the questioning. You know. The research aspect of it. It's more than one thing, the day-to-day data analysis type stuff. I mean…'cause you're not…What I'm doing …I'm just following protocols……..doing these …just kind of…amazing things that *will* help ultimately, but *I'm* not searching for any answer. My purpose isn't to look for any [unintelligible]

Jim: I guess the point I was trying to make was in it's, by *itself* it isn't science.

Facilitator: I see.

Jim: Doing PCR is not science. Like he was trying to say. I agree with what he said. We just kind of said it two different ways… I think.

All three teachers associate science with asking and answering questions. We will focus on Jim. Jim identifies scientific techniques, such as PCR, as tools of science but not as science itself. Jim's responses are particularly telling. Jim's fluent responses close as he jokes good heartedly about being drawn into using his metacognitive resources to compose them. Jim recognizes that he is using resources for understanding epistemological activities, such as checking, accumulation, formation (Hammer & Elby, 2003), to check his knowledge about the nature of science. If we go back to an earlier episode in this study, it was Jim who supplied his mentor's perspective by saying, "The guy I work for…constantly says that 90% of what we [scientists] do is perfecting technique and 10% is gathering data from it." Jim made this observation when talking about the kinds of communication that occur in research group meetings of a mentor with students and staff. Therefore, Jim has this knowledge but does not bring it up in the context of distinguishing scientific tools and tasks from science as a whole. Jim seems to have many fine-grained resources for describing the work that goes on in a laboratory some of which are knowledge as propagated stuff, i.e. passed down from the authority figure of his mentor, and knowledge as fabricated stuff, i.e. knowledge that he figured out on his own (for a detailed description, see Hammer & Elby, 2003). Jim's resources relating to the source of his knowledge may be unstable or stable. Activation is deliberate and context dependent. As a side note, it is interesting that Jim has preferentially activated knowledge as fabricated stuff but not knowledge passed down from an authority figure.

Relating the Nature of Science to Scientific Literacy

Our final example describes teachers' understandings of the relationship between the nature of science and scientific literacy. Over the course of the summer, teachers freely contributed their goals for their students in broad mission statements. Among them, scientific literacy was a high priority for almost all. Because we had been talking extensively about some of the aspects of the nature of science that related to current controversies over the teaching of evolution, the facilitator commented on the importance of understanding the nature of science to this debate. Several teachers denied the connection, while others had no comment. At a later date, several attempts were again made by the facilitator to tie the importance of the nature of science to scientifically literacy. Teachers responded by describing their ideas about scientific literacy. Topics such as blindly accepting whatever appears in the popular media, creating wise consumers, making informed health decisions and other decisions as consumers, nurturing problem solving and common sense were discussed. Despite many attempts by the facilitator to guide the conversation about the nature of science to scientific literacy, teachers did not make the connection. In the minds of these teachers, the "ways of doing and knowing science" as an important component of science remained divorced from scientific literacy. We interpret this separation as either not having adequate resources to activate or an inability to activate resources for the nature of science in the context of scientific literacy.

In conclusion, we can say that these teachers present no single unified epistemology of science across the cohort. Rather we find that individual teachers have epistemological resources for knowledge about the nature of science that vary in stability and context sensitivity. Our data suggest that teachers who are conducting authentic research supported by discussions facilitating epistemic discourse that explicitly aims to develop these resources do indeed develop them. What the cues are for activating them reliably is still an open question. Teachers have at least two immediate contexts through which these resources are viewed: their experience as teachers and their experiences in research laboratories. The manner in which current and historical resources interact remains unexplored.

Future Directions and Implications for Teacher Education

This study has implications for teacher education. First, we have shown that professional development programs grounded in authentic research experiences can be effective in challenging existing thinking and nurturing the development of more sophisticated ideas of the nature of science when they are accompanied by facilitated discussions that elicit them. We cannot say from our study that research experiences by themselves can or cannot serve that purpose. What evolves from this study is the question of how these epistemological resources get activated and operationalized in the classroom. That is, what are the contexts in which they become activated and are these contexts productive for supporting their students' development of, and understandings of, the nature of science? During the current academic year, we have the opportunity to observe these teachers in their practices and use our school year discussions to root out the epistemological resources they use to enact their interpretations of the nature of science.

Endnotes

(1) PCR is an acronym for polymerase chain reaction, a laboratory protocol for amplifying specific sequences of DNA.

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