Students With Sophisticated Epistemological Beliefs About Justification, but not Certainty, of Science Knowledge Revise Hypotheses More Frequently in Authentic Science Inquiry

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Abstract: Epistemological beliefs about science (EBAS), or beliefs about the nature of science knowledge, is an essential yet difficult to define aspect of science literacy. Given the challenges with defining EBAS, it is not surprising that existing metrics are criticized for their lack of reliability and validity. One solution is to examine students' authentic science practices as a proxy for EBAS. Our prior work suggested that practices in Science Classroom Inquiry (SCI) simulations, a computer-based authentic science inquiry experience, are reflective of EBAS. Here we extend our prior work to include an additional practice: hypothesis revision. Students who revised their hypothesis also had more sophisticated epistemological beliefs regarding the lack of a universal scientific method, but not the tentative nature of science knowledge. This study supports the use of practice-based assessments of difficult to measure cognitive constructs such as EBAS and suggests interesting future directions regarding evidence usage and epistemological beliefs about science.

Introduction

Epistemological beliefs about science (EBAS) are beliefs that an individual possesses regarding the nature of science knowledge and how that knowledge is generated through inquiry (Peffer & Ramezani, 2019). EBAS are closely related to nature of science (NOS) understanding, with some saying NOS and personal EBAS are interchangeable with one another (Elby et al., 2016). Our prior work posits that what you know about science (your NOS understanding) influences what you believe about science (EBAS) in a bidirectional relationship, and both of these factors influence what you do in authentic science practices (Peffer & Ramezani, 2019). There is some overlap between EBAS and NOS. For example, epistemological beliefs regarding justification, or how knowledge is generated through inquiry can also be considered overlapping with the NOS principle that there is no universal scientific method. The certainty of knowledge (EBAS) is related to the tentativeness of science knowledge (NOS). Both describe science knowledge as fluid and subject to revision in light of new evidence.

Achieving a sophisticated understanding of science knowledge as generated through the process of inquiry and subject to revision in light of new evidence is a key component of science literacy. For example, a less sophisticated stance may be that science knowledge is static and once we know something, it is always that way rather than subject to change in light of new evidence. Although important for science literacy, EBAS are difficult to define and assess. For example, in the NOS literature there is debate as to whether there is a single universal NOS understanding (Abd-El-Khalick, 2012; Schizas et al., 2016), or if it may be domain specific (Lederman et al., 2002). Practicing scientists have a variety of interpretations of NOS as well (Sandoval & Redman, 2015; Schwartz & Lederman, 2008) and their NOS understanding can be naïve (Wong & Hodson, 2009; Wong & Hodson, 2010). Given these challenges with defining EBAS, it is not surprising that there are numerous validity, reliability, and practical concerns with the administration of pen and paper metrics of NOS or EBAS (Peffer & Ramezani, 2019; Sandoval & Redman, 2015).

Assessing epistemological beliefs via practices

Given the importance of fostering sophisticated EBAS to attain science literacy, it is necessary to develop reliable, valid, and practically useful measures of EBAS. An emerging solution is to examine practices in a scientifically authentic activity, like inquiry, as a proxy for EBAS. Science Classroom Inquiry (SCI) simulations provide an authentic science inquiry experience via an interactive web application. The user is positioned as a scientist tasked with solving some real-world problem. The user is given autonomy as to how to approach the problem, including hypothesis development and revision, testing strategy, and when to complete their investigation. Our previous work qualitatively characterized the inquiry practices of experts and novices engaged in SCI and suggested that inquiry practices may reflect underlying epistemological beliefs (Peffer & Ramezani, 2019).

Here, we extend our prior qualitative work to examine a specific inquiry practice, the revision of a hypothesis. We chose hypothesis generation and revision since prior work indicates that hypothesizing is a key aspect of a scientific investigation (Osborne, 2014). We found that hypothesis revision among undergraduate students engaged in a SCI simulation was associated with more sophisticated understanding of the justification, but not certainty, of science knowledge. Therefore, hypothesis revision may be another potential target for a practices-based assessment of EBAS.

Methods

Participants (n = 91) were undergraduate students enrolled at a mid-sized public research university in the rocky mountain region of the United States. Participants were predominantly female (73.6%) and included 25 biology and 66 non-STEM majors. The two predominant ethic groups were white/European-American (63.7%) and Hispanic/Latin-American (16.5%). 40.7% were freshman, 22% sophomores, 9.9% juniors, and 27.5% seniors.

Data was collected in a single meeting that took place over 1-2 hours. First, students completed a pre-test assessment which included a selection of open-ended items from the Views of the Nature of Science (VNOS; Lederman et al, 2002) and Views about Science Inquiry (VASI; Lederman et al, 2014). We opted not to include the full metrics since not all constructs assessed by these metrics were relevant to our study and survey fatigue was a concern. Responses were assessed on two nature of science tenants with strong corollaries in the epistemology literature, namely the lack of a universal scientific method (justification) and tentative nature of science knowledge (certainty) (Hofer & Pintrich, 1997; Lederman et al, 2002). Two coders independently coded all items as either a sophisticated, mixed, or naïve response. Sophisticated responses were in line with current scholarship on NOS and epistemological beliefs about science, whereas naïve responses were the opposite. Mixed responses contained answers that contained elements that were both consistent and inconsistent with current scholarship. Items were coded blinded and overall agreement was fair (justification kappa = 0.31 and certainty kappa = 0.38). Disagreements were settled through mutual discussion. Due to low cell counts, Fisher's exact test was used and analyses performed in SPSS 26.

Following the pre-test, students then completed the *Invasion of the Grackles* SCI simulation. The SCI simulation engine captured all student clickstream data and inputs, including tests performed, rationale for each decision, the number of hypotheses generated as well as if the participant felt their hypothesis was supported, refuted, or neither supported nor refuted based on the data collected. Students were given complete autonomy as to how they wished to complete their investigations, including hypothesis generation, which tests to perform, and when to conclude their investigations. To avoid potential stereotype threat, students completed a survey of demographic information after completing the simulation.

Results

Undergraduates end investigations with a supported hypothesis

Given the importance of hypothesizing as an authentic science practice, we first examined differences in hypothesis revision. Since differences in practices could be the result of experience with the simulation content, we compared biology and non-STEM majors. Altogether students generated 111 hypotheses total, with the majority of students (80.2%) only generating a single hypothesis. Among the non-revisers, 66% stated their hypothesis was supported, 2.7% stated their hypothesis was refuted and 31.5% stated that their hypothesis was neither supported nor refuted. Among the revisers, 15 generated one additional hypothesis (two total) and three generated two additional hypotheses (three hypothesis total). When examining temporal order among the revisers, we noted that 39% of revisers stated that their first hypothesis was supported, 22% neither supported nor refuted and 39% refuted (Table 1). The majority of revisers ended their investigations with a hypothesis that the student claimed was supported by their collected data (72%) or neither supported nor refuted (22%) (Table 1). Together, these data suggest that students concluded their investigations when they believe sufficient data was collected to support their hypothesis. We noted marginally significant ($p = 0.08$) differences in hypothesis revision between our two undergraduate populations, with biology majors revising more often (32%) than non-STEM majors (15%). Therefore, there could be some influence of experience with biology content and hypothesis revision.

Table 1: Differences in categorization of hypotheses among revisers

Hypothesis Type and Order	Number of Occurrences
Supported/Supported	6 (33%)
Neither/Supported	3 (17%)
Refuted/Supported	3 (17%)
Refuted/Neither	1 (5.5%)
Neither/Neither	1 (5.5%

Refuted/Refuted	1 (5.5%)
Refuted/Neither/Supported	1 (5.5%)
Refuted/Refuted/Neither	1 (5.5%)
Supported/Refuted/Neither	1 (5.5%)

Sophisticated beliefs about justification, but not certainty, of science knowledge is associated with hypothesis revision

We next determined if hypothesis revision was associated with differences in the understanding of the justification or certainty of science knowledge. We noted no difference between student major and understanding of a lack of scientific method ($p = 0.31$) or understanding of the tentative nature of science knowledge ($p = 0.18$). Next, we examined if individual differences in understanding of either the justification or certainty of science knowledge could explain why an individual decided to revise or not. We found that revisers scored lower than non-revisers (indicating a more sophisticated understanding) on their understanding of the justification of science knowledge, namely the lack of a universal scientific method ($p = .02$) (Figure 1). In contrast we found no difference between revisers and non-revisers on their understanding of the certainty of science knowledge, namely that science knowledge is subject to change in light of new evidence ($p = .95$) (Figure 1). Therefore, students who have a stronger understanding of the lack of a universal scientific method also are more likely to revise their hypothesis, regardless of major.

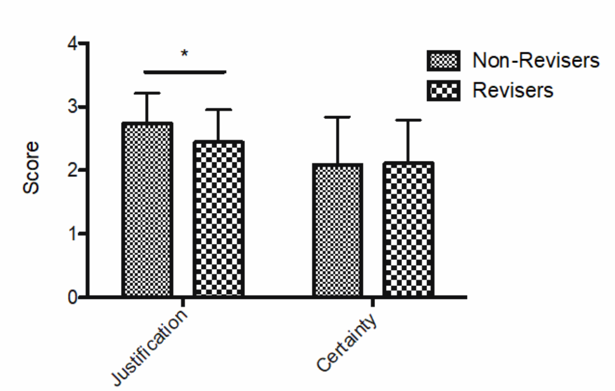

Figure 1. Differences in understanding of the justification and certainty of science knowledge between revisers and non-revisers. Note that lower score indicates more sophisticated understanding.

Discussion

Fostering sophisticated epistemological beliefs is an essential part of science literacy. In spite of the importance, defining and assessing epistemological beliefs about science remains pedagogically challenging. Our prior qualitative work (Peffer & Ramezani, 2019) suggested that inquiry practices in the Science Classroom Inquiry (SCI) simulations are reflective of underlying epistemological beliefs about science. Here, we extend our prior work to include quantitative information on one specific science practice, the generation of a new hypothesis and its relationship to understanding of two aspects of epistemological beliefs about science, the justification of new scientific knowledge, particularly the lack of a universal scientific method and certainty or tentativeness of scientific knowledge. This work contributes to a growing literature on assessing epistemological beliefs about science, or other invisible and difficult to measure cognitive constructs, using clickstreams derived from student practices in authentic science activities, such as inquiry.

Of the 111 hypotheses generated among all students, the majority (60%) were identified by the students as supported by their investigations. We noted that students who revised their hypothesis were also more likely to state that their initial hypothesis was refuted (26% for revisers and 2.7% for non-revisers). Among students who revised their hypothesis, only a single student ended their investigation with stating that their hypothesis was refuted. Perhaps students are biased towards stating their hypothesis is supported because the majority of inquiry experiences across the K-16 spectrum are simple in nature and/or geared towards arriving at a single correct answer. Students may be quick to state their hypothesis is supported after finding one piece of information that supports their hypothesis, then concluding. This could also explain why revisers often start by stating their hypothesis is refuted, but then completed their investigations with a hypothesis that is supported (Table 1). Students could also be iterating until they find a satisfactory answer, instead of concluding that there is not enough information to arrive at any conclusions. The focus on finding an answer, which is reminiscent of simple inquiry reflects a worldview of science as simply about fact finding (Chinn & Malhotra, 2002). This could be reflective of an individual having less sophisticated epistemological beliefs, since in authentic science inquiry not all investigations will result in a clear final answer. Additional research, such as interviews of why students made particular decisions, are warranted.

Our most interesting and provocative result is our observation that students with more sophisticated understanding of justification but not certainty were more likely to revise their hypothesis, regardless of biology content experience. This suggests that hypothesis revision is a scientific practice that is reflective of an underlying belief that science knowledge is generated through a variety of means, not by a single scientific method. It could also be that students who are more likely to revise understand the non-linearity of authentic science practices as well. This also suggests that this relationship between a sophisticated understanding of the source of science knowledge and revision of a hypothesis is a very specific phenomenon, not because one student versus another is has more sophisticated epistemological beliefs overall. Since we observed no difference in major and therefore experience with biology content area on performance of either of these assessments, this suggests that our observation is due to a difference in epistemological beliefs and not due to experience with the subject matter of the simulation. One important extension of these results will be to examine how students used and cited evidence when stating which hypotheses were supported, refuted, or neither supporter nor refuted. Evidence evaluation is another critical science practice (Osborne, 2014) and important facet of epistemic cognition. Assessment of how students manage uncertainty as part of their investigations could reveal insights into students' understanding of certainty and source of science knowledge. These results are provocative and support the use of practices-based assessment of EBAS.

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