Argumentation as Inquiry: Students' Engagement With Uncertainty in Written Arguments

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Abstract: In science education, analyses of students' arguments often focus on their ability to reduce uncertainty by supporting or rejecting claims. We contend that argumentation is part of scientific inquiry, where it functions not only to reduce, but also to maintain and raise uncertainties. We present an analysis of written arguments from a laboratory course designed to provide opportunities for students to encounter scientific uncertainty and illustrate how students in this course were able to engage with uncertainty to motivate, extend and deepen their scientific inquiry. We describe the features of the design that allowed for this engagement and suggest that more attention be paid to the varied roles of argumentation in scientific inquiry.

Introduction

In school science contexts, students are often expected to produce arguments that settle on well-supported claims, often by rejecting alternatives. For example Osborne, Erduran, & Simon (2004, p. 1016) suggest that argumentation in science *resolves* uncertainty, allowing students to "support one theory or another." This form of argument is familiar in science laboratory reports, in which students organize arguments to either support or reject hypotheses (Keys, 1999). One potential problem with this focus on resolution is that it can truncate students' engagement in scientific inquiry (Holmes & Bonn, 2014). Students may inappropriately settle on a conclusion supported by weak evidence or dismiss ambiguities as "error."

In scientific practice, argumentation does not function solely to reduce uncertainty. While argumentation may contribute to consensus building in the long term (Bazerman, 1988), in the everyday practice of science it plays a more varied role—maintaining alternative claims to prevent premature settling or generating new questions by pointing out inconsistencies or gaps (Manz, 2015; Phillips, Watkins, & Hammer, 2018).

Recently, there have been calls in science education to "embed" argumentation within students' scientific inquiries (Chen, Benus, & Hernandez, 2019; Manz, 2015). Doing so can allow students to learn how to use argumentation to construct and revise claims as well as to articulate and motivate problems. Additionally, research has begun to show how engaging with uncertainty in classroom discourse can help initiate and sustain scientific inquiry (Watkins *et al.,* 2018). We argue that providing students with opportunities to engage with uncertainty in scientific inquiry should also change our expectations of the products of argumentation—written arguments.

Most analyses of students' written arguments have focused on how students use evidence and reasoning to *reduce* uncertainty (e.g. Osborne et al., 2004). In this paper we broaden our analysis to consider how students reduce, and also *maintain*, and *raise* uncertainty in their lab reports. We illustrate how students' engagement with uncertainty in argument motivated, extended and deepened their scientific inquiries and discuss how this engagement was supported by the design of the laboratory course.

Methods

Study context and course design

We conducted this study in a large-enrollment undergraduate biology laboratory course at a small private university. Students attend lab sections of approximately 24 students taught by a graduate student instructor. The course has been a site of a design-based research (Cobb et al., 2003) project focused on creating opportunities for students to engage with scientific uncertainties.

Two features of the design are relevant to the present study. First, the labs couple experimental and computational methods. This coupling is intended to generate uncertainty as well as to motivate exploration of alternative approaches to inquiry. For example, uncertainty over whether computer simulations accurately represent real biological systems can motivate experimental investigations. Conversely, uncertainty over whether experimental results apply over time or for different parameter combinations can be examined using the simulation (Gouvea & Wagh, 2018). Second, in this design iteration, we created more opportunities for social interaction by encouraging students to use data produced by other groups in their lab reports. This move was intended to de-center groups' own results and expand the sources of evidence under consideration.

Data collection and analysis

We collected all reports (N = 16) from a laboratory section taught by an experienced graduate student instructor who had taken a pedagogy course emphasizing eliciting and responding to the disciplinary substance of students' thinking. Observations of this instructor's class showed her centralizing students' ideas. We therefore decided to sample student work from her section to examine the effects of the design under conditions of aligned instruction.

Following Chen et al. (2019), we began our analysis of lab reports by identifying markers of students raising, maintaining or reducing uncertainty (Table 1). Once we identified these moments, we looked across the reports to describe how these patterns of engaging with uncertainty functioned in students' arguments. For example, some students posed questions at the beginning of their reports, while others raised new questions during data interpretation that functioned to extend their inquiry. Some moves to maintain uncertainty about data quality expressed a lack of confidence in the data, while other moves functioned to keep multiple ideas in play. When students' claims reduced uncertainty, some settled on original conclusions, while others used multiple sources of data to revise and complicate original claims.

Table 1: Categories of engagement with uncertainty in laboratory reports

Category	Description	Example (*emphasis added*)
Raise	Articulate novel questions or problems	…the long-term dominance of [the low-mutator] in the region where antibiotic was added halfway, *contrasted* with the absence of any dominance in the region where antibiotic was never added, was interesting. *Why would the [low mutating] strain have an advantage when it was initially decimated, and no advantage when it was not?*
Maintain	Use hedging, qualifiers, or express doubts	Although this is what occurred in our experiment, *it is still unclear and rather unlikely* that lower mutators *always* have fitness advantages over higher mutators….
Reduce	Support or reject claims with evidence	Short-term benefits for a beneficial mutation arose for a higher-mutating strain. In the long term, *as shown in the simulation,* the relative effect of these benefits was reversed.

Findings

Our findings are organized into two sections. First, we present a single student's report to illustrate how she raised, maintained, and reduced uncertainty in her argument. Second, we describe how the features of her argument function as part of her inquiry and report on the extent to which this single case reflects broader trends in the data.

B's report as a case of engaging with uncertainty

B begins her report by proposing two factors that contribute to the fitness of a bacterial species—mutation rate and population size. She then raises questions about how the two factors might interact to affect fitness:

> If one increases the concentration of a strain (lower mutator strain) thereby yielding a bigger population and then grows this strain in the same environment as a smaller population of a higher mutating strain, will the viability of the two populations be similar? … Can increases in population size counter decreases in the mutation rate?

In choosing to begin her lab report with these questions, B sets the stage for her argument by establishing a need for the evidence that will follow.

Next, B explains her groups' experiment and describes the data it produces. B reveals that her group has decided to "void" the data due to a lack of growth on her control plates, as well as low numbers overall compared with an earlier experiment. However, although she casts doubt on the validity of the data for making a comparison, she also points out that any growth on the plate that contained a low mutator strain aligned with her prediction:

> This shows that within a large population of a lower mutating strain, there can still be growth. Evidently, this also gives reason that if our experiment was done correctly, perhaps without contamination or with greater concentration, it could have been successful in showing that a greater population of a lower mutating strain can yield a population just as fit as a higher mutation strain in a smaller population.

Rather than completely dismiss the data, B maintains the possibility that her results have meaning. Nevertheless, she maintains skepticism over the quality of the data, using “could” to propose a thought experiment that also signals her persistent uncertainty.

Next, B introduces output from the simulation, identifying one part as “particularly fascinating.” She had predicted that if the low-mutator started with a large population, it would be able to match the fitness of the high-mutator. Instead, B saw that the low-mutator maintained its advantage over time. B describes the misalignment between her hypothesis and the evidence from the simulation as something that she “never predicted.” Here B is showing how the simulation has *generated* uncertainty over the ultimate outcome of the population dynamics. She then poses the following question:

> Although a higher mutator strain may be more advantageous in initial generations, does a higher mutator strain remain beneficial over generations, or over time is it actually more advantageous to be a lower mutator strain?

Next B presents and coordinates several different sources of evidence to address her questions. First, she includes results from another group (Group 6) whose investigations revealed a similar pattern of benefit to the high-mutator in the short term and advantage to the low-mutator in the long term. B attributes this pattern to the “the high mutating strain los[ing] its ability to retain mutations faster than the lower mutating strain.”

B then describes how her group revisited the simulation to “expand on the conclusions” from Group 6. She includes screenshots from a set of simulated experiments that show the lower-mutator increasing over time, even when the populations start at equal numbers. Drawing together Group 6’s findings and the simulation output, B ends with support for her original prediction as well as a new claim about long-term dynamics:

> Lower mutator strains in larger populations are able to thrive at an equivalent rate to higher mutator strains in smaller populations for initial generations. But, and more importantly, over many generations, lower mutating strains are more fit than higher mutating strains as they are able to retain beneficial mutations, regardless of initial population size.

B’s conclusion reflects the evolution of her understanding over the course of her inquiry. While she has provided support for her original claim, she has also refined her original claim by introducing a more important effect (loss of beneficial mutations over time).

Argument as part of students’ inquiry

B’s argument does not simply support or reject a claim. Rather, B’s argument reflects her engagement with uncertainty that is part of her ongoing inquiry into this system. In this section we highlight how B’s engagement with uncertainty functioned to motivate, extend, and deepen her inquiry and report on broader trends in the data.

B begins with a question about whether population size can compensate for mutation rate. This question functions to motivate both the experiment (growing strains at different concentrations) and her exploration in the computer simulation. Of the 16 students in this class, 14 used questions to motivate their reports, while two began by asserting claims. Further, B points out an additional question that arose from an unexpected pattern she observed in the computer simulation. This question extends her investigation, leading her to include data from another group and conduct additional trials in the simulation. Nine of the 16 reports show a similar pattern of students extending their inquiries by posing additional questions or problems that arose from either their experiments, simulation output, or a mismatch between them. Across the reports, moves to raise uncertainty functioned to open up the argument to additional factors for ongoing consideration.

B’s move to maintain her interest in her experimental results despite the problems with it, functions to keep her original ideas in play. Rather than reject the data as “inconclusive,” B balances skepticism with an attempt to make meaning. We saw similar moves in 10 of the 16 reports. Some appealed to the underlying randomness of mutation to reject overgeneralization, while others presented multiple possible explanations without settling on one. In each case, students kept plausible alternative ideas in play, thus prolonging the need to continue to investigate.

In the end, B reduces uncertainty by using the simulation to compensate for the poor quality of her experimental results, arguing in support of her initial idea—that a large population size can help a low mutating strain generate enough mutations to compete with a higher mutating strain, at least initially. B then brings together multiple sources of evidence—data from another group and a series of simulation trials—to make a second claim that interacts with the first. In the long term, B claims that it is the ability of the low-mutator to retain beneficial mutations that is more important to its success than population size. That is, B deepened her understanding of how multiple factors interact to influence the biological system. Across the class, 12 of the 16 students also coordinated across sources of data resulting in modified, qualified, or more complex claims.

Discussion and significance

Our results illustrate that many students in this lab class were able to produce arguments that raised, maintained and reduced uncertainty to motivate, extend and deepen their scientific inquiries. We now discuss how the design of the lab may have supported this pattern.

The effects of coupling experimental and computer simulations methods are evident in many of the reports. For different students, either the experiment or the simulation or the interaction between the two surfaced problems or contradictions that students identified and articulated in their lab reports. In addition, discrepancies between the two modes contributed to maintaining uncertainty (Blikstein, Fuhrmann, & Salehi, 2016). For example, when B gets poor quality experimental results, she continues to pursue her original idea in the simulation. When output from experiments and simulations aligned, we saw students, quite reasonably, making stronger claims. These claims were stronger not just because they were supported by two sources of evidence, but often because students used the simulation to posit mechanisms that could explain the same pattern in the empirical data. For example, B explains the data pattern found by Group 6 in terms of the mechanism of "maintaining" beneficial mutations made evident in the simulation.

Data sharing among groups functioned similarly to provide additional evidence that students could use to either maintain or reduce uncertainty. Interestingly, not all groups did this, suggesting that when students did include data from another group, they did so because it was useful for the argument they were making. In general, having the ability to examine and coordinate multiple, imperfect, sources of evidence supported a diversity of ways of engaging with uncertainty in lab reports.

To conclude, we contend that the quality of students' written arguments should not be measured solely in terms of their ability to support one claim to the exclusion of others. Rather, science educators and researchers should value and study how students use argumentation to keep multiple ideas in play and draw attention to problems that can motivate ongoing inquiry.

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