What makes a "good" scientific question?
Supporting independent student-driven inquiry

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Abstract: Students rarely have the opportunity to pose scientific questions or participate in research design. In this study, we identify the criteria that scientists used to guide a group of seven undergraduate students during an extended phase of project articulation. We categorize the criteria according to epistemic and social dimensions and describe the ways in which the students were able to reason with these criteria as they developed their question and research plan.

Rationale

It is rare for undergraduate students to be given the responsibility of articulating a novel scientific question. When students are asked to do so, they are rarely given the appropriate guidance, leading them to pose arbitrary or trivial questions (Windschitl, Thompson, & Braaten, 2008). Part of the difficulty is that the criteria for developing a "good" scientific question are embedded within a community of practice of which undergraduates are not yet members (Lave & Wenger, 1991). Undertaking the difficult task of initiating a new research project requires repeated exposure to the norms and strategies used by the scientific community, rather than simply following an algorithmic "Scientific Method" (Chinn & Malhotra, 2002). We believe that when students are invited to participate in this community they gain opportunities to both engage in sophisticated scientific reasoning and develop their understanding of the nature of science - two key aspects of scientific literacy (AAAS, 1993). With these learning goals in mind, we investigate how faculty can productively support student-driven inquiry.

Study Context

In this research we had the unique opportunity to observe how a group of four scientists helped a group of seven undergraduates define and design a research project in mathematical biology. The context of this work was the Collaborative Learning at the Interface of Mathematics and Biology (CLIMB) program, a yearlong, NSF- sponsored traineeship for undergraduates. The CLIMB students worked collaboratively to solve modeling problems throughout the year and were responsible for executing a novel, model-based research project over the summer. In this study, we categorize the ways in which faculty mentors communicated scientific norms to guide students' progress over the course of the three months preceding the summer research project. We also track how the CLIMB cohort was able to attend to those criteria, identifying the successes and challenges facing the students in this difficult task.

Methods and Analysis

Our data set included detailed field notes of all student-faculty interactions, semi-structured interviews with both students and faculty, and students' written research proposal with faculty comments. We used field notes to both categorize faculty mentors' discourse related to project design as well as student reactions to their suggestions. In our analysis we used a grounded theory approach to develop categories, which were further corroborated by interviews with faculty. We then revisited field notes, the research proposal, and interview data from the CLIMB students to assess the degree to which they, as a group, were able to attend to each of these criteria.

Findings

We identified six criteria articulated by the science faculty, which we grouped into two broad categories: 1) *Epistemic Criteria* – in which faculty focused students' attention on the type of knowledge they sought to generate, and 2) *Social Criteria* – in which faculty emphasized the subjective nature of achieving consensus. We provide a brief description of each criterion grounded in examples from our field notes. It is important to note that we highlight these criteria because they emerged repeatedly throughout the project articulation phase, often in interaction with one another, highlighting the dynamic process of defining and refining a research project. Finally, we briefly comment on the extent to which CLIMB students were able to attend to these criteria.

Epistemic Criteria

1a. Consider the data patterns that need explaining. Faculty mentors urged students to ground their research project in a biological pattern in need of an explanation. When students expressed an interest in modeling either influenza (flu) or measles, faculty asked, “Are there patterns?” Students found that the yearly patterns exhibited by flu were too complex to reveal obvious patterns. This led them to focus on measles vaccination patterns in the UK, for which data on disease prevalence and vaccination were available. In general, finding data was not a major challenge for students, but understanding what about that data needed explaining required that they attend to other criteria. *1b. Consider the appropriate methods.* The students were urged to think about the modeling approach they would undertake simultaneously with refining their question. Faculty discouraged questions that were descriptive or statistical in nature, such as, “will measles prevalence continue to rise?” Instead, they pushed students to think about the *mechanism* they would build into their model. This prompted the students to consider mechanisms of disease transmission. Considering the mechanisms that drive patterns was more difficult for students; they often asked empirical or statistical questions instead of focusing on the underlying theoretical model. *1c. Evaluate existing models.* To guide students towards theory, faculty pointed them to the existing literature and asked them to evaluate the theoretical soundness and the empirical accuracy of prior models as a basis for their own research. This led students to understand that measles models should theoretically include age-structure to account for population heterogeneity in infection susceptibility. Students also considered a model of human behavior that relied solely on dyadic information transmission, which led them to think about adding direct learning from the environment into their model. Students were quite successful at finding gaps in existing research, but were less discriminating about which of these were most important. They had to overcome a tendency to add things into their model simply because “they had not been done before.” *1d. Imagine the possible results*. Faculty urged students to “imagine what the results might look like.” Students created a long list of possible components to add to their model, but the faculty mentors asked them to focus on the components that would make a difference in the results. This was especially difficult for students who instead tended to focus on adding in model criteria because others had added them or because they made the model “more realistic.” It was primarily in retrospect that students were able to see that some aspects of their model (such as age-structure) did not significantly alter the model results, while others (such as the structure of information transfer) had a significant impact. In response, some of the students modified their understanding of the research question even as they were preparing to present their results.

Social Criteria

2a. Do what is “worthwhile.” Faculty mentors urged students to choose a problem that would engage them throughout the summer. The mentors were willing to admit that this was a somewhat subjective decision, suggesting, “do what motivates *you*.” While students were initially hesitant about pursuing a disease model (because the previous year’s cohort had already done so) they ultimately agreed that they wanted to pursue a project with social relevance. This helped them narrow down their options substantially. *2b. Do what is practical.* Faculty encouraged students to bound the problem space in accordance with time and resources. Students decided to leave out many components of their original model in the interest of tractability. However, they were later encouraged to assess the epistemic implications of these decisions. For example, students were asked to explain why they ignored immigration but included age-structure – a task they found much more difficult. This is just one example of how each of these categories, both epistemic and social, overlapped and interacted with one another throughout the process, again emphasizing the need for students to consider many of these criteria simultaneously.

Implications

Throughout the process of project articulation, faculty mentors provided many opportunities for students to consider the social and epistemic criteria used by the scientific community. In general, the group was able to identify interesting questions, but students had more difficulty articulating the significance of questions that arose as they moved into model construction. This result suggests that students need to be continually reminded to think deeply about their research question even as they move into later stages of research. Future research will address the extent to which exposure to these epistemic and social criteria has lasting impacts on students’ images of science.

References

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