Let Your Data Tell a Story: Disciplinary Expert Feedback Locates Engaging in Argumentation in a Holistic System of Practices

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Abstract: Trends in science education promote engagement in authentic knowledge in practice to tackle personally consequential science problems. To better understand what authentic practice looks like in a classroom, we examine interactions between scientists and students on a social media platform during two pilot enactments of a project-based curriculum focusing on the ecological impacts of climate change. Scientists provided feedback to students on infographics meant to communicate to an audience about climate change. We conceptualize the feedback and student work as boundary objects co-created by students and scientists, and analyze the structure and content of the scientists' feedback. We found that in feedback on a particular practice scientists encouraged students to participate *systemically* in practices instead of isolating one practice. Engaging with scientists around established scientific texts and data sets provided students with a platform for developing expertise in other important scientific practices during argument construction.

Introduction
The *Framework for K-12 Science Education* and the Next Generation Science Standards were the first science education policy documents in the United States to position scientific practice on equal footing with science content knowledge through a three dimensional science learning model that partnered specific student performance expectations with related disciplinary core ideas, practices, and crosscutting concepts (NRC, 2012; NGSS Lead States, 2013). This practice turn in science education shifts focus away from knowledge accumulation to its application in context, with the intention of making visible to learners the performative aspects of research. In response to Next Generation curriculum structures, designed curricula should be oriented towards developing students' *disciplinary practice knowledge* in addition to content knowledge*,* and central to our understanding of this knowledge base is the inherent social, holistic, and systemic nature of science knowledge construction. However, more research is needed to understand what disciplinary practice knowledge looks like in diverse contexts, and how to equitably support implementation at scale. This study investigated how a curriculum design that partnered high school biology students with related disciplinary experts helped cultivate disciplinary practice knowledge through engagement in a holistic system of science-related practices during the shared construction of an evidence-based classroom artifact, an infographic, intended to communicate the research and implications of climate change on ecosystems.

We leverage social practice theory, specifically the lens of legitimate peripheral participation (Lave & Wenger, 1991) to understand how students became engaged in a system of disciplinary practices as they constructed evidence-based arguments to communicate the ecological impacts of climate change in partnership with disciplinary experts. Through the process of legitimate peripheral participation, individuals learn with others and develop expertise by observing and increasingly participating on the edge of a community of practice as they develop the shared discourse and practices of a given community (Lave & Wenger, 1991; Engle & Conant, 2002).

The curriculum design in this study leveraged everyday technologies to situate high school biology student on the boundary of related disciplinary communities of practice by partnering them with scientists as they developed a scientific artifact, the infographic. We analyze the infographic as a boundary object, which Star & Griesemer (1989) define as "objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them yet robust enough to maintain a common identity across sites." Here, the infographic helped scientists and students navigate disciplinary discourse around climate change argumentation, evidence, and communication and situated students on the boundary of a related community of practice in which experts modeled the rich system of disciplinary practice involved in crafting and communicating scientific arguments from professional data and evidence. Here, the infographic and the shared data set as boundary objects (Akkerman & Bakker, 2011; Star & Greisemer, 1989; Wenger, 1999) that mediated and scaffolded scientific discourse between learners and disciplinary experts.

Methods
This study draws on data from a larger curriculum development project to create year-long courses in Life Sciences and English Language Arts. Design principles included giving students opportunities to engage in

authentic scientific problems, to utilize scientific practices such as performing fieldwork, analyzing and using computer models, and writing scientific texts. The curriculum used a social media platform that connected students to each other, and also to disciplinary experts. Both courses were created using a design-based research approach in which individual modules were designed, implemented, and revised based on findings. This study examines the student-scientist interactions that occurred in the first two six-week pilot enactments of a module on the Ecological Impacts of Climate Change in the Life Science course. The first pilot implementation (11 students) occurred from March - April, 2011 at Shale High School, an alternative school in a rural town outside of a major city. We conducted our second pilot study of the climate change curriculum from Oct-Dec 2011 in two 9th grade classrooms (40 students) at Quartz High School, an alternative school in an upper-middle class suburb of a major city. In the climate change enactments, 14 disciplinary experts reviewed student work, interacted with students via Skype, and visited the classroom.

Analysis targeted the interactions between scientists and students that occurred during the two pilot enactments, including written feedback scientists gave students on their infographic drafts (5 from Pilot 1, 17 from Pilot 2, provided on the social media platform) and scientists' questions and feedback on student's final presentations (Pilot 2 only, in person). Documents containing student work and scientist feedback and transcripts of scientist-student interactions were analyzed using the mixed-methods software Dedoose. Assertions were generated based on emergent themes and we searched the data corpus for disconfirming evidence (Erickson, 1986).

Findings

In the feedback from the scientists, the construction of successful arguments and communication artifacts was deeply entwined with other scientific practices and scientists modeled ways in which they would approach a problem or improve the argument or communication. While scientists reference all practices included in the NGSS, below we discuss in detail the practices of asking questions, designing and conducting investigations, constructing explanations and communicating information.

1. Wondering, speculating and asking questions. Scientists' open-ended questions allowed them to engage with student work by using the evidence students provided as a starting point for further investigation. In doing so, they revealed their own problem-solving processes. For example, in one instance a scientist responds to a student group's work on sea level rise and the monk seal by considering other climate parameters that could be affecting the monk seal:

> I wonder if rainfall plays a major role in the Monk seal life . . . for instance – do they only go to the breading[sic] ground during the dry season or the wet season? If you can figure that out – then you might be able to argue that a change in climate can lead to a change in rain patterns and that might have some sort of impact on the seal life cycle?

In this excerpt, the scientist is pursuing a line of thought that would supplement and fortify the students' initial argument about the impact of climate change on monk seals by providing a second line of evidence about impacts. She "wonders" if changes in rainfall could potentially have consequences for the monk seal's mating. This is an open-ended, speculative question in that it is not a question that the scientist knows the answer to *a priori*. Instead, she models what her own practice would be in theorizing about relevant variables and interactions, offering a hypothesis that she encourages the students to "figure out" if it is supported or not by available evidence. If it is supported, the scientist suggests that having multiple lines of evidence would improve the argument. As opposed to a standard view of scientists as sources of information, through wondering or speculating questions, scientists did not supply any new "facts" or evidence, instead demonstrating how they would approach thinking through possible relevant interactions and evaluating whether or not they supported a particular argument. This example demonstrates the connection between two key practices in the Next Generation Science Standards: asking scientific questions and developing arguments from evidence. Asking these questions was a necessary step in developing rigorous, convincing arguments because it is how one obtains evidence and considers alternate or additional contingencies.

In many instances, scientists asked questions that were open-ended, but that it can be reasonably assumed the scientist already knew the answer to, either in full or in part. These were coded as "probing questions" and were the most common question type. These kinds of questions also modeled scientific questioning practice, and supported argumentation as through these kinds of questions, scientists processes of building arguments by highlighting the need for more evidence, more explanation or clearer logic.

2. Scientific explanation in argumentation. The infographic assignment required students to both explain the scientific evidence and use it in an argument about how climate change might affect ecosystems. In feedback to students, scientists critiqued the explanations for completeness and correctness, offered supplementary information that supported student explanations, and made suggestions about how to improve coherence between the text and graphics for explanations.

Scientists' comments included supplemental factual information that expanded student explanations. For example, one student group proposed that the Canada Lynx and snowshoe hare would not be able to shift their range north because they already live at high latitudes. The scientist giving feedback added in a comment: "In addition, the area north of the lynx's range is mostly tundra and lynx are found mostly in forest." This statement provides new information that both supports the student's argument but also builds out their explanation of constraints on range shifts. By providing this just-in-time content, scientists provided input aimed to help students create more thorough and conceptually accurate explanations.

Scientists also pointed out places that students could improve their argument by incorporating more scientific explanations. For example, in one instance a scientist encouraged a student to investigate and explain the impacts on plant growth in more detail:

> You might want to help the reader make the connection between climate change and plant growth by explaining some ways climate change might affect plants – what are some things plants need that might be changing?

In this instance, the scientist specifically gears the student to consider what would be helpful for "the reader"—thus, this scientist is concerned with explanations needed to communicate the student's argument. Scientists also noted when the text and graphics didn't align, specifically when explanations of figures and graphs were missing. Scientists' feedback centered on the importance of not only including data but explaining it well in order to clearly communicate to an outside audience.

3. Designing and carrying out investigations. In the unit, students designed and carried out an investigation into the effect of changing climate parameters (e.g. temperature, water) on Wisconsin Fast Plants, a fast-growing *brassica* species and conducted fieldwork on phenology through a citizen science effort. While students reported that they enjoyed both activities, students rarely utilized the data they collected themselves through these investigations on their infographic. Rather than using their own data, they instead pulled from established data sets, such as the climate model results discussed above. This deviates from a common inquiry model in science classrooms in which students carry out their own investigations through physical manipulation. Instead of using their own results, students engaged in an investigation more similar to data mining, in which individuals query existing data to answer questions. This is an authentic practice in climate science, as much work is conducted as analysis of large, shared data. The feedback scientists provided on this kind of investigation overlapped with feedback on data analysis, use and interpretation, and there were no instances in which scientists gave specific feedback on how to carry out empirical investigations or collect data.

4. Obtaining and communicating information. The infographic assignment provided students with the opportunity to employ multiple modalities in construction of their argument. This is congruent with common scientific communication practices in which both visual elements (e.g. graphs, tables, pictures) and text are used. One scientist noted the authenticity of the infographic product as similar to scientific poster presentations. She used the idea of a story to frame the construction of a poster (or infographic) and positioned the student's work as part of a real scientific practice and also provides insight into how a scientist might think about constructing a poster that tells a "story". A "story" provides a different connotation than an "argument" or "infographic." The scientist suggests adding visual elements that would also help tell the story: "You could even draw an arrow between the facts and analysis or put a box around them so that it's very clear that they're connected." This feedback highlights the role that design has on its success as a communication tool.

Many scientists made comments about the appropriateness of visual elements, the placement and arrangement of the elements, and suggested new visual elements to include to improve either the ability of the infographic to communicate to a particular audience, or the validity of the argument. For example, scientists evaluated whether or not visual elements actually provided support for the argument. Referencing the inclusion of a map of Florida sea level rise in an infographic about polar bears, one scientist asked: "Are changes in Florida relevant to polar bears?" suggesting that the visual element might not be the most appropriate. In some cases, scientists made comments about visual elements they thought would be appealing or helpful to readers from a communication standpoint.

Conclusions and implications

Disciplinary practice knowledge is a broad and diverse arrangement of knowledge and practices that take many forms in professional, community and learning settings. The findings from our study suggest that scientists' views and communication of their own practices align with the integrative three dimensionality of the NGSS. By modeling their own questioning and learning processes, scientists encouraged students to craft and interrogate their arguments by employing a suite of related practices. For the scientists, providing feedback on students' arguments and communication necessarily involved critique on the interrelated web of scientific knowledge construction practices. Multiple practices can and did occur in the same act-- developing an explanation was a part of argument construction, and using models required data analysis. The boundaries between the practices are more fluid than the rigid list of eight in the NGSS might suggest.

The practice of modeling through literary inscription (Latour & Woolgar, 1986) was also intimately tied to argumentation and communication of data, and professional data sets served as useful boundary objects that enabled students and experts to mutually construct climate change related arguments across classroom and professional boundaries. During the climate change unit, students generated their own climate-change related data through classroom phenology experiments, in addition to data mining publicly available professional climate change data sets. However, in this case the student-generated data was not robust enough to serve as a boundary object across contexts as students rarely leveraged their own data to support or communicate evidence for the ecological impacts of climate change on their infographics. Although the scientists were aware of the student-generated data, they also never requested or added to student-generated data pieces. In contrast, publicly available professional data sets proved to be robust boundary objects that mediated disciplinary discourse between students and scientists, and were easily leveraged to communicate the ecological impacts of climate change to diverse audiences. The adaptability of these professional data sets across contexts enabled the scientists to effectively model disciplinary ways of knowing for students.

Boundary objects, such as common data sets, are commonly used in professional science context to connect related communities of practice, to provide diverse lenses and expertise around existing knowledge bases and to engage related practitioners in sense-making practices around bounded pieces of evidence. Our research suggests that social networking technologies and disciplinary data sets can effectively position students as legitimate peripheral participants on the boundaries of related disciplinary communities of practice. As Wenger (1999) noted, innovative learning can happen on the boundaries of these communities in ways that enable students to maintain their existing identities regarding climate change perspective, while robust boundary objects can allow them to work in partnership with disciplinary experts to construct evidence-based stories of the ecological impacts of climate change that engage students in holistic learning as described by NGSS.

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