Supporting Alignments in Scientific Activity: Moving Across Question, Evidence, and Explanation

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Abstract: A core practice of science is planning and conducting investigations. This practice needs reconceptualizing, to account for where work happens between identifying a phenomenon and designing an investigation, and between gathering and analyzing data to support developing an explanation of that phenomenon (Manz et al., 2020). Teachers, supported by curriculum materials, need to engage students in becoming more involved in the decisions related to what data to choose as evidence, how to represent data to answer specific questions, and what conclusions can be drawn from data. We present results of a design study in which students investigated a dataset to answer a question about a major change to an ecosystem, using a technology tool, CODAP. We explore how the curriculum and teacher supported students in taking up different facets of data practices that support figuring out a phenomenon while moving between investigating and developing explanatory models.

Subject/problem

Historically, students' experience of science investigations follows a "cookbook" lab approach that involves following procedures given to them by teachers, with little opportunities for grappling with issues that scientists do of choosing measures and kinds of analyses to perform, or taking up questions of how to handle missing data (Banilower et al., 2018). That is, school science investigations give students little opportunity to gain a "grasp of scientific practice" (Ford, 2008) or gain a feeling for the work of science (Jaber & Hammer, 2016). This is a problem because recent reforms in science education reflect a "practice turn" (Ford & Forman, 2006), which views science learning as bringing students into the community of scientific practices through experiencing for themselves how and when to use such practices to understand a compelling, natural phenomenon. Engaging in disciplinary practices is intended to support students to see science as an enterprise concerned with improving understanding of the natural world through mutually supporting practices.

One of the core practices emphasized in *A Framework for K-12 Science Education* (NRC, 2012) is planning and carrying out investigations. Manz et al. (2020) argue that this particular practice needs reconceptualizing in science education, to account for where real work happens in identifying a phenomenon, designing an investigation, and gathering and analyzing data to support developing an explanation of that phenomenon (Figure 1). Aligning work across the elements in Figure 1 represent areas of uncertainty but also opportunities for students to be more involved in the decisions that occur in authentic scientific investigations which in procedural lab activities remain largely unseen. For instance, before analyzing data, students need to decide what data are relevant to answering questions.

In this paper, we explore how a curriculum and teacher supported students in engaging in data modeling (red box in Figure 1) within an investigation, where students define measures and articulate how such measures can help them make progress in understanding a phenomenon, and where they draw conclusions from data they represent. In this design study, students were given opportunities to consider how data could answer a question they had, represent data using a technological tool, and draw conclusions from it. We sought to understand how a curriculum, teacher, and students can work together to take up different facets of data modeling for making sense of a phenomenon while investigating and developing explanatory models.

Conceptual framing

In drawing upon a vision of science education that sees the importance of bringing students into the practices of science, we build on Manz et al.'s (2020) work towards conceptualizing the investigation as "developing alignments between phenomena, empirical models, data models, and explanatory models" (p. 1166-7; Figure 1). Much scientific practice unfolds in moving between these elements, and since the decisions and assumptions around methodology are often obscured from view, this 'alignment' work is needed to highlight the interconnected, interdependent, and iterative nature of moving between these elements as new questions arise and explanatory models get refined. Accordingly, there is a need for helping students engage with scientific practice in moving across these spaces, characterizing the facets of practices occurring there, and subsequently learning how to support teachers and students through curriculum and professional development.

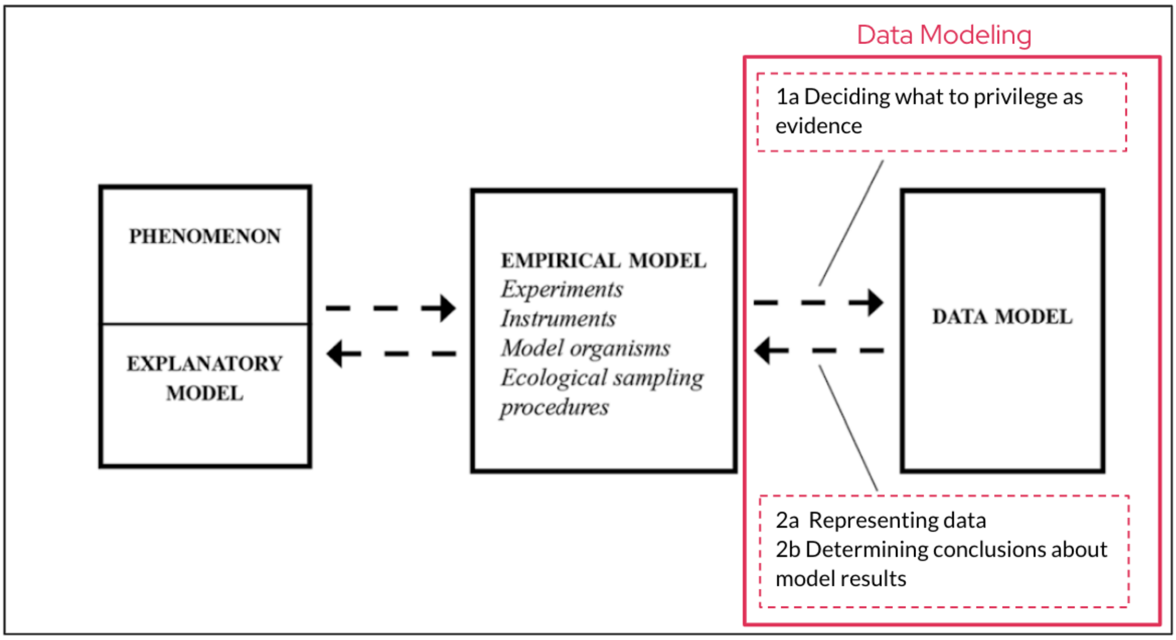
As we are concerned with supporting students in developing data practices, we focus on data model*ing* as occurring across the act of developing a data model. In our context, the data model is where students coordinate different artifacts from the lesson and try out different data presentations in the Common Online Data Analysis Platform (CODAP), a free, web-based data visualization tool developed by Concord Consortium (2019) that functions as a 'sandbox,' where students can explore and make sense of data. The alignment work taking place during data modeling serves to support students in developing a data model in the context of understanding a phenomenon, that is, engaging in such acts as defining measures, visualizing data, and constructing explanations with data. Of particular importance are data modeling activities that help students with moving from an initial, empirical model of a phenomenon towards specifying and then interpreting evidence from data models to draw conclusions that help students update their explanatory model of a phenomenon.

Teacher moves and curricular supports for specifying a data model

We are particularly concerned with studying how students are supported to engage with real world, messy data sets in the context of a curriculum that supports figuring out an ecological phenomenon. The data students engage with were collected by scientists to answer different questions, so one practice we focus on in specifying the data model is deciding what to privilege as evidence (1a in Figure 1) in response to *students'* questions.

Both curriculum materials and the teacher play crucial roles in supporting students' alignment work. Curricular tasks that engage students in determining, defining, and operationalizing data as evidence and help them grapple with decisions about what data to consider as evidence are important for facilitating students' scientific work in this alignment work (Manz et al., 2020). Teacher moves to problematize or make clear what is at stake in these decisions can help students see how the work is meaningful (Reiser, 2004). Talk moves that re-voice students' ideas about appropriate measures can also help students to narrow in on evidence needed to answer a given question (Watkins & Manz, 2022).

Figure 1
Investigations Framework; in red, we highlight the data-related practices occurring during data modeling. Adapted from Manz et al., (2020)



Teacher moves and curricular supports for interpreting evidence implied by the data model

Another key alignment involves investigating ways to represent data (2a) and drawing conclusions about data (2b), particularly to be able to communicate to themselves and to others how their data model helps explain part of a larger phenomenon (see Figure 1). The need to focus on these moves arises from both the opportunities to give students a feeling for the challenges scientists face in doing so and from prior research, which suggests interpreting and communicating data model results is difficult for students (Zangori et al., 2013).

There are a number of strategies for organizing curriculum activities and teaching that can facilitate this move from data model to explanatory model. In deciding how to represent data, students can be supported in grouping or “binning” cases in the dataset in various ways in order to surface different relationships (Erickson et al., 2019). Other strategies include inviting students to consider how the results of an investigation bear on the phenomenon at hand and addressing the gaps between their investigation models, evidence, and focal phenomenon (Manz et al., 2020). Talk moves can support students in expanding their initial thoughts towards pointing to the evidence that supports their claim (Michaels & O’Connor, 2017; Windschitl et al, 2020). We aim to better understand how curriculum tasks and teacher facilitation can work synergistically and with students to align an updated data model with the empirical model.

Methods

This embedded, single case study as part of a larger, multiple case study design (Yin, 2009) focused on one enactment of a lesson as part of a unit of study on ecosystems in which students engaged with real-world data about rainfall and large herbivore populations in the Serengeti between 1960 and 1975. The case is a paradigmatic one, chosen to illustrate what rich data modeling opportunities can look like in a classroom.

We address three primary questions based on the areas of alignment surrounding the data model: How did the teacher, curriculum, technology tools, and students work together to: (1) Decide what to privilege as evidence to answer the question? (2) Represent the data?, and (3) Generate tentative conclusions about what the data model reveals about the phenomenon?

Participants

The focal participants in the study were a teacher and students in a single classroom. The teacher was one of seven teachers who participated in a field test of materials as part of a larger initiative to develop open access (OER) materials aligned to the Next Generation Science Standards (NGSS Lead States, 2013).

The teacher in the study, Melissa, taught in an urban high school serving primarily Latinx students in a large school district in the Mountain West of the United States. At the time of the study, she had been teaching for 13 years, 12 as a high school science teacher. Melissa identifies as white and female. There were a total of 23 students in Melissa’s ninth grade biology class. Of these, 11 identified as female, 11 as male, and one as gender nonbinary. Nearly all identified as Latinx (20), with one Black student, one Asian American student, and one white student. She had three students with identified learning disabilities and one gifted student.

We chose this teacher for two key reasons. First, we had multiple sources of data available from her enactment: a video recording of the full lesson and multiple student work artifacts from her classroom. Second, her own teaching to us embodied a general approach of opening up investigations for students, where students were asked to make key decisions about data with her support, rather than simply follow her directions.

Intervention

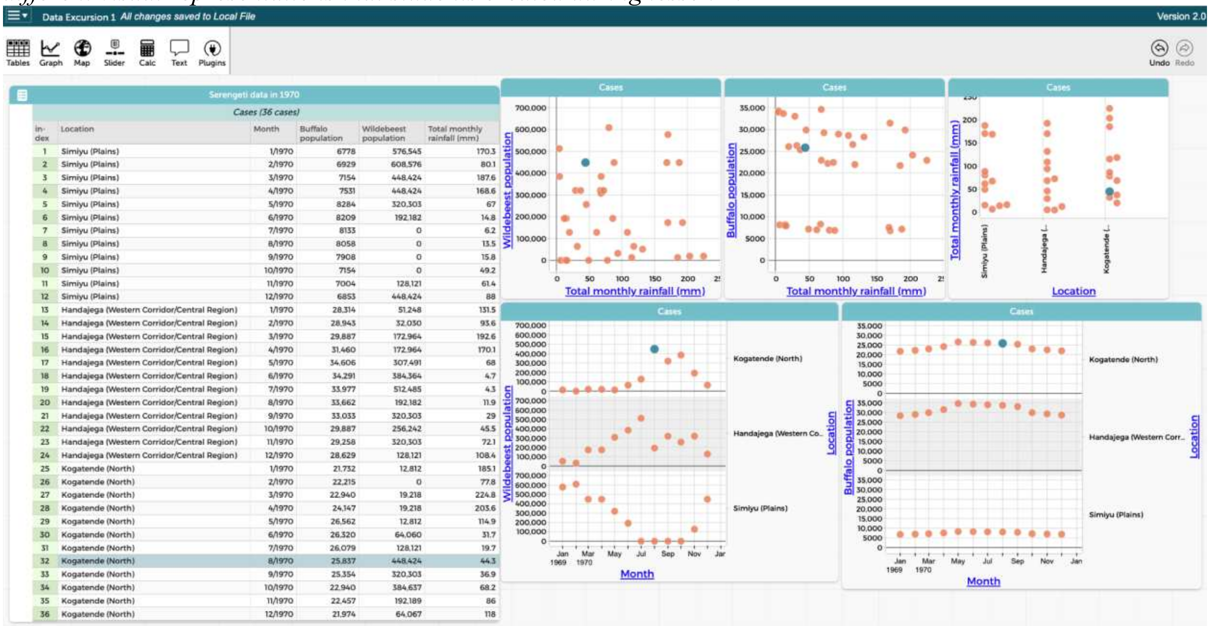
We took a design-based approach to developing and co-designing with teachers a set of *data excursions* and accompanying tools and routines for supporting students’ data literacy skills within two lessons of a widely used, open access, storyline-based high school biology curriculum. These data excursions were intended to allow students to interact with existing datasets to query their contexts, change the way they are aggregated and represented, and explore their properties, in order to explain changes to the Serengeti ecosystem that led to a dramatic increase in the populations of two large herbivores, buffalo and wildebeest, between 1960 and 1975. Rather than present students with cleaned up data, we sought out the original data for students to engage with to more closely approximate how scientists think about and use data (see Figure 2).

In the focal lesson, students addressed the question: “Was the increase in population of wildebeest and buffalo caused by an increase in the availability of food?” After an initial discussion to consider what data they might need to answer the question, students watched a video from an ecologist who studied the Serengeti during that time period, who said they did not have data on food from 1960-75, so they had to estimate food availability by looking at data on rainfall.

Students were then introduced to CODAP, which features a drag-and-drop interface that simplifies creating and modifying graphs of the dataset. All representations in a document—tables and graphs—are linked so that any data points highlighted in one representation are simultaneously highlighted in the others. Both the software’s ease of use and this “linked representation” feature is intended to help keep students focused on the meaning of the data and support their ability to see and interpret patterns in the data (see Figure 2).

The curriculum included a handout for student groups, to specify what data they planned to analyze, what patterns they noticed in the data, and their explanations of the lesson-level question in a "claim-evidence-reasoning" format (McNeill & Krajcik, 2012). After collaborating in small groups, the whole class discussed the groups' ideas to arrive at a consensus explanation.

Figure 2
CODAP platform with dataset for the lesson 2 data excursion, and student work examples demonstrating the different visual representations that students created during lesson 2.



Data sources

This case study relied on multiple sources of data, stemming from the enactment of lesson 2 in Melissa's class. Prior to the first author entering her classroom, Melissa underwent consenting procedures with her students. The first author captured video recordings of the lesson, which spanned two fifty-minute periods of instruction over two consecutive days. The camera was set up towards the front of the room and focused on Melissa to protect the privacy of students who had not consented. The first author created activity logs while observing the lesson over the two days. We made transcripts of the video recordings to support analysis through the Vosaic video analysis software. Melissa provided graphs from nine different student groups, each of which had between 2-3 students, and student notebooks from 11 students in the class which captured their responses from the handout described above. Lastly, we also drew on the curriculum materials as a data source.

Approach to analysis

The first two authors undertook an interaction analysis (Jordan & Henderson, 1995) to help us identify key moves made by the teacher and students to decide on what data to privilege as evidence and also to develop conclusions from the data, focusing especially on the moves made by the teacher to support student sensemaking related to data modeling. We relied on both inductive and theoretically-driven coding, guided by the Manz et al. (2020) framework. We also looked to Lehrer and English's (2018) data modeling framework for explicit data modeling moves - posing questions that can be answered with data, grappling with decisions about the design of investigations, and building understanding of the available attributes.

We began with an initial viewing of the lesson 2 videos to develop ideas about the teacher moves supporting data modeling. We then undertook an iterative process of developing a coding scheme and segmenting the video, resulting in a refined coding scheme allowing us to identify moments of moving across question, evidence, and explanation. Identifying moments moving across these elements highlight where students can be involved in scientific activity. The decisions around investigating support alignment - where students identify the relevant part of the larger phenomenon to investigate, decide how a dataset can help answer this part of the phenomenon, and develop an explanation based on data representations and conclusions. Table 1 represents these movements within our coding scheme. As we moved back and forth between developing our coding scheme and watching the video, we also noticed moments that did not align necessarily with these transitions but were necessary for supporting next steps - where certain knowledge or skills were needed for students to move forward. The first two authors discussed the coding together and adjudicated all disagreements. As a form of member checking, we shared our account with Melissa, who provided additional interpretations of her actions and students' experiences.

Table 1
Identifying Moments of Alignment Moving Across Data Modeling Coding Scheme

Code	Description / *Examples*
For Specifying the Data Model	
Deciding What to Privilege as Evidence	Build understanding of available attributes; Understand what the scientists did who collected the data; Identify the attributes that are best for answering their question; Predict or anticipate what the data might look like. Examples: *Students connect factors that affect food availability with how to measure it; Melissa problematizes this measurement dilemma, bringing students into this practice*.
For Interpreting Evidence from the Data Model	
Representing Data	Land on the data representation(s) that can communicate the claim with the data set. Example: *Some students graphed the relationship between rainfall AND population*
Determining Conclusions	Make sense of what the data and data representations tell in relation to their question. Example: *Melissa pressed for evidence-based explanations: "How do we know they are moving around?"*
Background Knowledge and Skills	Integrated as needed for supporting alignments and next steps: Using a new tool. Example: *Curriculum provided support for using CODAP*; Additional background information Example: *Curriculum and Melissa provided context of the Serengeti*; Connections to prior learning and students' everyday experiences. Example: *Student compares drought to Dust Bowl.*

Analysis and findings

We present our findings as a "play-by-play" (Derry et al., 2010) of the teacher enacting and students engaging in the lesson 2 data excursion, focusing on data modeling. We answer our research questions by describing how the teacher, curriculum, and students worked together leading up to and *specifying the data model*, in part by deciding what to privilege as evidence, and subsequently *interpreting evidence from the data model*, in deciding what data to represent and determining conclusions about the data model.

Specifying the data model

On the first day of this lesson, Melissa began by re-engaging students about the larger phenomenon under study, as called for in the curriculum. Having noticed there was a huge population increase in wildebeest and buffalo from 1960-75 in the previous lesson, she prompts students to consider why scientists wanted to investigate that. She asks, problematizing the phenomenon itself, "Why was that weird? Why did they start studying it?" Melissa then asked students to recall, "What did we think we should look at first?" Here, there is work in aligning the phenomenon to an initial investigation model, by helping students determine the relevant parts of the phenomenon and deciding what next steps are needed to build an explanation of it. Students came up with ideas like, "food, predation, and climate," as starting points for investigating the phenomenon further.

Melissa and the students agreed that the class should start with whether an increase in food caused the increase in wildebeest and buffalo populations. The curriculum calls for students to generate ideas for what the data would need to show, if the increase in food was in fact the cause of the population increase. As prompted in the materials, Melissa asks, "What changes would tell us that food was a reasonable cause for the [population] growth?" This prompted students to consider the attributes that are best for answering their question and beginning to anticipate what the data might look like.

This was a challenging thought experiment for students, so Melissa problematized how to answer the question for students, making clear this was not an easy task for scientists either. She started by asking, "How could they measure this?' and, "What might be challenging about measuring it?" One student puts forth, "have a robot do it?" Melissa, while acknowledging the idea, reminded students that this took place from 1960-1975, meaning the technology couldn't do that. Melissa followed with, "If they couldn't measure it directly, how could they estimate food availability?" These moves supported students in understanding what the scientists did and the context for collecting the data. Students seemed to struggle in coming up with a proxy for estimating this attribute, so she asks, "What do we think influences it the most?"

Melissa noticed a moment of needing to draw on prior background knowledge and explicitly invites students to make connections to what they've learned about how plants grow and thrive. Students drew on their prior everyday and school-based knowledge - responding with "sun, soil, water, and it depends on the weather." Melissa named this as similar to the real work of scientists: "This skill of figuring out what data to look at to answer a question is not an easy one. This is what legit, actual scientists have to do. Of all this data, how do we make sense of it? What do we need to pull and use and what do we need to be able to put aside?"

Before engaging in any graphing, Melissa asked students to consider what questions could, and couldn't be answered by the data at hand, as called for in the materials. Here, she supported deciding what to privilege as evidence (in this case, the attributes available) about whether the main investigation question could be answered with the given dataset. Also, as the curriculum directed, students made a plan for what relationships to graph and anticipate what the graphs would be likely to say, if more food is the cause of the increase.

In this part of the lesson, Melissa and the curriculum both supported students in aligning an investigation question to constructing a data model, by scaffolding what attributes would be helpful as evidence, bringing students into the uncertainty that the scientists grappled with around measuring food availability in a place as large as the Serengeti, and asking them to anticipate what the data model will show if food was the driver of the population increase.

Interpreting evidence from the data model

On day two, students made graphs focused on discovering, as the teacher put it, "what they can about the ecosystem," or as directed in the materials, whether there's a relationship between rainfall and buffalo and wildebeest populations (a question for which the dataset can provide an answer).

Students first watched a video explaining how to create and manipulate graphs in CODAP, providing the skills needed to access the tool, and modeling how to look at the population of buffalo and wildebeest over the course of a year in three locations in the Serengeti. Then, students made CODAP graphs in small groups. Melissa instructed them to construct "other graphs to better understand what was happening in the Serengeti." The graphs students produced mostly imitate the video tutorial in visualizing some attribute over the course of the year in the three locations. Students chose wildebeest population, buffalo population and monthly rainfall as the attribute to visualize in this way, but only two of the eight student groups made graphs that looked at both wildebeest (or buffalo) population AND rainfall simultaneously, which would be necessary to investigate the relationship between rainfall and population. In the subsequent discussion, Melissa called on those two groups to share what these particular graphs showed.

As students turned towards making sense of the data and representations, Melissa's interventions suggest they need reminders of what the data actually convey, and in some respects, the students' struggles with producing graphs that could help them see the patterns the curriculum intend prove to be a stumbling block for collective sensemaking. Melissa asked students to try and account for the relationship of rainfall and population through a line of questioning. Melissa pushed them for mechanisms, too, though it's not clear that they could answer the question she posed to them from the data at hand, she asks, "How do we know they are moving around? What are their needs that are different?" Student responses here included, "Wildebeest are in the plains in the wet season and then go to the other regions in the dry season," and, "They go to the other regions because there's water there," connecting to previous observations that there were rivers in certain regions.

She also pressed students to go beyond the simple statements of patterns they are seeing, and to specify what the connection between rainfall and population would be if food were the cause of the population increase: "We still haven't made a connection between them, though. So, what is the connection?" She started the sentence, "When the rainfall increases, they…" Here, we see Melissa guiding students in making sense of what the data and data representations tell them in relation to their question.

Towards the end of this lesson, Melissa invited students to go back to the Driving Question Board (DQB), a record of their own questions from the first lesson developed to guide their investigations, as a resource to remind them of the bigger question they came to the lesson with: whether the rapid increase in population from 1960-75 was due to an increase in rainfall. She asked, "Do we have data over several years?" "No," students say. In fact, the lesson did present them with such data, but students hadn't figured out successfully as a class which graphs would help them answer their question. She followed with, "What questions do we still have? What have we still not figured out? Let's go back to our DQB. Do we know why they are increasing? Remember, this is where we started."

In this part of the lesson, students interpreted evidence from their data models in order to answer the question about whether they see a relationship between rainfall and population size, and once they answered that, they considered if they can attribute food as the cause for the large growth in population size from 1960-75.

Melissa and the curriculum supported this ‘narrowing in’ on a piece of the phenomenon, taking a deep dive into the data, making sense of the data in order to explain this one aspect of the phenomenon, and then expanding back out to the central phenomenon of the unit, explaining the increase in buffalo and wildebeest populations on the Serengeti. Further, we see how students can be made aware of and be involved in some of the decision-making around data, and we see how the curriculum and the teacher support alignment in moving from question to evidence to explanation.

Discussion

Through this case study, we have analyzed how sensemaking about data can be supported in a high school biology unit focused on ecological systems. In addition to considering the complexities of using previously-collected data, we consider how data analysis is particularly challenging in the context of ecology, in which multiple time scales are relevant and simple causation is elusive. We have highlighted, too, how both curriculum and teacher moves can support navigating this complexity.

While Manz and colleagues (2020) and Lehrer and English (2018) wrote about contexts in which students collect firsthand data, our study provides the opportunity to showcase the complexities of presenting students with real-world datasets collected by scientists and what it can look like to engage students in understanding the circumstances under which the data were collected. We see here that the curriculum and the teacher are doing some of the “heavy lifting” students might have done if they had instead collected their own data. For example, the problems of measuring relevant quantities are highlighted to them in the materials, in the form of a video presentation and teacher moves that problematize how to measure food availability. The teacher, for her part, poses questions highlighting decisions needed to be made and why they are not simple to make.

In addition to the explicit data modeling moves outlined in Lehrer and English, we observed moves teachers can make to notice trends in data that then facilitate students’ sensemaking. We saw how Melissa was responsive to her students’ needs and took time to provide students with language and routines for looking at graphs, in one instance, not mentioned in our findings, introducing language around ‘positive’ and ‘negative’ relationships. As we have continued to revise the data excursions based on field testing, such instances have helped us realize that we need to provide more support for looking at and noticing patterns in data. Further, our coding helped us realize how the investigations framework does not yet account for a “time for telling” (Schwartz & Bransford, 1998), to provide students the background knowledge and skills they need to participate, while not giving away what we are hoping students can figure out together.

This case also highlights the zooming in and out that the teacher supports, so that students can see the big picture of what they are doing. This is a form of navigation (Reiser et al, 2021) – that is, helping students anticipate continuously where they are headed, so that they make sensible decisions in the present. This is especially salient in phenomenon-based units taking place over several weeks.

Though there was limited direct evidence of a broad range of students’ participation in the classroom from the video, Melissa expertly made space for students’ diverse ideas and frequently revoiced students’ contributions, so we were still able to get a sense of the ways students participated. However, it was not clear that this bid to engage in sensemaking was necessarily taken up by all students and we have more to uncover about how students’ own framing of the activity may have shaped their participation (cf., Munson, 2021).

Further, we saw many of the data modeling moves take place, but it is partly due to the intentional design of the curriculum and the skillful moves of the teacher, placing the heavy lift on the curriculum and teacher here, rather than on students. This may come at a cost for students’ opportunities to plan and carry out investigations, even if it is how science sometimes takes place in using data collected by others. It would be interesting to see how students work with collecting data firsthand, in contrast to a case like ours, where students are provided the datasets and the conditions of the scientists’ investigation model to work with.

Conclusion

This case study highlights some of the work needed to support the “practice turn” as part of current science education reform efforts, and reconceptualizing planning and conducting investigations, with particular attention on including students in the decision-making taking place in aligning questions to evidence to explanation. Such alignment work also mutually supports the use of the other science and engineering practices; for instance, we saw how students were engaged in asking questions and arguing from evidence while deeply engaged with data.

It is clear that students need support for data modeling even in a well-orchestrated classroom. This teacher played an active and nimble role in being responsive to students' needs as they grappled with data modeling, moving from phenomenon to explanation. We need to deepen our understanding of how teachers and curriculum work with students in moving away from ‘doing school’ and towards being actively involved in making and understanding the decisions surrounding data-based investigations.

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