# Negotiating Epistemic Agency and Target Learning Goals: Supporting Coherence from the Students' Perspective

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**Abstract:** A tension in designing classroom learning involves balancing the questions and interests of students with the goals of teachers and standards. One approach to navigating this tension in science classrooms is to simultaneously support and constrain students' questions about an observable natural phenomenon in the classroom and then take up those questions throughout a unit of instruction. Analyses of students' questions at the start of a middle school science unit and their responses to surveys throughout the unit suggest that students perceive that their questions are indeed driving learning, suggesting the promise of supporting students' epistemic agency through co-construction of questions, ideas, and investigations in storylines.

## Introduction

A core commitment of education reforms across disciplines is to bring disciplinary practices into classrooms. In science education, the focus is on making learning more meaningful by supporting students as they construct and use knowledge rather than learn about ideas that others have built (Duschl, 2008). An emphasis on scientific practices, like those articulated in the U.S. by the National Research Council (NRC, 2012), shifts the goal of science classroom from *learning about* ideas to *figuring out* those same ideas by engaging in practices similar to those used by scientists. This, in turn, shifts the role of students in science classrooms from passive, recipients of knowledge to agentive, constructors of knowledge (Berland et al., 2016). In particular, students engage in the communal construction of scientific understandings through scientific practices such as designing investigations, developing explanatory models, and arguing from evidence (McNeill & Pimentel, 2010; NRC, 2012).

Catalyzing and sustaining a shift from learning about science to doing science requires supporting the development of students' *epistemic agency*—students' involvement in directing and monitoring knowledge building processes (Damşa et al., 2010; Stroupe, 2014). In the science classroom, this means that students need to be a part of identifying problems to work on, deciding how to pursue these investigations, and partnering with teachers to reach consensus about what has been figured out (Edelson, 2001; Reiser et al., 2017). This active role facilitates coherence from the students' perspective, where students are aware of why they are doing what they are doing, as teachers guide them in building ideas based on questions and problems they have identified (Reiser et al., 2017). However, it is one thing for students to be aware of where they are going and why; it is another for them to feel like they the power to decide where to go next.

Attempting to support students' development of epistemic agency does not guarantee that students will embrace this potential role. Jaber and Hammer (2016a, 2016b) argue that this essential shift depends on epistemic affect, or the emotions felt as students do science, such as fascination with scientific phenomena, the unease that comes from discovering an inconsistency in a scientific explanation, and the joy in making a successful argument (Jaber & Hammer, 2016a, 2016b). They argue that these emotions motivate students to assume the role of epistemic agents and actively engage in the science classroom. This idea is central to epistemic agency. Creating a classroom where students have epistemic agency depends on students feeling like they can and should be doing the intellectual work of science knowledge construction. Therefore, it is critical not only to look at what students are doing in the classroom, but also to understand how students feel about what they are doing in order to create learning environments where students are truly directing the knowledge building.

At the same time, we are in an era of high accountability. Teachers, curriculum designers, and schools are responsible for addressing particular standards which articulate core science ideas. Thus, there is an inherent tension between supporting epistemic agency for students while also meeting target learning goals. This tension between externally mandated learning targets and student interests is not new, and goes back at least to Dewey (1902). With the articulation of the Next Generation Science Standards (NGSS) in the U.S. (NRC, 2012; NGSS Lead States, 2013), this tension emerges as a fundamental concern.

In this paper, we examine students' responses to a curriculum unit designed to help teachers negotiate this tension—guiding and supporting students as they meet target learning goals while they simultaneously partner with teachers in managing the focus and trajectory of investigations. The unit uses a storyline approach to optimize these tradeoffs. While each storyline has target NGSS disciplinary core ideas (DCIs) and performance expectations (PEs) and so the general pathway of the unit is pre-written, each storyline explicitly supports teachers in drawing out students' prior knowledge, working with students to identify questions and problems, and co-constructing next steps to investigate these questions and problems, engaging students as partners in the knowledge building (Reiser et al., 2017). This study examines students' experiences in a unit designed to both take up their questions and ideas about what to do and how to do it, as well as to develop core ideas and practices targeted in the standards and curriculum. First, we consider whether the questions students raise in response to observing an anchoring phenomenon align with the unit design. Further, while we, as researchers may recognize that the unit addresses students' questions, students' responses to the unit matter as well. Thus, we also examine the degree to which students perceive their epistemic agency, and the consequences of these perceptions for their affective reactions. As students move through the unit, do they see how their questions are being answered? Do they feel they play a role in deciding where to go next? What are their affective responses to these experiences?

## Methods and analysis

We invited teachers from across the United States to apply to participate in the *Learn While Teaching* project. We selected 27 middle school and high school science teachers from a pool of 86 applicants, 20 of whom agreed to participate in the program. Participating teachers were from urban, suburban, and rural school districts in CT, IL, MA, MI, OK and VT. All of the selected teachers had participated in previous professional development related to NGSS. Before the start of the school year, teachers participated in five days of in-person professional development on supporting NGSS-aligned classroom learning in general and prepared to enact curriculum materials for middle school physical science or high school biology. Teachers were supported during their enactment of the curriculum materials through biweekly virtual meetings.

This paper focuses on data collected from five of the middle school teachers using the Sound storyline unit designed by a team or teachers and researchers. The unit consists of 24 lessons across roughly 7 weeks. Four core questions drive the unit: (1) How is sound created? (2) How does sound travel? (3) How is sound detected? (4) How can technology store and recreate sound? The unit targets NGSS performance expectations that ask students to develop models of waves in terms of amplitude and energy (MS-PS4-1) and that account for the ways in which waves are transmitted, reflected, or absorbed by different materials (MS-PS4-2) and can be transmitted by signals that encode information (MS-PS4-3).

To support coherence from the students' perspective, the unit organizes learning in a storyline, in which students develop questions from phenomena that drives their knowledge building (Reiser et al., 2017). An anchoring phenomenon helps elicit students' initial questions, which are then used to uncover related questions from students' own experiences. At each step, pending questions or gaps students identify become the motivation for the next investigation. In this particular unit, the anchoring phenomenon is a homemade record player that plays music. The questions students generate about the anchoring phenomenon are organized on a driving question board (Figure 1; Singer et al., 2000), a public representation of student ideas (Windschitl et al., 2008).

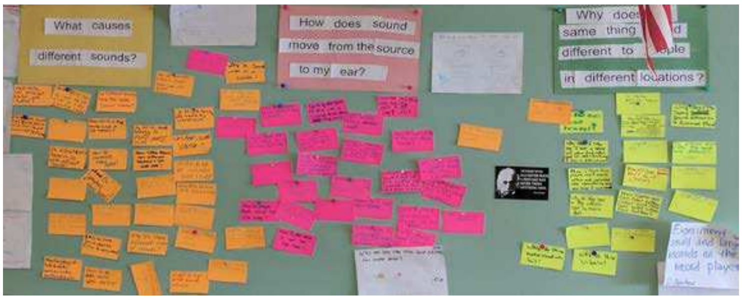

Figure 1. Example driving-question board (DQB) from a middle school sound classroom.

We consider two sources of data: (1) photographs of student questions posted on the DQB following the anchoring phenomena, and (2) surveys examining students' views of their own learning and engagement.

### Student questions

We analyzed students' questions from the DQBs from a sample of three teachers' classrooms to examine how students' questions aligned with the target science ideas. Analysis of DQBs from additional teachers is ongoing. Examining how the unit takes up students' questions is an important first step in determining whether the unit supports students in developing epistemic agency. Do students want to go where the unit will be taking them? If students raised a large number of questions that went unaddressed or did not ask questions at all, this could work against developing feelings of epistemic agency. The DQBs allowed us to examine whether the anchoring phenomenon precipitated questions that could be taken up in the classroom to drive learning.

Each teacher took photographs of their DQBs during the first few weeks of the unit. A researcher transcribed all questions that were visible (i.e., not covered up by another piece of paper) and legible (i.e., focus of photograph was clear as was students' handwriting). Three researchers, a designer who co-wrote the unit and two researchers who study the unit in classrooms, coded 265 questions from the DQBs across the three teachers' classrooms. Specifically, we considered each question in terms of two deductive codes: (1) *Question Match*, if the question asked was about a specific phenomenon and mechanism addressed explicitly in the lessons of the unit, and (2) *General Mechanism*, if the question could reasonably be expected to be answered mechanistically by the end of the unit as students have learned the relevant science ideas to be able to do so.

Table 1 includes example questions from two students alongside questions and related phenomena from the unit. Both students' questions require scientific explanations that address the creation and comparison of different pitches, which are the focus of Lesson 6. The first question, "How can peoples voices be different like deeper and higher for example my pit bull has a deep bark and the Jack Russell has a high voice?" involves a phenomenon, dogs barking at different pitches and ranges of pitch. The specific phenomenon of dogs barking was not addressed in the unit materials, so researchers coded the question "0" for *Question Match*. However, because the first question about dogs' barks could be at least partially explained by the general mechanisms uncovered in the unit, we coded the question with a "1" for *General Mechanism*. Specifically, in Lesson 6 students are expected to develop models for pitch and in Lesson 7 they read about human vocal cords. Therefore, the general mechanisms and even an analogous case (humans) might be enough to support students in reasoning about dogs barking at different pitches. In contrast, we awarded the second question in Table 1 about xylophones and pitches a code of "1" for both *Question Match* and *General Mechanism,* because the specific phenomenon of how different length objects, including xylophones in particular, can make different pitches is directly addressed in the unit. Researchers separately coded the *General Mechanism* and *Question Match* categories and then compared each of their 265 scores in both categories to arrive at consensus. Discussion often involved returning to the written curriculum materials. Table 2 includes these same questions to illustrate the way the questions were coded. We coded the third question in Table 2, which asks about dogs barking and cats meowing, "0" in both categories.

Table 1: Example questions and corresponding questions and phenomena investigated in the unit

| Example Student Questions | Related Unit Questions | Related Phenomena Investigated in Unit |
|---|---|---|
| How can peoples voices be different like deeper and higher for example my pit bull has a deep bark and the Jack Russell has a high voice? | Lesson 6: How do the vibrations from different sound sources compare for higher vs. lower pitch notes? | Guitar string plucked with finger pressing on string at different locations, xylophone bars of different lengths hit with mallet, and music boxes that students wind and play in their hands show patterns in pitch of note vs. length of object that is struck or plucked; patterns in effects on a long, thin wooden stick that we clamp down and strike and then, using a motion detector, measure the position of the end of the stick. |
| Why when you hit the larger key on a xylophone the lower the pitch is? | | |

Table 2: Example questions and corresponding codes

| Student Question | General Mechanism | Question Match |
|---|---|---|
| How can people's voices be different like deeper and higher for example my pit bull has a deep bark and the Jack Russell has a high voice? | 1 (yes) | 0 (no) |
| Why when you hit the larger key on a xylophone the lower the pitch is? | 1 | 1 |
| How come a dog barks and a cat meows? | 0 | 0 |

## Student surveys

Understanding the alignment between students' questions and the structure of the curricular unit is important, but what if students had aligned questions and they cared little about the answers? Or perhaps students might not have believed that their questions mattered and had little confidence they would be answered. Since we argue that epistemic affect is a key part of students developing epistemic agency, we used student surveys to capture students' thoughts and beliefs about their science classroom. The goal of these surveys was to better understand whether students felt like they had epistemic agency in their science classrooms and to start to unpack what the consequences of those beliefs were. Teachers administered the student survey, designed to take 10 minutes, approximately every other week during the curricular unit. Teachers had access to all of the responses in order to inform their teaching. Survey questions were adapted from previous work (Penuel et al., 2016). We developed three categories of survey questions that attempted to capture three dimensions of epistemic agency: 1) the intellectual work, 2) the social dimensions of that intellectual work, and 3) students' affective response to their classroom (see Table 3). While this study is ongoing, this paper examines 1119 completed student survey responses from 373 students from five teachers (21 class periods).

Table 3: Student perceptions survey questions by category

| Category | Questions |
|---|---|
| Intellectual work | [Learning was student driven]<br>On a scale from 1 – 5: "How did you learn today?"<br>(1 = "The teacher told us everything we need to know"; 5 = "We figured everything out as a class, with the teacher helping but not telling us the answer.") |
| | "I know why we did what we did in class today" (yes, no, unsure) |
| | "I figured out something today that helped us make progress on the DQB" (yes, no, unsure) |
| | "Do you think your class will figure out an answer to any of your questions" (yes, yes – at least part of one, no, other) |
| | "I know where we are going or what we are likely to do next time in class" (yes, no, unsure) |
| Social dimensions | "Today I shared my thinking out loud: 1) with people in my small group, 2) in a whole class discussion, 3) with people in my group and in a whole class discussion, or 4) with no one" (choose one) |
| | "Listening to other students in my group helped me improve my thinking" (yes, no, unsure, I didn't listen to another student today) |
| | "When other students shared their thinking out loud with the whole class today, I understood their explanations" (yes – most of the time, yes – some of the time, no – didn't understand, no – didn't hear, no – no one shared their thinking) |
| Affective response | "What we did or learned about in class today matters to me, matters to the class, matters to the community, none" (choose any) |
| | "Today's science lesson made me feel: excited, bored, confused, like a scientist, confident, happy, sad, afraid, angry" (choose any) |

The first category addresses key aspects of the epistemic work that students were being asked to do in the classroom such as who students thought was driving the learning and whether they believed that they were and would continue figuring out their own questions. The second category looks at the social nature of communal knowledge building: how did students share their own thinking, did they listen to others, and did they find listening productive. The last category focuses on the students' motivation: did they (or anyone) care about the work being done in their classroom, and what was their affective response to that work.

## Findings

Our findings consider the degree to which the unit, as designed, takes up questions students raised at the beginning of the unit as well as students' reported experiences in classroom.

### Student questions

41% of the questions students raised across the three classrooms examined in this part of the study (110 of 265 questions) are directly addressed in the unit design. Specifically, students' questions may be addressed by an investigation, uncovered in discussions guided by the teacher aimed at figuring out key ideas, and/or addressed in readings in the unit materials. Both the curriculum and teacher provide support for students to connect and reflect on the answers to these questions. (It is an open question about teachers' actual uses of these materials, a question which we do not take up in this paper but will address in future research.) An additional 21% of students' questions (55 of 265) can be figured out using a general mechanism that is at the core of the unit. Indeed, there is a range of questions and underlying phenomena that can be explained using the model that students co-create as part of the unit. Overall, 62% of students' questions (165 out of 265) are directly or indirectly addressed in the unit design.

The findings above support our design conjecture that the opening routine of the unit, which involves students observing and attempting to explain an anchoring phenomenon, connecting to their own experiences, and uncovering questions they have, can provide support for focusing students' questions on important learning goals, while also allowing for some freedom and heterogeneity of student questions. Furthermore, questions students raised in response to the anchoring phenomenon span all four sections of the unit: (1) How is sound created? (2) How does sound travel? (3) How is sound detected? (4) How is technology used to store and recreate sound? Thus, students' questions can be taken up as motivators for each section of the unit.

Some of the unanswered questions required mechanisms not addressed in the unit, such as questions involving the speed of sound (e.g., "What is a sonic boom?" and "Can a plane be faster than sound?"). However other questions reflect issues for which the unit may help students make partial progress. For example, consider "How do whales use echolocation?" coded as a "0" for both *General Mechanism* and *Question Match*. A number of relevant pieces of this puzzle are addressed in the unit—how one type of animal (humans) produces sound, how humans perceive sounds, how sound travels through water, and how sound can be reflected. Thus, students may be able to construct a more thorough (although still incomplete) explanation of this phenomena after the unit. In this analysis, however, we used the more conservative metric of full match on mechanism or specific question.

Some of these unanswered questions may be productive questions to address in high school. However, in some cases, the purpose of NGSS was to cut down on the amount of science topics that would be addressed in school curricula and focus on core explanations that address a broad of phenomena, a concern from even before NGSS (AAAS, 2001). Keeping concerns about unwieldly curricula in mind, looking closely at students' questions and whether that are answered as part of the classroom work using this unit allows designers to potentially expand and redesign the unit to incorporate questions that seem to be emerging across multiple classrooms in diverse settings. Indeed, we are seeing instances where teachers involved in this study are taking up questions and expanding the unit on their own, presumably to continue to make the unit student-driven.

Our next question is whether students actually recognize that the unit addresses the questions that they have or see how the general mechanism could be used to answer their questions. It is one thing for curriculum designers to assert that students' questions are addressed in the unit; it is another for students to recognize this or feel that science class matters to them. Students' responses to surveys provide evidence to address this question.

## Student surveys

When analyzing the student surveys, we were interested in students' responses along the three dimensions of epistemic agency outlined earlier and how these dimensions interacted with one another.

### Analysis 1: What were students' perceptions of their learning experiences?

When examining the survey questions targeting the intellectual work dimension, we found that many students had similar responses. 93.2% of students (1030 out of 1105) rated their class as a 3 or higher when asked how student directed the learning was in their class (1 = teacher driven and 5 = student driven). 89.7% of students (996 out of 1110) reported knowing why they did what they did in class. 73.6% of students (819 out of 1113) reported that they figured out something in class that would help them make progress on the DQB while 87.9% of students (950 out of 1081) reported that they believed that their class would figure out at least part of their questions. Additionally, 60.1% of students (656 out of 1092) responded that they knew where their class was going.

This pattern continued when examining the questions relating to the social dynamics of the intellectual work. 83.6% of students (929 out of 1111) reported sharing their thinking out loud with either their small group or the whole class, 90.3% (1004 out of 1112) felt that they understood their peers' ideas at least some of the time, and 79.4% (885 out of 1114) believed that listening to others helped them improve their thinking. Student responses were a little more varied with examining students' affective response to the unit. 72.0% of students reported a positive affective response to their classroom (excited, happy or confident), 41.1% reported feeling like a scientist, 22.1% reported feeling bored, 16.8% reported feeling confused, and 3.24% reported negative emotions (angry, sad or afraid). Similarly, while 83.5% of students (879 out of 1053) reported that what they did in class mattered to the class, only 61.1% (643 out of 1053) reported that what they did in class mattered to them and only 17.8% (187 out of 1053) reported that what they did in class mattered to the community.

These frequencies of responses, as well as the high agreement, are powerful because they are consistent across almost all of the three categories of questions. Students did not just like the unit, they also recognized that they were being asked to do the intellectual work in the classroom, participated in the class' discursive knowledge building process, had faith that their questions would be answered by the class, believed that listening to their peers would help them answer those questions, and overall recognized the coherence of the unit. What we can conclude from generally positive self-report responses, however, is limited. A more informative analysis needs to examine whether variation in responses to these questions is diagnostic of meaningful differences in experience. To examine this, we analyze how these responses are related to one another.

### Analysis 2: How are students' perceptions of these three dimensions related?

There are many interesting correlations between different responses, but what we are most interested in is the relationship across categories. Is there a relationship between what students believe learning is like in the classroom (i.e., the intellectual work), how students act in the classroom (i.e., the social dimension), and how students feel about their learning (i.e., the affective response)?

Our analysis revealed a number of interesting correlations between these dimensions. When looking at the relationship between questions about the intellectual work and the social dimension, for example, students who reported that "I know where we are going or what we are likely to do next time in class" were more likely to feel that "listening to other students in my group helped me improve my thinking," $\chi^2(1) = 20.42$, $p = 0.000$. Similarly, students who reported that "I figured out something today that helped us make progress on the DQB" were more likely to feel that "listening to other students in my group helped me improve my thinking," $\chi^2(1) = 45.47$, $p = 0.000$. These correlations are particularly promising because it shows a direct relationship between who has epistemic agency in the classroom and how students engage in the classroom.

There also is a relationship between the intellectual work and the affective response students have to class. Students were more likely to feel happy, excited, or confident in class if they reported that class was more student driven ($\chi^2(4) = 59.39$, $p = 0.000$), if they knew where class was going ($\chi^2(1) = 23.78$, $p = 0.000$), or if they made progress on the DQB ($\chi^2(1) = 31.88$, $p = 0.000$). These correlations are particularly interesting because students do not always respond positively when they are asked to take on a more active role in the knowledge building of the classroom; in fact, students can become frustrated with their newfound responsibility (Zivic, 2016).

### Analysis 3: What questions influenced students reporting that what they did in class mattered to them?

Our ultimate goal in this analysis is to begin to understand the development (or lack of development) of epistemic agency in these classrooms. We selected the response to "What we did or learned about in class today matters to me" as the most relevant indicator that students perceived ownership in their learning. This statement seems most related to the ideas of epistemic agency, in which students see the learning as under their control and serving their and their community's interests. To investigate the impact of other aspects of the intellectual work, social environment, and affective responses, we conducted a logit regression with the "class matters to me" as the dependent variable, and the other questions as predictors. Note that all independent variables were binary except "Class Learning was Student Driven" which was rated 1-5. Table 4 presents the results of this regression.

Table 4: Effects of intellectual work, social dimension, and affective questions on students' epistemic agency

| **Outcome: What we did in class matters to me** | | **Coefficient in Log Odds** (n = 996) |
|---|---|---|
| Affective Response | Feels happy, excited, or confident | 1.116*** (0.177) |
| | Feels like a scientist | 0.610*** (0.152) |
| | Feels confused | 0.589** (0.202) |
| | Feels bored | 0.0912 (0.194) |
| | Feels angry, sad, or afraid | -0.482 (0.443) |
| Intellectual Work | Class learning was student driven | 0.283*** (0.0783) |
| | Know why we did what we did in class | 0.0662 (0.235) |
| | Made progress on DQB | -0.0290 (0.170) |
| | My class will figure out my questions | -0.256 (0.224) |
| | Know where we are going in class | -0.161 (0.152) |
| Social Dimension | Shared my thinking in whole class discussion | 0.208 (0.154) |
| | Shared my thinking with no one | -0.290 (0.218) |
| | Listening to others helped improve my thinking | 0.118 (0.194) |
| | Understood others when they shared | 0.124 (0.265) |

Note: Standard error in parentheses, * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Interestingly, none of the survey questions in the social dimension had a significant effect on the outcome. While these social dimensions should be present in a student-driven classroom, they are not unique to this environment. That is, working with peers and helping one another might occur in a situation with work that is assigned from external authority rather than a classroom where students feel ownership over their learning.

Among the intellectual work questions, only the student driven nature of the class was a significant predictor of "matters to me" judgments. Surprisingly, knowing why they were doing what they did and making progress on the DQB were not predictive of feelings of ownership. There were however significant relationships between several aspects of students' affective response and students feeling that class mattered to them. It is interesting that the class mattering to students was not only associated with positive affects (happy, excited, confident) but also with confusion. One possible interpretation is that confusion is more likely with the kind of investment that comes with agency, and perhaps may be seen as a part of learning.

## Conclusion and implications

This study has explored an important tension. On the one hand, our education system is now organized around meeting performance standards, which invites the development of common learning sequences. On the other hand, there is interest in encouraging meaningful disciplinary practices that empower learners with epistemic agency, which might suggest allowing learners to choose their directions and focus. This study has explored the promise and challenges of a storyline approach (Reiser et al., 2017), in which curriculum designers aim to support teachers with sequences of phenomena designed to raise questions that help students build the target disciplinary ideas. Initial data from classroom enactments of a middle school unit on sound reveal that the combination of anchoring phenomena, modeling tasks, and productive talk strategies to support rich engagement in science practices (Michaels & O'Connor, 2017) can support some degree of epistemic agency that helps students pursue the target disciplinary learning goals. We examined whether students were able to generate explanatory questions, and whether these questions took them in directions productive for the learning goals. Analyses of students' questions from the driving question board revealed that students were indeed effective in generating a large number of explanatory questions that spanned the major subsections of the unit, reflecting the major components of the explanatory model targeted in the unit. The majority of students' questions were within the scope of the explanatory models the unit is designed to help students develop. In the model students develop, students explain how a vibrating object causes particles of a medium to collide and transfer energy to other particles, eventually reaching something that reacts to the vibrating particles (e.g., parts of an ear that detect changes in air pressure or a window that rattles due to vibrations in air). More than half of the students' questions are indeed explainable by this target model. In separate analyses, we are examining the extent to which students are successful in developing this explanatory model across classrooms and the teaching approaches that support this learning.

The analyses of student surveys then examined the consequences of linking students' investigations to their questions in the storyline. For example, it was possible that our analyses would uncover the potential connection of the units' lessons with students' questions, but that students would not see those connections or perceive them as important. It was also possible that even if students perceived these connections, they would not influence their affective response or feelings of agency. However, we found several strong positive relationships between the degree to which students perceived connections to their questions and their affective responses. The degree to which students perceived their role in the learning (figuring out vs. being told) influenced their likelihood of indicating that "what we did in class matters to me." Furthermore, these judgments of class mattering to the student were positively associated with positive affective responses (happy, excited, confident), and positively associated with "feeling like a scientist." There was also a positive association between reporting that class matters to the student and reporting feeling confused. While we do not know the direction of this relationship (do students feel that class matters more to them because they are confused or are they confused because they feel that class matters to them?), there does seem to be a relationship between feeling that class matters to you personally and reporting intense emotions about the learning process. The results also revealed insight into the importance of student perceived coherence (e.g., reporting an understanding of where the investigations should go next)—students who reported knowing "where we are going" were more likely to report positive affects. In general, these findings reveal a relationship between the intellectual aspects of coherence (knowing why we are doing what we are doing), and the affective underpinnings of the work (positive affect, feeling like a scientist).

In summary, we strongly agree with the concern that Sikorski and Hammer (2017) raise that to support science as a meaningful practice for leaners, coherence needs to arise from the *students'* perspective. We endorse their caution that "*premeditated coherence*, the kind of coherence that is planned and designed for students, may inhibit students' learning to seek coherence for themselves" (Sikorski & Hammer, 2017, p. 929). Our goal in developing storylines that are coherent from the students' perspective is to support teachers in involving students as partners in managing the trajectory of the knowledge building. We agree there is a potential tension for students' questions to take them in a different direction from the target learning goals or from developing the canonical science ideas targeted in the NGSS disciplinary core ideas. However, we suggest there are strategies to address these challenges. We suggest that professional learning situated in teachers' enactment of educative instructional materials can provide teachers strategies for developing students' questions and supporting their students' engagement in modeling and argumentation. Empirical studies of candidate phenomena can help identify phenomena for use in curriculum materials that can be effective contexts, with appropriate teacher probing, to elicit questions that, if investigated and explained, would help develop the DCIs. The present study suggests that these types of iteratively developed storylines, co-designed with teachers, can help navigate this tension between empowering students with epistemic agency and designing to support common disciplinary learning goals.

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