Enacting Rigorous Lessons: Leveraging Students' Ideas for Enhancing Demand on Student Thinking

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Abstract

Recent instructional reforms in science education emphasize rigorous instruction where students' engage in high-level thinking and sensemaking as they try to explain phenomena or solve problems. This study aims to investigate how students' intellectual engagement can be promoted through design and implementation of cognitively demanding science tasks. Specifically, we aim to unpack instructional practices that can help to enhance students' engagement in high-level thinking and sensemaking as they work in science classrooms. In our analysis, we focused on the implementation of five lessons across three different science classrooms that two middle school science teachers collaboratively designed as a part of a professional development about promoting productive student talk in science classrooms. Our analysis revealed the changes in students' intellectual engagement across the trajectory of these lessons and three instructional practices associated with enhancing opportunities for students' thinking: (a) Holding students intellectually accountable to develop explanations of how and why a phenomenon occurs through collaborative work, (b) Leveraging students' ideas to advance their thinking, (c) Initiating just-in-time resources and questions to problematize students' intellectual engagement. The study findings provide implications for how to generate opportunities to enhance students' thinking in the service of sensemaking.

Problem

The National Research Council (NRC, 2012) Framework for K–12 Science Education and the Next Generation Science Standards (NGSS) aim to support students' development of scientific proficiency through their engagement in science and engineering practices, crosscutting concepts, and disciplinary core ideas, so-called, "3-dimensional learning" as students try to make sense of phenomena (Author, 2019a; Furtak & Penuel, 2019; Kang et al., 2016; NRC, 2012). Rigor in science teaching aligned to this vision is possible, however, it is not yet prevalent in U.S. science classrooms (NASEM, 2015). While many science teachers strive to facilitate learning opportunities aligned with recent reform vision (e.g., Sandoval et al., 2018) more images of what is happening in science classrooms as students engage in rigorous 3-dimensional learning are needed (Author, 2019a).

Building on prior research, we contend that thoughtfully designed rigorous lessons structured around cognitively demanding science tasks, which require high-level thinking and sensemaking from the students, and enacted in ways that maintain this rigor is critical for students' opportunities to engage in 3-dimensional learning (e.g., Author, 2020; Kang et al., 2016). However, maintaining rigor throughout the trajectory of a science lesson continues to stay as a challenge in research and practice (e.g., Author, 2019b; Harris et al., 2015; Kang et al., 2016). Addressing this challenge, the current study aims to explore how students' intellectual engagement can be supported through the design and implementation of rigorous lessons. Specifically, we aim to unpack instructional practices that can help to enhance students' engagement in high-level thinking and sensemaking in science classrooms.

Conceptual Framework

Instructional tasks are classroom-based activities assigned to students that can shape opportunities for students' learning aligned to the reform vision (Author, 2020; Doyle, 1983; Hiebert & Wearne, 1993). Students spend most of their time in class while working on these tasks, which provide a context for the processes, practices, resources that students draw on and make use of during their intellectual engagement. Research has shown that not all classroom tasks provide similar opportunities for students' learning (Author, 2015; Henningsen & Stein, 1997; Stein & Lane, 1996). Based on the Task Analysis Framework (Author, 2015) which was developed to analyze science tasks in terms of the integration of science content and practices, and cognitive demand on student thinking, science tasks with low cognitive demand mostly require students to reproduce information or engage in a set of well-defined procedures without making sense of scientific ideas or practices. On the other hand, science tasks with high cognitive demand on students' thinking involve meaningful integration of scientific content and practices as students engage in high-level thinking and sensemaking (Author, 2015).

Rigorous instruction involves students' intellectual engagement in science content and practices as they work on cognitively demanding tasks aligned with the reform vision to figure out a phenomenon (e.g., Author, 2020; Resnick et al., 2010; Windschitl et al., 2012). Although cognitively demanding science tasks that involve the integration of science content and practices have the potential to support students' thinking and sensemaking, selecting to use these tasks in the design of rigorous lessons does not guarantee students' engagement in high-level thinking because cognitive demand on student thinking often declines in many classrooms during their enactment (Author, 2019a; Henningsen & Stein 1997; Kang et al., 2016; Stein et al., 2007). Task Phases Framework (Author, 2020) presents a lens to track cognitive demand on student thinking in three phases across the trajectory of a science lesson: (1) tasks as designed in the planning phase of a lesson, (2) during the launch of a lesson in the classroom, which involves setting-up the task for students to work on, and (3) during the enactment of the task with students and their teacher in the remaining of the lesson. These three stages show that how tasks design, it is set-up by the teacher, and teacher's and students' engagement in the task can shape the learning environment created in the classroom, and the type and level of thinking that students' engage in.

Prior research has begun to shed to light on the features of cognitively demanding tasks, which are important to select in the design of rigorous lessons as well as the factors associated with the maintenance and decline of cognitive demand on students' thinking (Author, 2018a; 2019a; Henningsen & Stein 1997), but, there is limited research about the instructional practices that can enhance opportunities for students' high-level thinking throughout the trajectory of a science lesson. This is the area that the findings of this study shed light on by uncovering the instructional practices of a science teacher that consistently maintained or improved the cognitive demand on students' thinking in her facilitation of science lessons.

Study Design

The study was conducted within the context of a National Science Foundation-funded project about fostering productive classroom talk aligned with the Framework vision for science teaching and learning (NRC, 2012). It focuses on teachers' carefully thinking through and co-designing argumentation-focused lessons that can engage students in productive science talk. The project included a year-long PD program, which started with a summer workshop in 2018. Four of the teachers, who attended the summer workshop in 2018, participated in four PD cycles throughout the academic year. Each PD cycle consisted of three parts: (a) co-designing a science lesson with another teacher or a member of the research team, (b) teaching of the co-designed lessons in PD participants' classrooms, (c) reflecting on the co-designed lessons by analyzing video clips depicting the enactment of their co-designed lessons in PD participants' classrooms.

Two middle school teachers, Ms. Kate and Mr. Jerry co-designed their lessons throughout these PD cycles while the other two teachers in the PD partnered with the research team members. In each of the four PD cycles during one academic year, Ms. Kate and Mr. Jerry co-designed a different lesson (with the exception of PD cycle 3, in which they designed multiple lessons as part of an instructional sequence). By building on our previous work (Authors, 2020), in this study, we focused on all five lessons co-designed and enacted by Ms. Kate and Mr. Jerry as part of these four PD cycles. This focus allowed us to examine how the lessons thoughtfully co-designed by two teachers were enacted differently in their classroom contexts (see Table 1) and what happened during the enactment in terms of the opportunities for students' high-level thinking and sensemaking. Therefore, the study was guided by the following research questions: (1) How did the rigor in students' thinking change across the trajectory of co-designed science lessons by Ms. Kate and Mr. Jerry? (2) How was the rigor in students' thinking enhanced by the teacher during the trajectory of the co-designed lessons in Ms. Kate's classroom?

Data Sources and Analysis

Three primary data sources were used to address the research questions: (i) the planning materials of all the lessons co-designed by Ms. Kate and Mr. Jerry throughout the PD cycles during one academic year, (ii) video recordings of these lessons in Mr. Kate and Mr. Jerry's classrooms, and (iii) interviews with Ms. Kate right after and before the co-designed lessons. Science Instruction Quality Rubrics* (Author, 2020), based on the Task Analysis Framework* (Author, 2015) and Task Phases Framework* (Author, 2019b), are used to assess rigor in students' thinking. The authors independently coded a subset of the data by using the rubrics and then discussed their coding to reach a consensus. Next, the first author coded the remaining data and discussed her coding with the second author by showing evidence from the data.

These analysis across Mr. Jerry's and Ms. Kate's classrooms revealed that in Ms. Kate's classroom, rigor in students' thinking was consistently enhanced during the enactment of the co-designed lessons (See Table 2). Thus, addressing the second research question, we conducted a more detailed analysis of instruction to understand how the cognitive demand on students' thinking was enhanced throughout the trajectory of lessons in Ms. Kate's classroom. In our analysis, we focused on video records and transcriptions of the lessons during which cognitive demand on students' thinking was enhanced during the launch and enactment phases of Ms. Kate's classroom. We supported this analysis by drawing on the interviews with Ms. Kate before and after these video-recorded co-designed lessons. By re-watching the parts of the lessons where cognitive demand on students' thinking was enhanced, we specified the moves and strategies that Ms. Kate used that led to shifts in students' thinking. Looking across these moves and strategies, we identified the common themes, which led to three main practices that she was using. Our coding in this stage of the analysis was informed by the literature on ambitious science teaching (e.g., Windschitl et al., 2012), teacher questioning (e.g., Author, 2018b; Benedict-Chambers et al., 2017; Chin, 2007), accountable talk (e.g., Resnick et al., 2010; Boston, 2012), responsive teaching (e.g., Author, 2018a; Levin et al., 2009), and productive disciplinary engagement (Engle & Conant, 2002).

Findings

Addressing the first research question, our analysis revealed variations in rigor in students' thinking across the phases of the co-designed lessons by Ms. Kate and Mr. Jerry (see Table 2). Cognitive demand of the tasks that they selected varied across the five lessons that they co-designed. For example, the cognitive demand of tasks selected for the co-designed lessons in PD cycle 3 (e.g., Task 3 & Task 4) was rated as level-2, which means that the tasks require students' superficial engagement in integration of science content and practices. On the other hand, the cognitive demand of the task in the co-designed lesson in cycle 4 (e.g., Task 5) was rated as level-4 because it requires students to use science content and practices to make sense of a phenomenon.

The ratings presented in Table 2 across the launch and enactment phases of the co-designed lessons indicate the importance of cognitively demanding tasks in providing opportunities for students' engagement in rigorous thinking. For instance, across all three classrooms, students engaged in the higher level of thinking during the implementation of Task 5, which had the highest cognitive demand level among the five tasks selected by the teachers. Consistently, students in classes A and B engaged in low-level thinking as they worked on tasks with low cognitive demand levels (e.g., Task 3 and Task 4).

Our analysis also indicated the critical role of teachers' instructional practices in providing opportunities to foster and enhance students' engagement in high level thinking and sensemaking. Although Ms. Kate and Mr. Jerry assigned the same tasks in the lessons that they co-designed, there were variations in the level and kind of student thinking during lunch and enactment phases in these lessons across three classrooms. In Mr. Jerry's classrooms, we observed a pattern of decline in cognitive demand on student thinking across most of these lessons. In Ms. Kate's classroom, the cognitive demand on student thinking was consistently improved during the launch and enactment phases.

Addressing the second research question, our analysis revealed consistent patterns in Ms. Kate's instructional practices that appeared to play a role in students' thinking and sensemaking. Firstly, throughout the lessons Ms. Kate consistently hold students' intellectually accountable to develop understanding of how and why a phenomenon occurs through collaborative work. She assigned phenomenon-based questions which required students' engagement in disciplinary practices as they reason about the scientific ideas. Students were required to construct arguments by focusing on the connections between their claims, corresponding evidence, and justifications. The quality of an argument or explanation regarding a phenomenon assessed by the strength of these connections. Also, students asked to comment on their peers' arguments and revise their work based on their peers' feedback. For example, while implementing Task-3 about characteristics of patients with cancer, Ms. Kate asked students to think about a question, which was not part of the task as designed: *"Why do you think cancer is more common in older people vs younger people?"*, which led to an increase in demand on students' thinking. Students' intellectual engagement was observed as they constructed explanations with evidence and reasoning, and commented on other proposed explanations addressing this question.

Second, Ms. Kate demonstrated an effort in leveraging students' ideas to advance their thinking. She regularly monitored students' thinking around the phenomenon to understand how and what they were thinking, and to decide how and when to advance students' thinking in service of their sensemaking as she tried to refine their understanding of the core ideas targeted in the lesson. For example, after she observed that students had challenges working on Task 1 on the first day of the lesson, she started the next class with a guiding question that she introduced as part of the bell work:

> *When analyzing data, you notice that there seems to be some inconsistencies or data that appears to conflict (ex..). What should your approach be? Should you toss the data and determine that it is unreliable or should you look for possible reasons behind the conflicting data? Why or why not?"*

During the discussion, students developed more complex approaches to analyze the data incorporating their initial knowledge resources on ecosystems regarding the phenomenon. This engagement continued at small group work as students worked on making sense of this data.

Third, Ms. Kate initiated just-in-time resources and thought-provoking questions to problematize students ongoing intellectual engagement. When she noticed students were "stuck" on an idea and could not progress in their thinking, she introduced new resources and questions to problematize students' thinking. This often led to students' considering alternative approaches or explanations by drawing on these new resources in their intellectual engagement. For instance, in Lesson 3, a group of students started to claim that the unknown organism is a plant because it has uniform structural cells like in the plant cells whereas animal cells have non uniform structure. Ms. Kate set up a microscope and invited students to examine a muscle tissue (which has a uniform structure). Seeing a counter evidence to the claim that students were in the process of developing resulted in a puzzlement, followed by a progress in their thinking.

Consistent with her teaching practices, during the interviews Ms. Kate commented on her instructional practices regarding fostering students' thinking and talk. For example, reflecting on lesson 3, about classification an unknown organism, she talked about her teaching as:

> *They [students] have a hard time letting go of some original ideas. So, I tried to foster talk by when I saw them going down that direction of hey, it's an animal or a plant, reflecting on what the question is, does it have to be?*

Conclusions and Contributions

Overall, this study contributes to the existing knowledge base in several ways. The results of this study provide further evidence into the role of cognitively demanding tasks in student thinking by showing that students are more likely to engage in a high level of thinking as they work on cognitively demanding classroom tasks (e.g., Author 2019a; Kang et al., 2016). In addition, our findings provide a concrete depiction of teachers' critical role in enhancing opportunities for students' rigorous thinking as emphasized by Author (2020). The common themes that we identified in Ms. Kate's instructional practices to enhance opportunities for students' thinking provide a concrete depiction of means to facilitate rigor in students' thinking in science classrooms. While we, as a field, are seeking ways to facilitate the enactment of Framework's vision in science classrooms, the study findings can contribute to a better understanding of how to enact reform-based science instruction and inform professional development efforts to support teachers' capacity for promoting students' high-level thinking.

Table 1. Information about the study participants

Pseudonym	Experiences	Class*	Demographics
Mr. Jerry	3 years of teaching	Class A	6 African American, 12 Asian, 5 White
		Class B	9 African American, 10 Asian, 1 Hispanic, 5 White
Ms. Kate	21 years of teaching	Class D	3 African American, 4 Asian, 1 Hispanic, 17 White

*: Only Lesson 1 is implemented in Class C (12 African American, 5 Asian, 7 White).

Table 2. Change in rigor across the phases of a science task throughout the trajectory of the co-designed lessons

Tasks	Teacher/Class	Design	Launch	Enactment Part 1	Enactment Part 2*
Cycle 1/ Task1	Jerry Class B	3	3	2	1
	Jerry Class C	3	3	2	1
	Kate Class D	3	4	4	NA
Cycle 2/ Task 2	Jerry Class A	3	3	2	1
	Jerry Class B	3	3	2	1
	Kate Class D	3	4	4	NA
Cycle 3/ Task 3	Jerry Class A	2	3	1	1
	Jerry Class B	2	3	1	1
	Kate Class D	2	4	3	3
Cycle 3/ Task 4	Jerry Class A	2	3	2	NA
	Jerry Class B	2	3	2	NA
	Kate Class D	2	3	3	3
Cycle 4/ Task 5	Jerry Class A	4	4	3	3
	Jerry Class B	4	3	3	2
	Kate Class D	4	5	5	5

Note: Rigor ratings are on a 6-point scale: 0,1,2,3,4,5. * Concluding Whole group discussions, NA: No whole group discussion.

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