Promoting Uncertainty in Science Classrooms through Cognitively Demanding Tasks

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Abstract

The reform vision brought forth by the Framework for K-12 Science Education emphasizes the integration of scientific knowledge with scientific practices as students try to figure out a phenomenon. During this process of making sense of phenomenon, students experience moments of uncertainty which is important because scientific activity is driven by this need to manage uncertainty. Using cognitively demanding tasks in science classrooms presents a means to integrate uncertainty into students' experiences. Our analysis of video records of science lessons during the implementation of chemistry tasks at different cognitive demand levels revealed how types of uncertainty that students experienced differed in these lessons and the ways in which uncertainty was evoked during the implementation of cognitively demanding science tasks.

Purpose

Uncertainty is a part of what scientists' experience while solving a problem or answering a question (Manz & Suárez, 2018). Learning science requires "ways of dealing with uncertainties" (NRC, 2012, p. 251). Providing opportunities for students to experience uncertainty by working on perplexing problems is crucial (Manz & Suárez, 2018). Students experience uncertainty as they attempt to make sense of a phenomenon by using their understanding of science ideas and engaging in scientific practices (NRC, 2012; Odden & Russ, 2019). However, this is not a typical experience for many students in science classrooms (e.g., Manz & Suárez, 2018). Consistently, there is a growing need to intentionally build into classroom activities specific forms of uncertainty to establish the need to develop explanations of phenomena by drawing on disciplinary ideas and practices (Manz & Suárez, 2018).

Addressing this need, we posit that one way to integrate uncertainty into students' experiences is through cognitively demanding science tasks (Author, 2015). As students work on these complex tasks, evoking uncertainty can help to foster students' high-level thinking and sensemaking. In this exploratory study, we seek to understand different types of uncertainty experienced by students and how uncertainty was evoked during the implementation of cognitively demanding science tasks to provide more nuanced understanding of uncertainty experienced by students in relation to the level and kind of students' thinking.

Theoretical Framework

Expressing a moment of uncertainty is an important initial step in a student's sensemaking (Odden & Russ, 2019). Uncertainty is defined as "an individual's subjective experience of doubting, being unsure or wondering about how the future will unfold, what the present means, or how to interpret the past." (Jordan & McDaniel, 2014; p.492). Uncertainty is raised, maintained, and declined (e.g. Cullicot & Chen, 2018) as a part of the sensemaking process, which is important because scientific enterprise is driven by the need to resolve uncertainty. There has been a growing demand for understanding how to promote students' experience of uncertainty to foster their intellectual engagement in science classrooms (Manz & Suárez, 2018).

Instructional tasks are classroom-based activities that shape students' learning opportunities (Author, 2020a). Not all tasks provide similar opportunities for students' thinking (Author, 2015; Stein et al., 1996). Based on the Task Analysis Tool[1] (Author, 2015), which was designed to distinguish between science tasks based on their cognitive demand levels, tasks at the highest cognitive demand levels offer opportunities for students' sensemaking and engagement in scientific practices and content in an integrated way. When these tasks are enacted effectively in the classroom, students work towards *figuring something out* by engaging in high-level thinking and sensemaking. Thus, we argue that integrating cognitively demanding tasks in science classrooms can support promoting uncertainty during the process of sensemaking.

Although uncertainty can be planned in design of the cognitively demanding tasks, this is not sufficient; research has consistently shown that cognitive demand of tasks changes once they are unleashed in classroom contexts (Author, 2019a; Kang et al, 2016; Stein & Smith, 1998). The Framework presented by Author (2020a) helps to explain the changes in students' thinking across the phases of a task as (i) designed, (ii) launched by the teacher, and (iii) enacted by the teacher and the students. Therefore, it is important to explore how students experience uncertainty during the launch and enactment phases of tasks designed with a potential for high cognitive demand on students' thinking. Current research is limited about the relationship about the nuances in students' thinking and the type of uncertainty that they experience.

Study Design and Context

This study was guided by these research questions: (1) How was uncertainty experienced by students in Mr. Daniel's classroom during the implementation of science tasks at different levels of cognitive demand on students' thinking? (2) How was uncertainty evoked in Mr. Daniel's classroom during the implementation of science tasks at different levels of cognitive demand on students' thinking?

The study was conducted as part of an NSF-funded project that focuses on supporting science teachers' learning to facilitate productive discussions. The project involves a professional development (PD) structured around science teachers' co-designing, teaching and reflecting on science lessons to learn to facilitate productive discussions in their classrooms. PD started in summer 2018; four of the teachers from summer agreed to participate in a yearlong PD during the 2018-2019 academic year, which consisted of four cycles of Design-Teach-Analyze sessions.

In this study, we focused on two lessons that Mr. Daniel, a chemistry teacher with 5 years of teaching experience, designed with the second author as part of this PD. Building on our earlier work (Author, 2020b), these lessons were selected because both of them were (i) structured around a cognitively demanding task, and (2) planned to facilitate productive science discussions but showed stark differences upon their implementation. (see Table 1 for details about these lessons).

Data Sources and Analysis

The data sources for this study included the planning documents and video-records of the two focal lessons in Mr. Daniel's classroom (see Table 1). The first three-day lesson (*Bending-Water*) focused on students refining their understanding of intermolecular forces by designing and conducting an investigation to explain why water stream bends when placed next to a charged rod. The second three-day lesson (*Chemical-Equilibrium*) required students to find equilibrium

[1] For the purpose of the blind review process the name of the instructional quality measure that was developed by the Author and colleagues was not used.

positions of given chemical equilibrium reactions based on experimentation and their understanding of equilibrium.

For data analysis, we used two analytical lenses. The first is the Instructional Quality Measure* (Author, 2019b) based on the Task Analysis Tool*(Author, 2015) and Task Phases Framework* (Author, 2020b) which provides a lens to examine the changes in the type and level of student thinking across the phases of a science task: (1) potential cognitive demand of tasks as designed, (2) the level and kind of thinking that students are expected to engaged based on the framing of the intellectual work during the launching of the task, and (3) actual intellectual work that happens during the task enactment. In our analysis, we broke the lessons up into the parts described in Table 1 and used the instructional quality measure to code them. The last two authors independently coded the lesson plans and classroom videos by using this measure. They, then, discussed their coding to reach a consensus.

Our second analytical lens was identifying and defining moments of uncertainty in each of the phases presented in Table 1. We adapted Jordan and McDaniel's (2014) definition of uncertainty to identify moments of uncertainty. Then, these moments of uncertainty were described and characterized (Table 2). Next, those moments were coded with respect to the factors that evoked uncertainty (Table 3), such as teacher's conceptual questions or students' observations. Initial rounds of coding were done by the first author based on the literature and emergent codes during the analysis, resulting in detailed codebooks with descriptions of codes and examples from the data. These codebooks were then shared with all three authors for a discussion to refine the codes and their descriptions. The data was then re-coded collaboratively with the second author. If there were any discrepancies between codes, the coders discussed until a consensus was made. This process resulted in further refinement of the codes and consensus coding of all the moments of uncertainty with respect to (i) types of uncertainty and (ii) the ways in which moments of uncertainty were evoked.

Results

Overall, our analysis revealed nuances in types of uncertainty experienced by students in the same classroom during the implementation of science tasks with different cognitive demand on students' thinking. As shown in Table 4, our analysis addressing the first research question revealed that students experienced uncertainty differently in the two focal lessons where the level and kind of student thinking also differed during the launch and enactment of the cognitively demanding tasks selected.

In the *Bending-Water*, the cognitive demand on students' thinking was planned, launched, and enacted at the highest level based on the instructional quality tool used for the analysis. Science tasks at this level have the potential to engage students in sensible versions of the intellectual work in which scientists engage (Author, 2015). Consistent with the potential of the task on students' thinking, Mr. Daniel launched it by using a puzzling phenomenon and positioning students to explain how and why that happened. Cognitive demand on students' thinking was maintained at this highest-level throughout the enactment phases as students tried to figure out how and why the water stream bent. As shown in Table 4 and Figure 1, the type of uncertainty that students experienced was mostly about *figuring out a phenomenon* (~55%) and *understanding a core idea* (~25%) throughout the lesson.

Our analysis revealed that the cognitive demand of the task around which *Chemical-Equilibrium* was structured afforded limited opportunities for students' thinking. The cognitive demand of the task as designed was level-3, which suggests that while students were required to engage in high-levels of thinking, the emphasis is more on learning about and understanding a science idea. Students' thinking focused more on what was occurring rather than why it was happening. While launching the lesson, Mr. Daniel tried to increase the cognitive demand on students' thinking by creating uncertainty through a puzzling phenomenon, which was not maintained in the rest of the lesson during the enactment phases (Table 4). The type of uncertainty students experienced was coded mostly as related to brainstorming without elaboration (60%). Specifically, as shown in Figure 1, students experienced uncertainty moments while brainstorming (a) *predictions for what might be happening* (~36%), (b) *ideas about experiments* (~13%), and (c) *ideas surrounding the phenomenon* (~11%) without moving much beyond these initial ideas that they brought.

The second research question aimed to understand how uncertainty was evoked during the implementation of cognitively demanding science tasks (Table 5). In both Bending-Water and *Chemical-Equilibrium*, uncertainty was evoked mostly by the teacher's or students' questions and ideas that focused on the core concepts embedded in the task. The percentage of conceptual questions or ideas that evoked uncertainty was slightly higher in *Bending-Water* (~86%) than *Chemical-Equilibrium* (~74%). In *Chemical-Equilibrium*, uncertainty was evoked by procedural questions and ideas from the teacher and students 21% of the time, whereas, in *Bending-Water* uncertainty was evoked only 5% by questions and ideas (Figure 2).

Conclusions, Implications, and Scholarly Significance

Going beyond whether or not students experienced uncertainty, this study provides insights into the kinds of uncertainty that students experience in science classrooms when students are assigned to work on tasks at different cognitive demand levels. The study findings have started to shed light on the kinds of uncertainty experienced in relation to the kind and level of thinking in which students engaged and the opportunities for sensemaking. In *Chemical-Equilibrium*, students mostly experienced uncertainty while brainstorming ideas without much elaboration. Brainstorming refers to one of the first steps in the sensemaking process where students offer ideas or beliefs (Odden & Russ, 2019). Although these moments of brainstorming can provide students with seeds that can be used to sense make about the phenomenon, Odden and Russ (2019) underlined that these brainstormed ideas must be elaborated and connected to one another in order to be considered as sensemaking. In *Chemical-Equilibrium*, the majority of the moments of uncertainty were coded as brainstorming. Consistently the level and kind of student thinking was coded as level-3, suggesting limited opportunities for students' thinking and sensemaking. On the other hand, in *Bending-Water,* which mirrors the Framework's vision for students' intellectual engagement, the same group of students experienced different kinds of uncertainty (i.e., *figuring out a phenomenon* and *understanding a core idea*) and the level and kind of student thinking was rated as level-5, suggesting students' engagement in sensemaking. Therefore, the study findings suggest that design and effective implementation of tasks at particular cognitive demand levels can create a medium for students to experience uncertainty in service of sensemaking, which is important as the field is seeking productive means to build uncertainty in students' experiences.

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Table 1: Description of the Focal Lessons

Lesson	Implementation	Brief description of activities
Bending Water	Launch	Observing the teacher using a rod to move the stream of water
	Enact #1	Discussion of students' claims, explanations for the phenomenon, and plans for how to test them.
	Enact #2	Designing investigations to test students' claims regarding the phenomenon.
	Enact #3	Conducting investigations to test their claims; developing explanations and arguments.
	Enact #4	Presenting posters with their arguments and developing a consensus for the mechanism of the phenomenon.
Chemical Equilibrium	Launch	Observing video of liquids changing color when manipulated.
	Enact #1	Selecting the tests to apply for shifting the equilibrium positions of the given reaction systems by selecting from the list given by Mr. Daniel.

	Enact #2	Conducting experiments and data collection about the stresses.
	Enact #3	Interpreting the findings to determine the equilibrium position and preparing posters with the findings.
	Enact #4	Presenting posters regarding the equilibrium position

Table 2: Description of Types of Uncertainty

Type of uncertainty experienced while...	Definition Students experience moments of uncertainty …
(1) Figuring out a phenomenon	Students experience moments of uncertainty when they are unsure how to explain how and why a phenomenon takes place as they are productively engaging with the "disciplinary ideas and practices embedded in the task" to figure out a phenomenon
(2) Understanding a core idea	Students experience moments of uncertainty when they are unsure how to use/explain a disciplinary idea as they engage in discussions to refine their understanding.
(3) Engaging in epistemic practices	Students experience moments of uncertainty when they are unsure about how to engage in epistemic disciplinary practices such as designing investigations, interpreting the results.
(4) Using correct terminology	Students experience moments of uncertainty when they are unsure or wondering how they might proceed while wrestling with the correct wording or what a word means as they are trying to collect information about a scientific term.
(5) Following lab procedure	Students experience moments of uncertainty when they are unsure or wondering how they might proceed in coordinating and managing themselves and their group as a part of the lab.
(6) Brainstorming ideas	Students experience moments of uncertainty when they are unsure or wondering about while brainstorming: (a) what they are seeing as a part of the investigation or predictions for what is happening (b) what tests they need to do or what would happen during the experiment (c) ideas surrounding the phenomenon without elaboration on their ideas or making links between these ideas.
(7) Other	Students experience moments of uncertainty that are not described by the specific codes given in the code book.

Table 3: Description of How Uncertainty was Evoked

Uncertainty was evoked by a...	Definition	Example
Conceptual Question or Idea	A teacher or student question or idea that invites the use of one's understanding core ideas embedded in the task.	"So, does anyone else have a different prediction for what they think will occur?"
Terminology Question	A teacher or student question that focuses on the wording used in a certain subject of study.	"What does it mean for something to be polar?"

Procedural Question or Idea	A teacher or student question or idea that focuses on coordinating or managing themselves or their group.	"What did you test and what were your results?"
Observation	A student observing something happening as a part of the lab and describing it with words.	"It's turning blue."

Table 4: The Cognitive Demand and Type of Uncertainty in Focal Lessons

Lesson	Codes		Phases of Task					
		Potential	Launch	Enact 1	Enact 2	Enact 3	Enact 4	(Average)
Bending Water	Type and level of student thinking	5	5	5	5	5	5	5
	Type of uncertainty experienced while...		Launch	Enact 1	Enact 2	Enact 3	Enact 4	Total
	(1) Figuring out a phenomenon		4 (9%)	3 (7%)	1 (2%)	9 (20%)	7 (16%)	24 (55%)
	(2) Understanding a core idea		1 (2%)	4 (~9%)	1 (2%)	1 (2%)	4 (9%)	11 (25%)
	(3) Engaging in epistemic practices				4 (9%)			4 (9%)
	(4) Using correct terminology				1 (2%)			1 (2%)
	(5) Following lab procedure					2 (5%)	1 (2%)	3 (7%)
	(6) Brainstorming ideas	6.a				1 (2%)		1 (2%)
		6.b						
		6.c						
	Other							
Chemical Equilibrium		Potential	Launch	Enact 1	Enact 2	Enact 3	Enact 4	(Average)
	Type and level of student thinking	3	4, 3	3	3	3	4	3
	Type of uncertainty experienced while...		Launch	Enact 1	Enact 2	Enact 3	Enact 4	Total

	(1) Figuring out a phenomenon		4 (9%)	1 (2%)		2 (4%)		7 (15%)
	(2) Understanding a core idea							
	(3) Engaging in epistemic practices							
	(4) Using correct terminology		1 (2%)		1 (2%)	1 (2%)		3 (7%)
	(5) Following lab procedure			2 (4%)	4 (9%)			6 (13%)
	(6) Brainstorming ideas	6.a			4 (9%)	9 (19%)	4 (9%)	17 (36%)
		6.b	2 (4%)	1 (2%)	2 (4%)		1 (2%)	6 (13%)
		6.c	5 (11%)					5 (11%)
	Other		1 (~%)		2 (4%)			3 (6%)

Note. The codes for the type of uncertainty experienced are described in moments. The number given describes the number of that uncertainty found in that phase of the implementation. All percentages are approximate.

Figure 1: Type of Uncertainty Moments Lesson Comparison

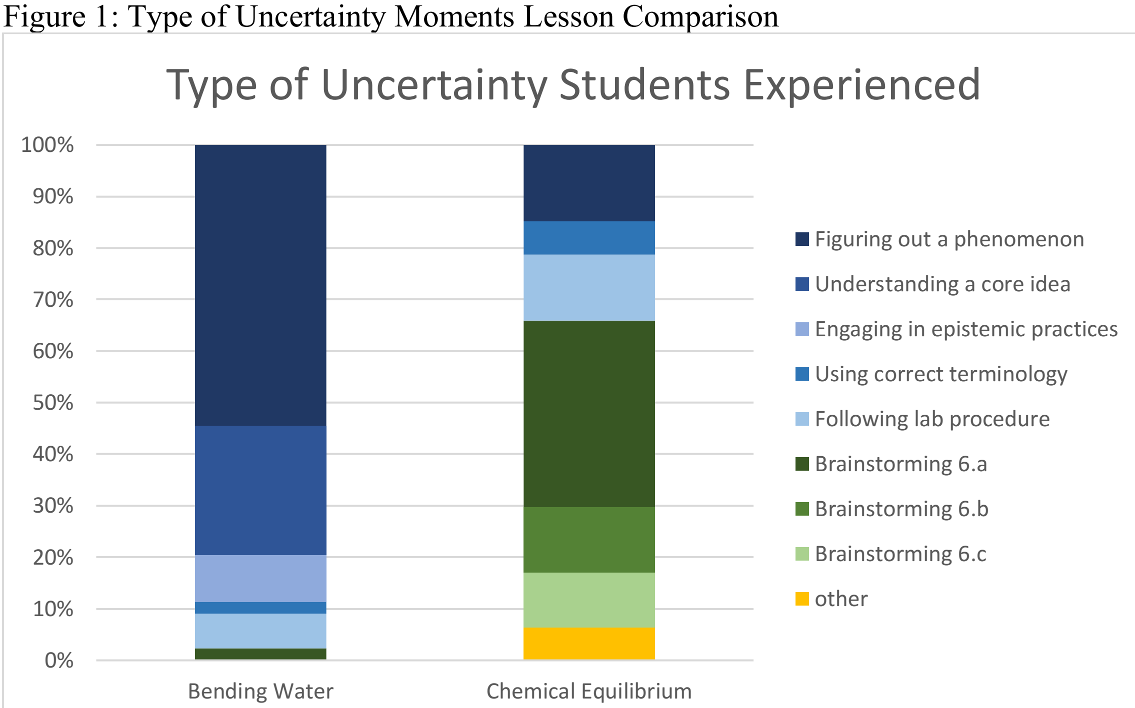

Table 5: How Uncertainty was Evoked in Focal Lessons

		Phases of Implementation

Lesson	Uncertainty was evoked by a...	Launch	Enact 1	Enact 2	Enact 3	Enact 4	Total
Bending Water	Conceptual question or idea	5 (11%)	6 (14%)	6 (14%)	9 (20%)	12 (27%)	38 (86%)
	Terminology question or idea		1 (2%)		1 (2%)		2 (5 %)
	Procedural question or idea			1 (2%)	1 (2%)		2 (5%)
	Observation				2 (5%)		2 (5%)
Chemical Equilibrium	Conceptual question or idea	13 (28%)	2 (4%)	4 (9%)	12 (26%)	4 (9%)	35 (74%)
	Terminology question or idea			1 (2%)			1 (2%)
	Procedural question or idea		2 (4%)	8 (17%)			10 (21%)
	Observation					1 (2%)	1 (2%)

Note. The codes for how uncertainty was evoked are described in moments. The number given describes the number of that type of evoked uncertainty in that phase of the implementation. All percentages are approximate.

Figure 2: How Uncertainty was Evoked Lesson Comparison