Uncertainty and Cognitive Demand on Students' Thinking in Science Classrooms

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Abstract

This study focuses on the kinds of uncertainty experienced by students in relation to the level and kind of students' thinking during the implementation of a cognitively demanding science task. The Framework for K-12 Science Education together with the Next Generation Science Standards emphasize the integration of scientific knowledge with scientific practices as students try to figure out phenomena. During this process of sensemaking, students experience moments of uncertainty that are a key part of doing science and drive scientific pursuits. By examining video-records of a science lesson in which the teacher and the students worked on a cognitively demanding science task, and by analyzing students' interviews about this lesson, we identify the types of uncertainty that students experienced during the implementation of this task across the trajectory of the lesson. Moving beyond an all or nothing approach to uncertainty, our analysis reveals different kinds of uncertainty that students can experience and presents cognitively demanding tasks as a means to integrate uncertainty into students' experiences.

Problem

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 then crucial (Manz & Suárez, 2018). Students experience uncertainty as they attempt to make sense of a novel phenomenon by using their prior understandings 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 motivate the explanation 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, uncertainty can help to foster students' high-level thinking and sensemaking. In this exploratory study, we seek to understand the types of uncertainty experienced by students during the implementation of a cognitively demanding science task to provide a more nuanced characterization 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 efforts (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) throughout the sensemaking process, and these waves of uncertainty are in part what drives and sustains scientific pursuits. There has been a growing demand for understanding how to promote students' experience of uncertainty to foster their intellectual engagement and persistence 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 as emphasized in the Framework for K-12 Science Education (NRC, 2012). When these tasks are enacted effectively in a classroom, students work towards figuring something out by engaging in high-level thinking and sensemaking. Thus, we argue that integrating such cognitively demanding tasks in science classrooms can support promoting uncertainty during the process of sensemaking.

Although uncertainty can be planned in the design of cognitively demanding tasks, this is not sufficient; research has consistently shown that cognitive demand of tasks changes as the teacher and students work on them throughout the lesson (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

[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.

(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 a cognitively demanding task in to better support their engagement in the kinds of thinking envisioned in the Framework.

Design

This study was guided by the following research questions: (1) How was uncertainty experienced by students in one high school chemistry teacher (Mr. Daniel)'s classroom during the implementation of a cognitively demanding science task? (2) What were the students' perceptions of the opportunities for learning in the lesson structured around a cognitively demanding science task?

The study was conducted as part of an NSF-funded project that focuses on supporting teachers' learning to facilitate productive discussions in the science classroom. The project involves a professional development (PD) structured around science teachers' co-designing, teaching, and reflecting on science lessons to learn to facilitate productive science discussions. The PD started in summer 2018; four of the teachers 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 the *Bending-Water* lesson that Mr. Daniel, a chemistry teacher with 5 years of teaching experience, designed with the third author as part of this PD. Building on our earlier work (Author, 2020b), this lesson was selected because it was structured around a cognitively demanding science task, which had the potential to intellectually engage students in figuring out a puzzling phenomenon by drawing on science content and practices.

Data Sources and Analysis

The data sources for this study include the video-records of the *Bending-Water* lesson in Mr. Daniel's classroom (see Table 1) and interviews with a subset of his students. The three-day lesson focused on supporting students' sensemaking, exploring intermolecular forces by designing and conducting an investigation to explain why water stream bends when placed next to a charged rod.

For the analysis of the lesson, 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 engage in based on the framing of the intellectual work during the launching of the task, and (3) the actual intellectual work that happens during the task enactment. In our analysis, we broke the lesson up into the parts described in Table 1 and used the instructional quality measure to code them. Two raters independently coded the lesson plan 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 which we then described and categorized along 5 codes (Table 2). The first author conducted initial rounds of coding drawing on themes from the literature and on emergent insights during the analysis. These rounds of analysis resulted in detailed codebooks with descriptions of codes and examples from the data. These codebooks were then shared with the other authors for a discussion to refine the codes and their descriptions. The data was then re-coded collaboratively with a second rater. If there were any discrepancies between codes, the raters discussed until a consensus was made. This process resulted in further refinement of the codes and consensus coding of all the moments of uncertainty.

Finally, for the analysis of the interviews, we read through the transcripts to develop generative themes (Braun & Clarke, 2006) about students' learning experiences in the *Bending Water* lesson as they worked on a cognitively demanding task.

Findings

Overall, our analysis revealed nuances in the types of uncertainty experienced by students in relation to the level and kind of students' thinking across the phases of a cognitively demanding science task. In the *Bending-Water* lesson, the science task had the potential to engage students in the kinds of the intellectual work in which scientists engage (Author, 2015) its cognitive demand on students' thinking was maintained at the highest level in the launch and enactment phases of the lesson based on the instructional quality tool used for the analysis.

As seen in Table 3, Mr. Daniel launched the task by using a puzzling phenomenon for why water bends when a charged rod is placed near the stream. Students were positioned to explain how and why that happened. During the launch phase students mostly experienced uncertainty around *figuring out the phenomenon.* Across all the parts of the enactment, the level and kind of students' thinking were maintained at the highest level because students worked on explaining the phenomenon and used science ideas and practices as they tried to make sense of it. Enact 1 focused on students creating initial claims and explanations of the phenomenon, followed by students planning for how they might test their claims. While engaging in this phase of the task, students' uncertainty was mostly about *figuring out the phenomenon* and *understanding a core idea.* Students were asked to design an investigation to test their claim during Enact 2. Students in this part of the enactment of the task experienced uncertainty mostly around *engaging in epistemic practices.* During Enact 3, students conducted investigations to test their claims and began developing their arguments and explanations. Students experienced uncertainty mostly about *figuring out the phenomenon.* Enact 4 concentrated on students presenting their explanations and developing a consensus for the mechanisms behind the phenomenon. During this part students experienced uncertainty around *figuring out the phenomenon* and *understanding a core idea.*

Our analysis of the student interviews revealed consistent patterns about the nature of students' intellectual engagement in this lesson. All students commented on how much they were puzzled by the bending of the water stream phenomenon, which maintained their intellectual engagement throughout the lesson. Rose for example said, "I even went home to my mom and was like, mom, what's the answer? She wouldn't tell me and then I was just like. And I looked it up and I kept like researching and then I like watched videos on it just because I was like, why the heck is this water bending?" They expressed how they were driven by this uncertainty and how they eventually figured it out. Student interviews also revealed students' satisfaction with understanding the underlying mechanistic explanation of the phenomenon that they explored in this lesson.

Conclusions and Contributions

As the field is seeking ways to intentionally build into classroom activities specific forms of uncertainty to motivate the explanation of phenomena by drawing on disciplinary ideas and practices as emphasized in the Framework for K-12 Science Education, this study provides a detailed analysis of classroom interactions throughout the trajectory of a science lesson with respect to students' thinking and the types of uncertainty that they experience. By doing so, it contributes to the limited knowledge base about the relationship between the nuances in students' thinking and the type of uncertainty that they experience. The findings go beyond whether or not students experienced uncertainty, specifically, this study provides insights into the types of uncertainty that students experience in science classrooms while engaging a cognitively demanding science task and presents cognitively demanding tasks as a means to promote uncertainty. Therefore, the study builds on theory by connecting the literature on uncertainty with the literature on cognitive demand and provides implications for classroom practice to promote the vision established in the Framework for K-12 Science Education.

Table 1. Details about the launch and enactment phases of the *Bending-Water* lesson

Phases	**Brief description of activities**
Launch	Observing the teacher place a charged rod close to the stream of water.
Enact #1	Discussion of students' initial claims, explanations for bending water 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, explanations to develop a consensus for the mechanism of the phenomenon.

Table 2. Characterizing Uncertainty

Codes	**Example**
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	Students ask questions and come up with ideas why the water might be bending.
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.	Students have questions and discuss what polarity is.
Engaging in epistemic practices: Students experience moments of uncertainty when they are unsure about how to engage in disciplinary practices such as designing investigations, developing arguments.	Students work together to decide what to test to support their claim.
Following lab procedure: Students experience moments of uncertainty when they are unsure or wondering how they might proceed in coordinating and managing the investigation.	Students are unsure about how to use lab materials.
Other: Students experience moments of uncertainty that are not described in the codebook.	

Table 3: The Cognitive Demand and Type of Uncertainty in Bending-Water

Phases:	**Launch**	**Enact-1**	**Enact-2**	**Enact-3**	**Enact-4**	
Rigor ratings:	Level-5	Level-5	Level-5	Level-5	Level-5	
Types of uncertainty:						
Figuring out a phenomenon	4 (9%)	3 (7%)	1 (2%)	9 (20%)	7 (16%)	24 (55%)
Understanding a core idea	1 (2%)	4 (9%)	1 (2%)	1 (2%)	4 (9%)	11 (25%)
Engaging in epistemic practices			4 (9%)	0 (0%)	0 (0%)	4 (9%)
Following lab procedure			0 (0%)	2 (5%)	1 (2%)	3 (7%)
Other			1 (2%)	1 (2%)	0 (0%)	2 (5%)

Note. The codes for the type of uncertainty experienced are described in moments of interaction. The numbers provided in this table describes the number of moments of uncertainty found in each phase of the lesson.

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References

Author, 2015

Author, 2019a

Author, 2019b

Author, 2020a

Author, 2020b

Cullicott, C. E.*, & Chen, Y.-C. (2018). Uncertainty management in science argumentation. In J. Kay & R. Luckin (Eds.), Rethinking learning in the digital age: Making the learning sciences count: 13th International Conference of the Learning Sciences (ICLS) 2018, Volume 3, (pp. 1479-1480). London, United Kingdom: International Society of the Learning Sciences.

Jordan, M. E., & McDaniel, R. R. (2014). Managing Uncertainty During Collaborative Problem Solving in Elementary School Teams: The Role of Peer Influence in Robotics Engineering Activity. Journal of the Learning Sciences, (4), 490.

Kang, H., Windschitl, M., Thompson, J. (2016). Designing, launching, and implementing high quality learning opportunities for students that advance scientific thinking. Journal of Research in Science Teaching, 53, 1316-1340.

Manz, E., & Suárez, E. (2018). Supporting teachers to negotiate uncertainty for science, students, and teaching. Science Education, 102(4), 771-795.

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: National Academies Press.

Odden, T., & Russ, R. (2019) Vexing questions that sustain sensemaking, International Journal of Science Education, 41:8, 1052-1070.

Stein, M. K., & Smith, M. S. (1998). Mathematical tasks as a framework for reflection. Mathematics Teaching in the Middle School, 3(4), 268–275.

Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building Student Capacity for Mathematical Thinking and Reasoning: An Analysis of Mathematical Tasks Used in Reform Classrooms. American Educational Research Journal, 33(2), 455–488.