Patterns of Mechanistic Reasoning in an Integrated Earth Science and Geotechnical Engineering Unit

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Abstract: In the NGSS era, engineering has become prevalent in elementary classrooms; it is often used as a context for science lessons, with an assumption that adding engineering design will support students' sensemaking. To investigate this assumption, we develop a case study to examine the patterns of reasoning that fourth grade students employed over the course of an integrated earth science and geotechnical engineering unit in which inquiry and design activities are intended to inform each other. Applying Krist, Schwarz, and Reiser's (2019) framework, we found ample evidence of mechanistic reasoning during inquiry lessons, but minimal evidence during design activities. This disciplinary difference in types of sensemaking is reasonable, as engineering is focused on creating functional solutions and not on describing phenomena. Supporting mechanistic reasoning during engineering requires reflecting on *why* designs work, including leveraging intentional strategies for talk and making thinking visible.

Introduction

In the NGSS era, engineering has become prevalent in elementary classrooms, often as part of integrated science units. Engineering is commonly used as a context for teaching science concepts, with an assumption that adding in engineering design will support students' sensemaking (NRC, 2012). However, as science and engineering have different disciplinary aims, this assumption needs to be closely examined; in fact, prior research shows that design challenges and related learning activities need to be carefully designed for opportunities for students to build science content knowledge and practices while working to solve a design problem (Kolodner, 2006; Sadler, Coyle, & Schwartz, 2000).

We are interested in looking at the patterns of reasoning that children employ throughout an integrated science and engineering elementary curriculum. We build on the extensive literature on student talk in science inquiry settings (e.g., Carlone, Haun-Frank, & Webb, 2011), and seek to extend it to integrated science and engineering units, where science is typically contextualized by a framing engineering design challenge. While there is a body of prior research that characterizes elementary students' discourse in engineering or integrated STEM units at the conversation level (e.g., Jordan & McDaniel, 2014), studies that trace the dynamics of classroom discourse over an entire engineering or STEM unit enactment are just beginning to emerge (McFadden & Roehrig, 2018). We aim to build on these studies by focusing on student reasoning in particular.

In this paper, we develop a case study to address the research question, *How do fourth-grade students employ mechanistic reasoning over the course of an integrated earth science and geotechnical engineering unit in which inquiry and design activities are intended to inform each other?*

Methods

Participants and context

This study is part of a larger, design-based research project (ConnecTions in the Making: Elementary Students, Teachers, and STEM Professionals Integrating Science and Engineering to Design Community Solutions), aimed at developing and studying community-connected, integrated science and engineering curriculum units that support diverse elementary students' science and engineering ideas, practices, and attitudes. This study focuses on the "Make Way for Trains" fourth grade unit, an 8-lesson unit on earth science and geotechnical engineering, with alternating science inquiry and engineering design lessons. For the unit's design task, student teams designed, built, and tested table-scale prototypes of retaining systems to hold back sand that supports a model house without falling onto the model train tracks. We develop a descriptive case study of a single fourth grade classroom in a racially, ethnically, linguistically, and socioeconomically diverse public school as they engage in the Make Way for Trains unit. The class of 24 students worked through the unit in teams of four.

Data collection and analysis

Instead of looking in great detail at a single conversation, here we are interested in larger-scale patterns of reasoning, so we draw from data collected across the whole unit, including science inquiry and engineering design lessons. We include multiple data sources: video data of whole class discussion and small group work, photos of student artifacts, copies of the students' written work and digital design notebooks, and researcher interviews with individual students.

Drawing from descriptive case study methodology (Merriam, 1998) and interaction analysis (Jordan & Henderson, 1995), we explore this particular classroom's mechanistic reasoning as a way to understand the kinds of reasoning we may expect of students in integrated science and engineering units. With the goal of making and supporting claims about the students' sensemaking and decision making approaches, research team members reviewed video excerpts of student talk, and then proposed claims and supporting evidence. Student artifacts were used as triangulating evidence. Conclusions emerged when the team confirmed claims with multiple pieces of data and failed to find counterexamples.

We conducted discourse analysis (Gee, 2010) on all episodes of sustained student talk through the 8 days of the unit. We then applied Krist, Schwarz, and Reiser's (2019) framework to the episodes to characterize students' mechanistic reasoning. This scheme synthesizes and builds on existing frameworks, most directly Russ et al. (2008), and proposes three essential heuristics for mechanistic reasoning: (a) *considering what occurs at the scalar level below the level of the observed phenomenon*, (b) *identifying and characterizing the relevant elements at that lower level*, and (c) *coordinating those elements over space and/or time to see whether and how they give rise to the observed phenomenon*. While this scheme was developed to highlight epistemic heuristics across science content areas, we expected it to provide insights to engineering activities as well, since considering what to create to solve a problem and making sense of a design's performance provide ample opportunities for mechanistic reasoning. Multiple researchers coded each transcript, with all disputes settled by discussion and consensus. While we coded every turn of transcripts, because we are interested in patterns over the entire integrated unit, we present an analysis of characterizations of reasoning at the level of conversations.

Findings

We present examples of the kinds of reasoning we saw during the unit, using episodes from different days and featuring different kinds of activity. On many days, small group work was followed by whole-class discussion.

Day 2: Whole class discussion of science inquiry on angle of repose

On Day 2, students engaged in an inquiry lesson on the concept of angle of repose using the focus question, "How do different materials act in a pile?" Students poured four different earth materials onto elevated cardboard circles and attempted to get the piles as tall as possible. After consolidating all teams' height data, the teacher asked students to reflect on the results, asking, "Why do you think there was a difference between some of these? [...] What do you think made up the differences?" In the whole class discussion, students reasoned about the phenomena by narrating their observations, e.g., "*Once you added a lot of, like poured in a lot of sand it collapsed and just like it kept falling, so if you added more, it would still be the same height because of some of it was falling,"* and describing properties of the materials they thought might matter, e.g., *"the soil is easy to work with and you can mold it to like get it bigger and then the sand doesn't, it's like thin and fine, so like it just falls apart."* Students did not explicitly reference the grains or material particles; or, using the coding scheme, they did not consider the lower scalar level in order to reason about the observed phenomenon (the pile height or steepness). Thus, they seem to be engaging in describing relevant factors (heuristic 2) without first explicitly doing the work of thinking across scalar levels (heuristic 1), and there is no evidence of students trying to coordinate across levels (heuristic 3), possibly as a result of not fully recognizing a need to attend to the scale of sand grains.

Day 5: Small group sand grain forces modeling activity

The goal for Day 5 was for students to reason about the effects of surface roughness; this was scaffolded using a handout with diagrams of a pile of magnified sand grains on a smooth surface and an identical pile on a rough surface (drawn as triangles). Students were asked to reason in groups about why, after pushing down on both piles of sand grains, the pile on the smooth surface flattens more than the pile on the rough surface. In these small group conversations, we see evidence of all three mechanistic reasoning heuristics: students reasoned by *thinking across scalar levels* (considering both the sand grains and the piles), *identifying and unpacking relevant factors* (sand grains fitting between triangles), and *coordinating across the different levels* (the bottom grains are "stuck", so only the top grains fall), as seen in this example excerpt from one small group conversation:

Amelia: So this is what I think would happen with the flat rocks. So before pushing down it would be good, like high, I mean, it wouldn't be that high so, and then when you push it down all the rocks would just kind of fall (gestures falling).

Elias: That's what I think as well.

Amelia: And then with this one--it like fits in the, like, triangle so it's not going to fall out--

Elias: (unclear) between the triangles it won't (unclear) (partners agree)

Amelia: Only like the top ones would fall because of the force but then the bottom ones won't fall. It's, like, stuck in there.

Day 6: Small group talk while designing

On Day 6, student teams spent the lesson building, testing, and iterating on designs; at a mid-point during the lesson students did a silent gallery walk to observe other teams' designs and get inspiration for their next iterations. While this design task drew directly on concepts from previous lessons, including inquiry lessons, there was almost no mention in small group talk of concepts from previous activities. Instead, students discussed their design ideas, and occasionally, but not consistently, justified those ideas; the most common justification was referencing previous test results. Students did not typically push teammates for deeper reasoning. For example:

Luis: I feel like they [toothpicks] should go in front of the sticky notes for some reason.

Janice: Yeah.

Luis: Cause then it can hold it with the sand (gestures pushing together).

Janice: It can hold it better.

Later, Luis directed his teammate to add to their design, based on past experience with sand "leaking": "Oh, you need to put a sticky note in that corner (points) it's gonna leak from the corners (pause) 'cause last time we did it, it was leaking from the corners, like the sand was just pouring out."

There was no coding of mechanistic reasoning in any of the three focus groups on this design day. Some groups told narratives about how they expected their design to function, but these were not causal stories that rise to the level of mechanistic reasoning.

Day 8: Student interviews on design work

We saw reasoning about identifying and unpacking relevant factors sustained in student interviews on the last day of the unit. For example, in describing the earth material-textile layering her team employed in their retaining system design, Asmae said, "*Yeah and like um that [mesh material] didn't work because the holes—the sand would go through it. And then we tried using the uh, the napkin kind of thing and the thing just fell off because it wouldn't hold the sand. And then we tried aluminum foil which worked the best because we tried crumpling it like a bowl so it would hold the sand.*" Asmae reasoned about how the textile materials interacted with the sand, using a combination of observations and mechanistic reasoning, including considering how the sand interacted differently with each of the textile materials, depending on material properties.

Earlier in the interview, Asmae explained how her team made an engineering design decision based on test results, but her reasoning relied solely on test results; there is not strong evidence of mechanistic reasoning: "*...and we tried thin layers and that didn't work and then we tried thin and thick layers and that didn't work so we then we tried only thick layers and that worked the best.*"

Discussion

Overall, the data provide evidence that students engaged in aspects of mechanistic reasoning throughout the integrated science and engineering unit. The kinds of reasoning students used varied over the unit; we discuss two key influences in this unit enactment: pedagogical choices in the design of activities and whether the activity was science or engineering focused.

Consistent with prior findings on instructional design, we found that the prompts, instructional materials, and framings of the activities had a strong influence on students' mechanistic reasoning (Russ et al., 2008; Wilkerson-Jerde, Gravel, & Macrander, 2014). For example, in the Day 2 piles discussion, the focus question of *Why are different piles different heights?* likely cued students to focus on identifying properties of the materials (identifying and unpacking relevant factors), rather than on telling causal stories of how the grains interact with forces like gravity to limit the pile height, which may have occurred if the focus question had been something like *Why can't we make the piles taller?* In contrast, the handout on Day 5 with magnified sand grains cued students to consider and reason about this lower scalar level, a key aspect of mechanistic reasoning. In this class, we did not see students spontaneously consider the grains of sand even after four classes, so we made an instructional choice to highlight this lower scalar level by creating an activity focused specifically on interactions between individual sand grains.

We found ample evidence of mechanistic reasoning in the science inquiry lessons related to engineering design challenges (Days 2, 4, 5), and minimal evidence of it in the small group work on the design challenges (Days 3, 6), although there were many instances of collaborative reflective decision making (Wendell, Wright, & Paugh, 2017). During the small group designing, there were moments of reasoning, and opportunities to discuss mechanism, but these opportunities were not pursued by students. Since the activity had an explicit goal of designing a functional retaining system, rather than a goal of explaining sand or retaining system behavior, it is reasonable that mechanistic reasoning was not a meaningful way for students to spend their limited time. Students appeared to only do as much reasoning as was necessary to answer their immediate questions related to the design task, but did not pause their design work to fully flesh out the phenomenon.

In order to ensure mechanistic reasoning reliably occurs in engineering curriculum enactments—if and when this is a goal—educators and curriculum developers likely need to build in design-related inquiry lessons and teacher-supported talk that explicitly references the mechanistic reasoning behind design performances.

Conclusions

With integrated science and engineering units becoming prevalent in elementary classrooms, it is important to look closely at the patterns of student reasoning throughout these units, to examine what disciplinary goals are being supported. In this study, we found that even in an integrated unit, with inquiry and design activities created to inform each other, students used reflective decision making during engineering design, but did not often engage in mechanistic reasoning, despite opportunities to do so. An implication is that supporting mechanistic reasoning during design requires going beyond focusing on simply *whether* designs work to allowing ample time for considering *why* designs work, by employing intentional strategies for making thinking visible and supporting reflection through talk and documentation.

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