2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering
Education for 130 Years
ASEE
Paper ID #38603

# Board 161: Elementary Students' Mechanistic Reasoning about Their Community-connected Engineering Design Solutions (Work in Progress)

**Dr. Mustafa Sami Topcu, Yildiz Technical University**
**Dr. Kristen B. Wendell, Tufts University**

Kristen Wendell is Associate Professor of Mechanical Engineering and Education at Tufts University. Her research efforts with the Tufts Center for Engineering Education and Outreach and the Tufts Institute for Research on Learning and Instruction focus on supporting knowledge construction in engineering classrooms at the pre-college and undergraduate levels.

# Elementary students' mechanistic reasoning about their community-connected engineering design solutions (Work in Progress)

## Introduction

Mechanistic reasoning is an approach to explaining a phenomenon by identifying its entities and the cause-effect relationships among their properties and activities (Machamer et al., 2000; Russ et al., 2008). It allows scientists and engineers to produce predictive models of both natural and designed systems. Because mechanistic reasoning supports explanation and prediction, it is important not just in professional science and engineering endeavors but also in the learning of science and engineering at the K-12 level. Information about how pre-college students reason mechanistically about their own engineering designs could help educators assist students in understanding how and why a design functions as it does.

Previous literature on children's mechanistic reasoning about engineering solutions has mostly focused on the context of highly structured mechanical systems. Yet there is growing interest in community-connected engineering design contexts for elementary students. Important questions remain about how a specific community context influences opportunities for engineering design practice and reasoning. In this study, we explore whether comparisons in students' mechanistic reasoning can be made across a range of five different community design contexts.

## Literature Review and Framework

Work in science education provides a basis for studying mechanistic reasoning among engineering students. A large body of work characterizes mechanistic reasoning within the doing of science. These efforts, broadly speaking, define mechanistic reasoning as making sense of the processes that underlie cause-effect relationships in the physical world. Several studies have shown how children in particular use mechanistic reasoning in their scientific pursuits. They have examined students' spoken discourse, writing, and drawing and highlighted the elements of students' mechanistic accounts of phenomena (e.g., Grotzer & Basca, 2003; Sengupta & Wilensky, 2009; Van Mil, Boerwinkel, & Waarlo, 2013; Wilkerson-Jerde, Gravel, & Macrander, 2015). To provide a snapshot of this prior classroom research, we will focus on frameworks proposed by Russ et al. (2008) and Krist et al. (2019). They differ in important ways, and we find that the combination of these two frameworks works well to describe the ways mechanistic reasoning emerges in children's engineering.

Drawing from depictions of mechanistic reasoning by philosophers of science (Machamer et al. 2000), Russ et al. (2008) developed a coding scheme to enable education researchers to conduct systematic analysis on the substance of mechanistic reasoning in students' science inquiry. Their scheme includes seven hierarchical categories suggesting that mechanistic reasoning is evident when students describe the *target phenomenon* (category 1), identify the *set-up conditions* for the phenomenon (category 2), identify the *entities* that play a role in producing the phenomenon (category 3), identify the *properties, activities*, and *organization* of those entities that affect the outcome of the phenomenon (categories 4 through 6), and finally *chain* the current state of the entities backward to what happened previously or forward to what will happen next (category 7). The higher the category, the stronger the evidence of mechanistic reasoning by students.

While Russ et al. (2008) focused on classroom discussion in physical science, Krist et al. (2019) examined mechanistic reasoning in students' written explanations in multiple science content areas. Their approach made use of the elements of mechanistic accounts proposed by Russ et al. (2008), the structure-function-behavior framework developed by Hmelo-Silver and Pfeffer (2004), and Wilensky and Resnick's (1999) idea of thinking about complex systems "in levels." Synthesizing all of this prior work together, Krist et al. (2019) proposed that science students produce mechanistic reasoning by applying three epistemic heuristics – that is, three ideas about how to guide one's intellectual work in science. These heuristics include (1) *considering what occurs at the scalar level below the level of the observed phenomenon*, (2) *identifying and characterizing the relevant elements at that lower level*, and (3) *coordinating those elements over space and/or time to see whether and how they give rise to the observed phenomenon* (p. 175).

In summary, Russ et al.'s (2008) framework foregrounds the distinct elements of a mechanistic account - what learners say about the phenomenon's entities and their characteristics and actions, and Krist et al.'s (2019) framework foregrounds scalar levels - how learners describe what is happening at a scale other than the observed phenomenon. Previously, we conducted a study of the mechanistic reasoning expressed spontaneously in elementary students' discourse while building and testing prototypes (Authors, in Preperation). In that study, we found that a subset of Russ et al.'s seven levels and a subset of Krist et al.'s three heuristics fully described the ways that students used mechanistic reasoning as a tool to discuss their design ideas, artifacts, test results, and plans for iteration, as shown in Table 1.

Table 1. Aspects of mechanistic reasoning and their definitions

| Aspect of mechanistic reasoning | In elementary school engineering design | Related elements from Russ et al. (2008) and Krist et al. (2019) frameworks |
|---|---|---|
| ***Identifying* target performance** | Describing how a design (or design sub-system) performed in a test or describing a specific goal for future design performance | Russ: Describe the target phenomenon (#1) and identify the set-up conditions (#2) |
| ***Naming* entities** | Recognizing the distinct components of a design (or its user) that matter to design performance | Russ: Identify entities (#3)<br>Krist: Identify factors (#2a) |
| ***Describing* entity factors** | Describing different properties, structure, shape, location, movement, or other action of a component | Russ: Identify entities' properties (#4), organization (#5), and activities (#6)<br>Krist: Identify and unpack factors (#2a, b) |
| ***Linking up* to performance** | Pointing out explicitly that a particular entity or factor plays a role in an explicitly stated design performance (without explanation of how or why that role is played) | Russ: Chaining backward and forward (#7)<br>Krist: Link interactions to the scalar level above (#3) |
| ***Connecting* entity factors** | Providing cause-and-effect explanation between entity factors; explaining "how or why" one factor or entity influences another factor or entity | Russ: Chaining backward and forward (#7)<br>Krist: Consider the scalar level below the phenomenon (#1) |

## Research Question and Methods

In our previous work, we combined these frameworks to identify mechanistic reasoning (MR) that students used "in progress" while making engineering design decisions in the classroom with their design teams. In this study, we shift to characterizing elementary students' use of MR in "final design" accounts in individual interviews. We ask: *how do elementary students use MR when describing and explaining their design prototypes at the conclusion of five different community-connected engineering units?*

For this qualitative descriptive study, we focus on interview data collected after each of five community-connected curriculum units: accessible playground design (3rd grade, N = 8), displaced animal relocation design (3rd grade, N = 10), migration stopover site design (4th grade, N = 4), retaining wall design (4th grade, N = 13), and water filter design (5th grade, N = 9 students). In the interviews, students were shown a photo of the artifact they constructed to solve the community-connected design problem. They were then prompted to (a) describe and explain their final design solution, (b) compare it an alternative solution (also shown in a photo), and (c) evaluate how well it connected to the real-life design problem. We coded the interview transcripts for four of the elements of MR shown in Table 1: *naming entities, describing entity factors, connecting entity factors,* and *linking up to design performance*. We did not code for *identifying target performance* because the interviewer reminded the student of the design goal in the interview prompts.

## Findings

In the interviews after all five curriculum units, when describing and explaining design solutions, the majority of students used all four of the elements of MR included in our coding scheme. Below we provide examples of how students expressed each of these elements. As shown in Table 2, all students *named entities* and *described entity factors* for the design solutions for all five community contexts. For three of the contexts (playground, displaced animals, stopover sites), some students described the design artifacts without expressing *connections between entity factors* and/or the way factors *linked up to the design performance*.

Table 2: Proportion of students who used elements of mechanistic reasoning when describing and explaining design solutions to community-connected problems

| | **Playground (3rd grade)** | **Displaced Animals (3rd grade)** | **Stopover Sites (4th grade)** | **Retaining Walls (4th grade)** | **Water Filters (5th grade)** |
|---|---|---|---|---|---|
| **Naming Entities** | 100% (8/8) | 100% (10/10) | 100% (4/4) | 100% (13/13) | 100% (9/9) |
| **Describing Entity Factors** | 100% (8/8) | 100% (10/10) | 100% (4/4) | 100% (13/13) | 100% (9/9) |
| **Connecting Entity Factors** | 88% (7/8) | 80% (8/10) | 50% (2/4) | 100% (13/13) | 100% (9/9) |
| **Linking up to Performance** | 63% (5/8) | 60% (6/10) | 100% (4/4) | 100% (13/13) | 100% (9/9) |

**Naming Entities -** Students *named entities* to identify what they perceived as the major components of design artifacts. For example, after the water filter unit, Molly named the entity of "net stuff" used to remove pollutants, to point out a key difference between her team's design solution and the alternative solution shown by the interviewer: "I thought that they um, well, one thing that I thought was different was they used that **net stuff**, and we didn't use that for ours." After the playground unit, Tia *named entities* for a different reason. She identified components -

“metal and stuff” -  that would have made her team’s design function even better: “like, um, for the swing, it was kind of hard because like, um, there’s not like- we needed **metal and stuff**.”

**Describing Entity Factors -** Students *described entity factors* when they identified the characteristics or actions of a component that mattered to the design’s functioning. Examples of entity factors include shape, size, texture, orientation, location, and motion. After the playground unit, Paula pointed out several entity factors that caused trouble with their design. She talked about the moisture content, location, and sticking action of the clay: “all **the clay we used dried up**, so we couldn’t use that , like, to make, **put it underneath there** and like **make it stick on**, but we didn’t have enough time.”

**Linking Up to Performance -** Students *linked up to performance* when they pointed out explicitly that a particular entity or factor played a role in the performance of the design artifact as a whole. For example, after the water filter unit, Rebecca linked the entity of “straws” and the factor of their orientation (“facing that way”) up to the performance of blocking the beads: “then we put some **straws** right there um they were supposed to be facing that way (makes a turning motion while pointing at the image) um to **stop some of the beads**.” After the playground unit, Payton mentioned “cardboard” and “stilt things” as entities and linked them to the performance of safety: “our slide but it was like [gesturing the slant of the slide structure], it was like a stable [motions the roof of a stable], then it was dampened this way [tilting hand]. Because [points to design] the cardboard wouldn’t keep it up. So, I thought, if we put the **cardboard** first and then add the, **the stilt things** then it might be **a little safer.”** Students also linked up to performance when accounting for design failures. For instance, Gary linked the entity of tape to the disappointing performance of his team’s filter: “most of **it didn't like work because** there was **a lot of tape**.. and it kind of messed up the-- one of the-- some of the materials.”

**Connecting Entity Factors  -** Students *connected entity factors* to give cause-and-effect explanation between the characteristics or actions of multiple design components. Making connections between factors involved explaining how or why one characteristic, action, or component influenced another, all at a level below the overall design performance. For the water filter unit, **Riley** connected the entity factor (sponges at the top of the design) to another factor (stopping oil and glitter) by explaining that using sponges was the reason of stopping oil and glitter in their design. “Yeah so we (points) did the um sponges to stop the oil and we put the sponges on top um because the oil floated (gestures rising motion) to the top- floats to the top of the water cuz the water has a greater density (I: uh huh) umm and.. we (pointing) used that to stop um the glitter.” After the playground unit, Tia named the entities of a model wheelchair and swing as design components that mattered to the design’s failure; she described the relevant factors: weight placement, and flipping over; and she connected the factor of weight placement on swing to the factor of swing flipping over. She explained that “then it’ll go a little lower. So, it like- you won’t fall down. Like it can- the wheelchair, it **weighs too much on the swing**, then it’ll f**all down, flip over**, upside down. So, it’s going to like- something that’s sturdy enough.”

## Discussion and Conclusion

The findings showed that *linking up to performance* and *connecting entity factors* occurred less often than *naming entities* and *describing entity factors*. Students may have *linked up to the overall design performance* more consistently after the water filters, retaining walls, and stopover sites units because testing occurred frequently and at discrete moments in time for these units. Students could therefore focus on the effects of particular entities and factors on the success or failure of their design. The testing procedures for these units were very observable (either by eye or with a measurement device), and it was clear to students what counted as a successful test result – the blocking of beads, sand, or light and sound. By contrast, the playground and displaced animals units included more open-ended instructions about how to test designs. In these units, students had much more choice about what materials and procedures to use in testing their designs. Therefore, linking up from a single entity or factor to the overall design performance required more interpretation and effort.

We can also speculate on why students *connected entity factors* most consistently in the water filter and retaining wall units. In these units, the community contexts were narrower and focused on concrete interaction with specific elements of the natural environment – water or sand. In the other three units, the community contexts involved hypothetical interactions with people and/or animals. When constructing and testing filters and retaining walls, students could touch and see the water and sand and observe how these natural elements interacted with each entity they had chosen to include in their design solution. Since these interactions were more concrete, it was likely easier for students to observe cause-and-effect connections between entity factors.  In the more abstract and hypothetical scenarios used in the playground, displaced animals, and stopover site units, it was more difficult for students to see patterns of cause and effect.

The finding that students did not always connect entity factors and link from entities and factors up to design performance is consistent with our prior research on students' use of MR during team design conversations (Authors, year). In that research, students often needed instructor prompting to think causally about relationships among design components and between components and their overall design. Findings from both studies imply that connecting entity factors when explaining an engineering design is difficult for elementary students. This difficulty is consistent with findings about students' mechanistic reasoning in science. Russ et al. (2008) put "chaining" – which involves making causal connections - at the most sophisticated end of their mechanistic reasoning framework, and Krist et al. (2019) showed that some students need substantial support to making claims about entities at a scalar level below the phenomenon.

Our findings suggest that the particular community contexts used in community-connected engineering curricula influence students' opportunities for mechanistic reasoning about design solutions. However, future research is needed to confirm which characteristics of community contexts support or hinder aspects of mechanistic reasoning in engineering learning. In this study, we were limited by examining only five curriculum units and by eliciting student reasoning only after the units had concluded. Future work is also needed to disentangle the influence of design context from the influence of students' grade level and previous experience with engineering design.

**References**

Grotzer, T. A., & Basca, B. B. (2003). How does grasping the underlying causal structures of ecosystems impact students' understanding? *Journal of Biological Education*, *38*(1), 16-29.

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science*, *28*(1), 127-138.

Krist, C., Schwarz, C. V., & Reiser, B. J. (2019). Identifying essential epistemic heuristics for guiding mechanistic reasoning in science learning. *Journal of the Learning Sciences*, *28*(2), 160-205.

Machamer, P., Darden, D., & Craver, C. F. (2000). Thinking about mechanisms. *Philosophy of Science, 67*, 1–25.

Russ, R. S., Coffey, J. E., Hammer, D., & Hutchison, P. (2009). Making classroom assessment more accountable to scientific reasoning: A case for attending to mechanistic thinking. *Science Education*, *93*(5), 875-891.

Sengupta, P., & Wilensky, U. (2009). Learning electricity with NIELS: Thinking with electrons and thinking in levels. *International Journal of Computers for Mathematical Learning*, *14*, 21-50.

van Mil, M. H., Boerwinkel, D. J., & Waarlo, A. J. (2013). Modelling molecular mechanisms: A framework of scientific reasoning to construct molecular-level explanations for cellular behaviour. *Science & Education*, *22*, 93-118.

Wilkerson-Jerde, M. H., Gravel, B. E., & Macrander, C. A. (2015). Exploring shifts in middle school learners' modeling activity while generating drawings, animations, and computational simulations of molecular diffusion. *Journal of Science Education and Technology*, *24*, 396-415.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and Technology*, *8*, 3-19.