The Tension Between Pattern-Seeking and Mechanistic Reasoning in Explanation Construction in Elementary Science Classroom

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Abstract: Through analysis of a representative case, we illustrate how instructional practices favor empirical pattern-seeking at the expense of mechanistic reasoning. When students spontaneously come up with hypothetical mechanisms to explain why a lightbulb in an electric circuit does or does not light, the teacher, following the guidance of curricula, redirects them to pattern-seeking. We argue that the bias toward pattern-seeking in Chinese national standards and curricula, combined with students' ability and propensity to propose at least the seeds of mechanistic explanations, helps explain the classroom tension between pattern-seeking and mechanism reasoning. In discussion, we extend the argument to show a less severe but similar bias toward pattern-seeking in the United States' Next Generation Science Standards (NGSS).

Introduction

It is widely acknowledged that seeking for mechanistic explanations is a central task in professional sciences (Machamer, Darden, & Craver, 2000; NRC, 2013). While accounts of learning show extensive evidence that students have inclinations and resources for mechanistic thinking from early on, and argue for the necessity and possibility of promoting such thinking through experiences in science (NRC, 2013; Russ, Coffey, Hammer, & Hutchison, 2010), sustained inquiry into mechanisms remain unusual in science classrooms of various levels (Zangori & Forbes, 2013; Talanquer, 2017).

This rarity is often explained in terms of characteristics of students or teachers. For example, researchers have argued that students often follow the everyday heuristic of explaining by invoking regularities or the closest agent (Driver, et al., 1996), or encounter difficulties in recognizing causes or mechanism (Abrams & Southerland, 2001), or have no awareness of the need to build a causal or mechanistic account in science (McNeil, Lizotte, Krajcik, & Marx, 2006). Similarly, researchers have argued that teachers may lack a solid understanding of what constitutes scientific explanation (Zangori & Forbes, 2013), or believe that their students cannot reason beyond concrete data (Zangori & Forbes, 2013), or focus primarily on textbook correctness when assessing student ideas due in part perhaps to institutional culture and pressures (Russ, et, al., 2010).

In our opinion, such attributions seem to oversimplify and decontextualize the issue. From a more contextualized perspective, we explore the phenomenon of concern by examining a case from a typical fourth grade Chinese science classroom, in which students initiated mechanistic explanation but the instructional guidance focused on empirical pattern-seeking instead. We argue that such instructional focus reflects a systematic tendency in the curriculum and standards of Chinese elementary science, and that it is also evident in NGSS.

Epistemic activities in explanation: Pattern-seeking vs. mechanistic reasoning

The distinction we consider here is between activities focused on observable patterns and those focused on mechanistic explanation. The former concerns experimental design and data analysis, efforts to collect and use evidence to support or refute claims (McNeill & Krajcik, 2011; Songer & Gotwols, 2012). The latter concerns theorizing and sense-making, efforts to find connection and coherence, to fill gaps and reconcile inconsistencies (Mathayas, Brown, Wallon, & Lindgren, 2019; Odden & Russ, 2019).

A number of authors have highlighted such a distinction. Some have discussed it as the difference between *argumentation* and *explanation*. Osborne and Patterson (2011, p. 633), for instance, suggest that in terms of epistemic function, argumentation concerns evidence to "justify a claim to knowledge or to persuade," while explanation concerns understanding. Lederman, Lederman & Antink (2014) present it as the difference between *laws* and *theories*: Laws are "statements or descriptions of the relationships among observable phenomena," whereas theories are "inferred explanations about observable phenomena." Such distinctions are not clean enough to be used in discourse or standards analysis. First, there is contextual variation in the epistemic meanings of the terms. *Explanation* may refer to either justification or causation (Braaten & Windschitl, 2011), whereas the term *law* unnecessarily denotes empirical regularities in all contexts. Newton's *laws*, for instance, refers to principles of a theoretical framework instead. Some authors (Osborne & Patterson, 2011) recognize the variation but argue that, for the sake of clarity and effective pedagogy, science educators should take care to use the terms consistently.

The difficulties, however, go beyond terminology. Empirical pattern-seeking and mechanistic reasoning overlap and entangle in many ways. There are often mechanistic assumptions underlying the choice of seeking patterns among a set of variables but not the others. What patterns can be inferred through observation also depend on the theoretical framework employed. The complexity of the relationship raises questions for science education, in particular whether to teach the practices as distinct. Responding to Osborne and Patterson (2011), Berland and McNeill (2012) argued that maintaining a dichotomy of terminology and meaning between argumentation and explanation may encourage students to see them as separable and independent.

Finally, part of the challenge is that the notion of *mechanism* has been difficult to define, for scientists and for philosophers (Salmon, 1998; Machamer, Darden, Craver, 2000). Hume famously attributed a sense of causality as induced from the experience of "constant conjunction" in observed events. On this account, mechanisms are, ultimately, patterns of experience. For instance, observations of what happens when a projectile strikes an object leads to the sense that collisions can function as causal agents. Mechanistic models of fluids and gases draw on this sense, explaining gas pressure or Brownian motion in terms of collisions at microscopic scales.

Yet even in this Humean sense there is psychological (if not always philosophical) distinction between the kinds of patterns highlighted in pattern-seeking and the kinds of patterns cued up in mechanistic reasoning. The notion of pattern-seeking denotes a set of activities that are relatively simple and straightforward to describe. Effective pursuit of such patterns depends on the control of variables strategy (i.e., Ford, 2005), which has been emphasized in Chinese and US standards. Seeking a mechanistic explanation, in contrast, is a search for a story of causes and effects that feels satisfying and coherent—a psychological activity that is hard to formalize. DiSessa's (1993) "knowledge-in-pieces" model set an example for this. It posits *phenomenological primitives* (p-prims) as elemental patterns induced from informal everyday experience, and shows how these patterns, when spontaneously activated in certain contexts, contribute to the formation of a person's intuitive sense of mechanism. By this view, conceptualizing a role for mechanistic reasoning in science may require a model of continuity between commonsense thinking and scientific understanding.

Despite the asymmetry in how precisely we can characterize mechanistic reasoning vs. pattern seeking, scientists and philosophers broadly agree that mechanism plays a significant role in science, and we take it as a premise that engaging in science means engaging in both empirical pattern-seeking and theoretical, mechanistic reasoning. The relationship is complex, and it is difficult to draw a line, but it is possible to discern the two within scientific activities. Identification of a pattern would trigger the desire to come up with the underlying story that can give birth to the pattern. For example, Mendel first noticed the mathematical patterns connecting parent and offspring traits, and he then constructed a possible mechanistic account for how inheritance occurs. Or, noticing a conflict between an observation and some established patterns may trigger efforts to construct a new mechanism, as when diffraction patterns led to accounts of light propagating not as particles but as waves.

A balanced integration of pattern-seeking and mechanistic reasoning, however, is unusual in classroom. Students usually lack opportunities to engage in extended explanation construction and evaluation activities (Zangori & Forbes, 2013). Even in cases with such opportunities, pattern-seeking often became the dominant epistemic activity (Driver, et al., 1996). In the present study, we illustrate how a "bias" toward pattern-seeking at the expense of mechanistic reasoning emerges and persists in the unfolding classroom discourse, which is in turn embedded in the broader national education system, including the curriculum standards that favor pattern-seeking over mechanistic reasoning, and we offer a few related conjectures for why that might be.

Methods

The focal case: Data collection and analysis

The case came from the first author's project on how classroom social environments influence inquiry teaching and learning, which videotaped every session of three elementary science classrooms from average-ranking schools for the 2013-2014 school year. Since the project introduced no educational interventions, the classroom data reflect "normal" educational settings; the teachers operated under routine pressures from the system. During the time, the first author and her graduate students conducted video-prompted interviews with each teacher at least once a month. Interviews focused on how teachers interpreted the students' emergent inquiry practices, and what informed the teacher's instructional responses. For each unit, the research team also conducted pre- and post-clinical interviews with five students on their understandings of the central concepts. When invited, the first author also attended group lesson preparation meetings, lesson polishing activities, and lesson-based open discussions organized in these schools, treating them as extra opportunities for data collection.

Epistemic activities in explanation were not an original focus of that project, but the first author found that 30 out of the 41 snippets chosen for the video-prompted interviews included student explanation construction and/or evaluation, suggesting its commonness in the classrooms we studied.

The focal case started with "lighting the lightbulb," the second lesson in a textbook unit on electricity. According to the textbook design, the students should first observe the structure of a lightbulb, and then try to light it with a battery and a piece of wire. The teacher's manual suggests the following conceptual goals: 1) the bulb lights when electricity flows through the filament; 2) it requires a complete circuit to light a bulb with electricity; 3) there is more than one way to construct a complete circuit using the same materials; 4) a short-circuit occurs when a piece of wire directly connects the two ends of a battery. According to the manual, the first goal can be accomplished by observing a bulb's structure and reflecting on daily experience with electrical devices, while the other three can be accomplished through the "light the lightbulb" activity and associated discussions.

The case also extended to the next lesson, for which the textbook design adds battery holders and bulb holders and encourages students to build circuits with more lightbulbs and/or batteries. The main focus, according to the teacher's manual, is to enforce the students' understanding of a complete circuit.

We performed a line by line analysis of the transcript of the whole-class discussions, drawing on methods from conversation and interaction analysis. Specifically, we attended to discourse markers including conversational opening and closing moves (Schegloff & Sacks, 1973), take-up vs. lack of take-up of bids for ideas (Strijbos & Stahl, 2007), repair (i.e., spotting and correcting lack of mutual understanding; Schegloff, Jefferson, & Sacks, 1977), and bids for frame shifts—resetting the nature of the classroom activity (Goffman, 1974).

To ascribe pattern-seeking, we looked for talk of associations or covariations between observable variables/factors. To ascribe mechanistic reasoning, we looked for evidence of students trying to construct or evaluate an underlying story. In particular, we relied on our earlier interpretation of Humean causation as explanations based on "very familiar patterns," and the holistic sense underlying Russ et al.'s (2010) coding scheme for mechanistic reasoning. The former guided us to examine students' ideas for the involvement of intuitive patterns that can possibly be induced from everyday experience. The latter guided us to recognize the students as engaging in mechanistic reasoning when they identify the *entities* and *activities* involved in a phenomenon, or identify *properties* and *organization* of entities that make it possible for the activities to take place, or expand and connect bits of mechanisms through backwards/forward *chaining*.

Our interpretation of the classroom data was also crosschecked with additional data from an interview with the teacher Mr. Z, and an interview with Lumin, a student who plays a key role in the case.

The curriculum standards: Textual analysis

Finally, for the two most recent editions of the Chinese national curriculum standards for elementary science, we analyzed all passages that contained the word "explanation" or "explain." The first author and a graduate student individually coded the contextualized meanings of all 26 occurrences of "explanation/explain" in these two documents into three categories: *foreground pattern-seeking*, *foreground mechanistic reasoning*, and *others* (including situations where explanation took on the meaning of "explication" and where no clear meaning can be inferred). The inter-rater reliability is 92.3%. All the discrepancies have been discussed and solved.

Analysis of the case "Can this connection work?"

Segment 1: In what situation can the lightbulb be lit?

Mr. Z's science class spent 10 minutes learning about the structure of a lightbulb, and another 15 minutes in small groups, trying to light the bulb with one battery and one piece of wire and drawing all the working arrangements. After they shared the findings of two working connections, Mr. Z asked the students to summarize "in what situation can the lightbulb be lit" by "looking at the drawings of connections that worked." The first idea—"when you have electricity and the string [referring to the wire]" —triggered a few giggles and a shout of disagreement. Keyi then came up with the second idea that "the circuit needs to be fully connected." When probed by the teacher, he further elaborated it as "Make a circle for the electricity, so it has a path to move forward." The third idea from Jiangya focused on how parts should be connected in a working circuits. Mr. Z scaffolded her expression through 20 turns, and finally summarized the idea as "one end of the wire connects to the battery, the other end connects to the 'iron ring' of the lightbulb, the bottom of the lightbulb connects to the other 'iron part' of the battery."

We note first that Mr. Z attended to the substance of the students' ideas, as opposed to just correctness or vocabulary use. He often checked with students his understanding of the ideas they shared, requesting further explication. For instance, he asked Keyi to elaborate on what he meant by "fully connected" and probed Jiangya for a clear and complete expression. He also summarized students' contributions on the board without judgment. When probing and scaffolding, he often took up the words students invented. For instance, when summarizing Jiangya's idea, he followed her expression, referring to the positive and negative ends of the battery as the "iron part," and the screw thread on the lightbulb as the "iron ring".

However, his attention to students' reasoning favored pattern-seeking over mechanistic reasoning. His initial prompt, to identify "in what situation the lightbulb can be lit" by "looking at the drawings of connections that worked," called for inductive pattern-seeking rather than mechanism. All three students who shared took up this call, providing some similarity between the connections that worked. The second student, Keyi, when prompted for further explanation, supplied the only piece of *mechanistic reasoning* in this segment: a circular path is needed so that the electricity (*entity*) "has a path to move forward (*activity*)." This seems to align with the intuitive mechanistic element of guiding (diSessa 1993), a general schematization of experiences such as of water in channels or runners on paths. The observable pattern of circle is a common way to avoid any free end where that guidance—the pathway the electricity follows—would end.

This seed of mechanistic explanation, however, was not taken up in the ensuing discourse. Mr. Z recognized it, yet stressed the pattern identification only ("make it into a circle") when revoicing and recording Keyi's idea, then quickly moved on to Jiangya. Pattern-seeking seems to be the main epistemic activity in play here. Once an observable pattern was clearly described, there is no need for further probing. This interpretation is also supported by what Mr. Z stated in a later interview, that he considered Keyi and Jiangya as expressing "the same idea in different words, from different aspects" and that he "thought so until I saw what happened next."

Moreover, Mr. Z's teaching was consistent with the common conceptual goal of the teacher's manual and the curriculum standards, that is, to understand that "it requires a complete circuit for common electrical devices to work." While the manual did raise a more mechanistic conceptual goal, that "the bulb lights when electricity flows through the filament (p.9)," and encouraged "opening space for students to imagine and reason about how electricity flows", Mr. Z did not, perhaps in part because neither the standards nor the manual articulated a concrete learning goal for that imagining and reasoning, and the time is limited. In their earlier district-level lesson preparation meeting, several teachers complained that they saw "no point for making students just guess around [about how electricity flows] without a knowledge foundation" and that "after the observation [of lightbulb structure] and the tryout, there is barely time left for getting to the point of complete circuit."

Segment 2: "Teacher, I have a question."

When Mr. Z was about to close the discussion, Lumin, a student in the same group as Jiangya, raised a question: "Can this connection work?" With Mr. Z's permission, he brought up the drawing shown in figure 1.

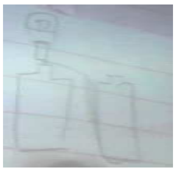

Figure 1. The drawing Lumin brought up.

The discussion suddenly became heated when Mr. Z projected Lumin's drawing and tossed his question to the class. Lumin's circuit fits the pattern Jiangya identified but violates the pattern Keyi identified—the lightbulb connects with both battery ends but the circuit is not "fully connected" in the sense of providing a circular path. The inconsistency between the two seemingly equivalent patterns opened space for argumentation.

In the post-unit interview, Lumin provided the rationale behind his problematizing move: "So I sort of agreed with Jiangya. The two ends-, it is important to have both ends of the battery connected. But then I wondered, what if it is not the same battery? If you have positive electricity and negative electricity from different batteries, can it still light the lightbulb?" Lumin's move stemmed from his mechanistic assumption and wonderment. He explicitly identified the "positive and negative electricity" as key *entities* functioning to light the lightbulb, and implicitly identified the connections between lightbulb and battery ends as the *spatial organization* that allow the two types of electricity to reach the lightbulb. Such mechanistic reasoning also connects to a general schematization of "opposites combining", such as of attracting magnets snapping together, collisions of objects moving in opposite directions, or heterosexual relationships. With the two battery ends conceptualized as suppliers of different types of "electricity," Lumin wondered whether the two suppliers can work independently ("from different batteries"), or they have to be somehow connected ("the same battery").

Yet Lumin did not introduce this retrospectively reported mechanistic layer of reasoning when raising question, and in the first 20 turns of the debate, all the participants, including Lumin himself, only based their arguments on whether the proposed circuit obeys the pattern(s) identified in segment 1. Those who claimed it cannot work emphasized that "the circuit is not fully formed" or "all connected," whereas those claimed the opposite stressed "that is what Jiangya meant" and "everything *is* connected." Mechanistic reasoning may have undergirded their sense of why the circuit needs to be "fully connected," but it did not enter the discourse.

As the debate continued, mechanistic reasoning did emerge. Addressing the discrepancy first led one student, Zhaoxin, to reason mechanistically, uncovering what processes he assumed led to the patterns:

> ((runs up to the board)) Right here, because on the top of this battery, from here to here the electricity from the positive end can go through ((drawing a line from the left battery to the lightbulb)). And for this battery, from here to here the electricity from the negative end can also go through ((running finger along the wire, from the right battery to the iron ring of the lightbulb)). ((Bell rings))

The "how-possibly" mechanism Zhaoxin constructed, that lighting the lightbulb would require the entity of electricity from both ends flowing into the lightbulb through the wire connections, was identical with what Lumin suggested in the interview. The class ended, but Mr. Z indicated they could take up this issue again.

When the class returned to the problem two days later, the discussion took on a clear mechanistic focus for about three minutes. Those who argued "it [Lumin's circuit] would work" identified more specifics about activities and spatial organizations, hypothesizing that "electricity (entity) can flow (activity) from both positive and negative ends of the batteries into the lightbulb, colliding (activity) and generating light (activity) in the filament (spatial organization)." Those who went for the opposite also based their argument on the entity of electricity needing "to circulate (activity) in order to light the lightbulb."

These represent different mechanistic bases for understanding why bulbs light. The idea for Lumin's circuit could represent the activation of an *opposites combining* schematization of the unobservable "lighting the lightbulb" process, as we noted above. It could also represent what research on student conceptions has identified as the "clashing currents model" (Osborne, 1983). The idea that the circuit must be complete aligns with the "closed circuit model" (Kärrqvist, 1985). An analogy to water flow, or a "continuous flow" schema abstracted from experiences with water and the like, could be what informs this piece of mechanistic reasoning.

The two mechanistic accounts differ in whether one or two types of electricity flows in the wires, and if electricity is "used up" during the process. (A schematization of opposites combining should indicate consumption.) Such understandings, if established through discussion, would powerfully contribute to students' sensemaking towards the conceptual learning goal set by the curriculum and the standards. It would allow the students to go beyond simply identifying thie pattern to constructing a rationale for why that pattern is necessary.

In the next segment, however, Mr. Z guided the class back to pattern-seeking.

Segment 3: Refocusing on pattern-seeking

A feature of Lumin's problematizing move was that it invited an empirical test. Trying out the circuit he suggested can produce evidence supporting one mechanism over the other. Mr. Z's instruction immediately following the discussion in last segment made space for such exploration but also added some other elements:

> Mr. Z: So, some of you said it [Lumin's circuit] can work, some said it can't. Can it work or not? So today I prepared battery holders. Hopefully each group has also brought your two batteries. Let's try it. I also prepared four wires and a bulb holder for each group. To connect the wire-, notice that these two posts are the connecting parts. You need to connect your wire to this metal part. Look carefully. I'm demonstrating here. Here is the metal part, put the nut on, and screw it tightly. Ok, let's try and see if such connection can work or not. If you find out how to make it work, draw down your connection and share with the class later.

The battery holders and the bulb holders were materials for the next activity in the curriculum, an activity designed for the students to "further explore the variety of connections that can work with more batteries, wires and lightbulbs, developing inductively the understanding of complete simple circuit.(Yu et al., 2015, p. 9)." Mr. Z's prompt in this segment to "draw the connection [that works] and share with the class later" responds to emergent student thinking while aligning with the curriculum. As Mr. Z explained in a video-prompted interview:

> So to me their interest in finding out how the circuit works aligned well with the goal of this activity-, this lesson. They were going to find out that the connection couldn't work, and that should solve their disagreement. They can then try to make two batteries work, and they will see if the working connections have the same patterns they suggested before. This, I think, can help them understand what matters for a working circuit.

Although Mr. Z was aware of the students' interest in "finding out how the circuit works," he did not distinguish its mechanistic orientation from the textbook goal of reinforcing the "patterns" of working circuits.

This conflation simplified the problem by treating the disagreement as something that can be fully addressed by "find[ing] out that the connection couldn't work." The positioning of the Lumin circuit test falls within a broader set of instructions that foregrounds pattern-seeking.

The first author observed and videotaped Lumin's group during the experiment. After finding out that the circuit Lumin proposed did not work and confirmed that both of their batteries can light the lightbulb. They reported to Mr. Z, who instructed them to "try and find out what works with two batteries." When the two batteries are finally placed in tandem, the whole group shouted cheerfully to announce their success: "We made it! It is so much brighter!" During this 15-minute exploration, there was no discussion about the implications of these empirical results for how to understand the underlying mechanisms.

The sharing and discussion afterwards ran in parallel to the sharing and discussion after their exploration with a single battery. After pulling out drawings of the working circuits (see figure 2), Mr. Z guided the class towards pattern-seeking, asking "Why can all these different ways light the lightbulb? What do they have in common in terms of connection?" The students' ideas that followed addressed visible patterns rather than hypothetical mechanisms of the working circuits, in terms of either the general configuration—"(the circuit) should start from [one of] the post and return to the original position without repeating any part of the course," or the position of batteries: "only when positive end touches negative end can the lightbulb be lit."

Two bids for mechanistic reasoning was made towards the end. Mr. Z dropped both and closed the discussion with a pattern-based summary—"The kind of connection that forms a circle is called a simple circuit."

On the representativeness of the case

In this episode, pattern-seeking predominated students' explanation construction, but not because students failed to offer mechanistic ideas. Students repeatedly put forth the beginnings of mechanistic explanations or bids for discussion of mechanism, but in most cases, the teacher moved to shift the activity back to pattern-seeking.

The tension between student-initiated bids for mechanistic reasoning and instructional focus on pattern-seeking was not unique to the above case. It was typical in Chinese elementary science classes. While teachers, following the curricular foci, prioritized the seek for patterns between the amount of solute and the amount of solvent, paper bridge structure and load bearing, or the angle of inclined plane and the force required for moving a cube, student initiated moves showed that they were curious about how dissolving actually happens, why triangle structure can bear more loads, and how come the inclined plane can make it easier to "lift" object. In each case, the classroom activity was in line with the prescribed emphases in the curriculum materials.

Pattern-seeking and mechanistic reasoning in Chinese curriculum standards

As the core document that guides curriculum development and teaching practices, Chinese Elementary Science Standards systemically emphasize pattern-seeking over mechanistic reasoning. The 2001 version of the Standards (MOE, 2001), which was in effect when our focal case took place, provide no explicit definition of explanation, but contained 21 instances of "explain" or "explanation." Among them, eight foreground pattern-seeking, four connote mechanistic reasoning (all in a single exemplar case), and nine remain unclear in meaning. For instance, the standards for attitudes required the students to "know that science can already *explain* many myths of the world, and there are more waiting for exploration (p. 6)," where "explain" can refer to either causations or patterns.

The current version of elementary science curriculum standards (MOE, 2017), alike the older version, provides no clear definition of explanation. It decomposes scientific inquiry into eight components, yet none of them foregrounds the practices of explanation construction and evaluation. The term "explain" or "explanation" appears only five times in this document. Among the five, three foreground pattern-seeking, one aligns with "explanation as explication"(Braaten & Windschitl, 2011), and one is ambiguous in meaning. Two of the pattern-seeking may involve implicit mechanistic understanding. For instance, one encouraged students to "gain evidence to support one's own explanation," which was exemplified by "Porcellio has no ear since it does not scrunch to our shouts." While the example highlights the need to support a claim by identifying pattern-based evidence. The interpretation of the pattern would require *chaining* together pieces of mechanisms, including how shouts create loud sounds, how loud sounds can be heard with ears, and how certain reactions should show up when a living organism hears loud sound. But again, the construction of underlying story has not been explicitly mentioned.

In summary, to the extent they address explanation, both the 2001 and the 2017 versions of the Chinese elementary science standards emphasize pattern-based, empirical argumentation over mechanistic reasoning. In alignment with this foregrounding of pattern-seeking, the specific content standards and curricular designs also focus on patterns and related applications. Instructional emphasis on pattern-seeking, such as in the circuit lesson analyzed above, therefore makes perfect sense. We are in no position to criticize teachers for not attending to or making space for mechanistic reasoning if this practice has not yet gained its deserved attention in the standards.

Discussion

The predominance of pattern-seeking: extended argument and potential mechanism

Our study proposed a potential mechanism for why mechanistic explanation is rare in science classroom: the lopsidedness toward pattern-seeking in the standards is reflected by the lopsidedness of curriculum, which, when enforced through the system, leads to the lopsidedness in teachers' planning and real-time attention and response.

The lack of inquiry into complex, deeper causal mechanisms is not an issue unique to Chinese science classrooms, but more of a widely existing phenomenon (Braaten & Windschitl, 2011; Zangori, et al., 2013). That leads us to wonder whether the Standards-based institutional pressures identified above also contributes to the imbalanced epistemic activity in science classrooms elsewhere. For instance, with NGSS and its framework informed by decades of progress in science education research, one may expect that it presents a stronger conceptualization of "explanation" and avoids prioritizing pattern-seeking over mechanistic reasoning.

Indeed, when compared to the Chinese standards, NGSS and its framework did a much better job in valuing explanation and mechanistic reasoning. It identified "constructing explanations" as a major scientific practice, and clearly defined scientific explanation as accounts that "explain observed relationships between variables and describe the mechanisms that support cause and effect inferences about them (NRC, 2012, p. 67)"—a definition that places dual emphasis on patterns (relationships between variables) and mechanisms.

Yet when looking into the details, we noticed a tilt toward pattern-seeking. The expectations regarding *constructing explanations* for both k-2 and 3-5 only emphasized the construction of evidence-based accounts of natural phenomena. The goal of developing an explanatory account is defined as pursuing "multiple lines of empirical evidence and greater explanatory power of phenomena (NRC, 2013, Appendix F, p.74)." "Greater explanatory power" could mean mechanistic theoretical accounts that subsume a greater range of phenomena, but it could also mean showing with evidence that a pattern can apply to a broader range of phenomena.

Even for the cross-cutting concept on "cause and effect: mechanism and prediction," the k-2 expectation emphasized "events have causes that generate observable patterns" and the 3-5 expectation emphasized "identify and test causal relationships and use these relationships to explain change"(NRC, 2013, Appendix G, p.83). Again, mechanistic reasoning about specific phenomena or events is not foregrounded.

We would therefore argue that even NGSS, which is probably the most internationally influential set of standards in science education, still affords a vision of explanation construction/evaluation in elementary school science that is slightly lopsided toward pattern-seeking at the expense of mechanistic reasoning. This lopsidedness manifest itself not in NGSS' abstract definitions and ideals, but in the grade-band-specific expectations. Therefore, even if elementary teachers *did* fully understand and implement the NGSS K-2 and 3-5 grade-band expectations for constructing explanations, pattern-seeking would still be emphasized over mechanistic reasoning.

Here we put forward a few conjectures about the potential mechanisms underlying such common lopsidedness. First, as a kind of science classroom activity, empirical pattern-seeking is "cleaner" than mechanistic reasoning. The need for clear, concise statements that can be assessed in the very notion of "standards" may create a bias towards things that are more described, identified, and assessed. Second, the notion of mechanism depends on a connection to intuition, and there remains in literature the influence of long-held conceptualizations of science as a departure from common sense (i.e., Osborne, 2019). Finally, there may be a lingering development psychological view that elementary school are not developmentally "ready" for abstract theorizing.

Implications: What should be done to open more space for mechanistic reasoning?

If we want to opening more space for engagement in mechanistic explanations in Chinese or American elementary science classrooms, transforming the view of explanation presented in the standards should be an initial step. For the Chinese curriculum standards, it is important to first recognize explanation construction as the central driving force behind scientific inquiry, and to develop the understanding that pattern-seeking and mechanistic reasoning both play critical role in the explanation construction process. The framework of NGSS (NRC, 2012) set a great example in how to do that. Then for both Chinese curriculum standards and NGSS, there is the need to:

- Demonstrate through examples from professional science and classroom discourse a variety of potential ways that pattern-seeking and mechanistic reasoning can be integrated in the explanation construction.
- Make room for mechanistic reasoning in the expectations for explanation construction. The performance expectations should encourage students to conjecture the unobservable entities and activities underlying natural phenomena and develop coherent accounts regarding how changes occur.
- Identify from the content standards opportunities that can afford elementary students to productively pursue mechanistic explanations and use classroom cases to exemplify such pursuit.

For sure, opening up classroom opportunities for students to engage in mechanistic reasoning would require much more work to be done throughout the system, including designing curricular materials promoting mechanistic explanations, helping teachers refine their understandings, developing strategies for initiating and scaffolding students' mechanistic reasoning, etc.. What we want to suggest is this: if the standards document itself, or the work helping teachers interpret the standards, can integrate the above points into the picture, it would reduce one potential source of institutional pressure distracting science class' attention to mechanism.

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