"I Guess My Question is Like": Problematizing in an Introductory College Physics Lab

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Abstract: There are beginnings of research studying how college students manage the experience of not-knowing in instructional laboratories. Previous work in introductory physics focused on student problematizing has had mixed results in activities designed to guide students to recognize and address an apparent discrepancy. Here, we study an instance of a student's successful problematizing, starting from her initial puzzlement during her group's exploration of a Newton's Cradle. We highlight the idiosyncrasy of the instance and suggest it raises questions for curriculum design.

Doing science in lab entails being puzzled by natural phenomena

For more than a century, physics educators have called for reforms in instructional labs to encourage students to observe and interpret natural phenomena, rather than to confirm known results (Otero & Meltzer, 2017). Recent work has provided new motivation for these reforms, finding confirmatory labs do not result in any measurable gains in students' conceptual understanding (Smith et al., 2020). As well, the shift toward objectives of students' *doing science* has had support in national standards (National Research Council, 2012) and in strands of research on how students learn to appreciate and engage with experiences of *not-knowing* (Watkins et al., 2018).

A number of researchers (Chen & Qiao, 2020; Manz, 2018) have focused on feelings of uncertainty, "the uneasy sense that something is missing or amiss" (Phillips et al., 2017, p. 1), as the beginnings of scientific inquiry. While much research has focused on student learning about *measurement* uncertainty, we consider the broader construct of *epistemic* uncertainty: the feeling and assessment that there is some gap or inconsistency in one's understanding. Taking that sense seriously entails the often-difficult work of *problematizing*: "identifying, articulating, and motivating a problem or clear question" (Phillips et al., 2018, p. 983).

Recent lab reforms have designed activities guiding students to experience a planned surprise or discrepancy—their data in conflict with their expected results. Part of the goal of these activities is students taking up the opportunity to problematize and construct their own knowledge. These efforts have sometimes led to success (Sundstrom et al., 2020), but the outcomes are highly variable (Descamps et al., 2022; Phillips et al., 2021). The diversity of findings in previous research motivates further study of how students come to problematize in lab. Here we examine an instance of successful student problematizing in a context of an open-ended lab activity.

The students were enrolled in an introductory physics lab as part of a course taught by the third author. There were four lab activities in the course, each lasting 2 or 3 weeks with progressively reduced structure, designed to encourage students to problematize. The lab activity presented in this study was the final and most open-ended of the semester.

We collected video data as a part of a larger project that studies what shifts or sustains undergraduate students' framing in physics labs (Descamps et al., 2022; Phillips et al., 2021). Here, we studied an episode of one group's exploration of a Newton's Cradle and selected it as an instance of successful student problematizing. This clip interested us because of the sudden onset of confusion that a student expresses in the activity. Our analysis of this clip followed Derry et al. (2010)'s video research methods and had iterations of the following process: we viewed the clip, gathered multiple interpretations, and watched it again to refine our initial interpretations. The first author wrote the interpretations and revised them after discussing with the other two authors. Here we present a moment-to-moment analysis of an emergence of student problematizing.

A student problematizing in a physics lab

There were three students in the lab group, Esther, Abby, and Anita (pseudonyms), all first-year undergraduates in the school of engineering. Demographic course data informed us that all three students identified as women, Esther and Anita as Asian, and Abby as White. Leading up to the episode in this paper, the students start their final activity of the semester, with the assignment to arrange some form of collision and study it, and the students were free to ask whatever empirical question they choose. After some initial exploration, this group decides to build and study a simplified Newton's Cradle comprised of three pendula.

Anita and Abby try to make it work the way it is "supposed to": an outer ball hits the middle ball, which does not move but hits the other outer ball up in the air, which falls back to make the first ball go up again and so on. Esther is with them at first and then retreats to her laptop. When Anita and Abby finish setting up the apparatus, they see that all three pendula swing after the first collision—they do not behave as they are "supposed to."

Anita proposes adding more mass to the middle ball, and explaining, "if it's more massive then it'll have more inertia, will be more resistant to acceleration." Neither Abby nor Esther takes up this bid; Anita decides to do it herself. She hangs a hook with masses on the string that holds up the middle ball, and she watches the first couple of collisions: The middle ball stays relatively still after it gets hit by the first outer ball, and the other outer ball swings up farther than before. Abby and Anita see this, and Anita immediately expresses her confusion, the moment at which the transcript begins. The entire episode occurs over two minutes.

01 Anita: Why does it do that? I don't get that. [looks at the setup]
02 Esther: What?
03 Abby: What?
04 Anita: Why it, why it {[unclear]} [points at the middle ball]
05 Esther: {'Cause it's} harder to, to resist. [releases the left ball] It's
06 harder — {It can resist}
07 Anita: [Points at the middle ball, left ball, and back to the middle ball]
08 {But wait these,} wait, it [left ball] went all the way back up. Right?
09 Wait wait wait.
10 Abby: It should. {It should.}
11 Anita: {It [unclear].} But why? [in a whisper, looking to Abby]

Anita becomes puzzled by how the outer ball bounces off a stationary middle ball. She points at the middle and left balls and articulates the source of her confusion, that the outer ball goes "all the way back up" (line 08). Keeping her eyes on the apparatus, she is struck by the outer ball's clear bounce that happens after she adds mass to the middle ball to make it more stationary.

We are struck ourselves that Anita expresses confusion about the phenomenon that she has been trying for some time to arrange. Seeing it happen seems to shift her into wondering: Why does the outer ball bounce up in the air when the middle ball is stationary? While Anita has focused on adding mass to the middle ball until this moment, she now notices the phenomenon is puzzling, which she tries to identify and articulate. Esther and Abby ask Anita to clarify (lines 02 and 03), and they try to answer her questions (lines 05, 06, and 10). Their responses, however, do not seem to address Anita's confusion, as she points at the left ball (line 07) and emphasizes "why" (line 11) in a whispering tone. Their efforts to respond apparently supports Anita to articulate her question further, perhaps because they do not seem to understand what troubles her.

Anita's efforts to problematize continue

About thirty seconds pass, during which Anita suggests making the middle ball even more massive. Abby points the group's attention to the first collision, and Esther and Anita raise questions about its underlying mechanism.

12 Abby: 'Cause like, it, although because it's, it's not perfect, it's not perfect,
13 but like, [releases the right ball] we have the first one.
14 Esther: But why is it, why is it working?
15 Anita: [Leans in closer toward the apparatus, remaining in her kneeling
16 position] Yeah, I don't know why that the ball is [unclear]
17 Abby: 'Cause it's supposed to be
18 Esther: But why put an extra mass there?
19 Abby: 'Cause it makes it not move. Just because of our error and have it
20 [unclear] collision
21 Anita: I don't understand why
22 Abby: 'Cause the energy
23 Anita: How like, how the – the energy is being transferred
24 Abby: I wanna see if it works. [releases the right ball]
25 Esther: The energy is transferred.
26 Abby: The, the only thing it does is make sure it stays still. It stays in the
27 middle.

Esther's question (line 14) seems to support Anita's confusion, as Anita agrees and continues (line 16). She reiterates her uncertainty (line 21) and revises her question in terms of energy transfer (line 23). In the group's earlier discussion with the TA, Esther explained that she expects full transfer of energy between the balls, which may be what Abby and Anita recall at this moment. What remains unclear for Anita, though, is *how* the energy transfers. She refines her question from wondering about why the outer ball bounces up in the air (lines 07-11) to wondering about how energy transfers (line 23).

In this way, Anita formulates her question in a collaborative effort with her peers: She reiterates Esther's question (line 14), and she asks about energy after Abby mentions it (line 22). Throughout this interaction, Anita is kneeling on the floor, at eye level with the apparatus, and pointing at different features. The materiality of the phenomenon drives her curiosity.

Anita further refines her question

Still thinking about energy transfer, Anita clarifies her question further.

28 Anita: But I guess my question is like [takes hold of the middle ball], when
29 this stays still how does the energy
30 Esther: Transfer?
31 Anita: Yeah. Do you know? [points at Esther with her finger]
32 Esther: Yeah. It [left ball] hits this [middle ball] and it goes through, hits
33 that [right ball]. Passes through.
34 Anita: But, but what if this. What if this [middle ball] is, this [middle ball]
35 stays completely still. It [middle ball] won't do anything?

Anita takes hold of the middle ball, and she asks, how does the energy transfer when the middle ball "stays completely still" (line 35)? That the middle ball stays still, and the outer ball bounces, does not make sense: How can the middle ball transfer energy if it stays still?

She begins her question with the words, "But I guess my question is like" (line 28), which show her effort to arrive at a question. She is still crouched on the floor with her eyes on the apparatus, holding the middle ball in her hands. Anita's physical handling of the apparatus continues to drive her wondering about it. Esther also contributes to Anita's problematizing, as she helps to finish the question (line 30) and offers the idea that "it goes through" (line 32)—probably to mean the energy goes through, or "passes through", the middle ball (line 33). Esther's explanation does not satisfy Anita, who articulates her question again: If the middle ball "stays completely still" would the phenomenon still happen (line 35)? Anita and Esther's different understandings of the mechanisms that underlie energy transfer afford Anita an opportunity to further refine her question.

Contextual dynamics of a student problematizing

To review, Anita's wondering begins with her seeing the very phenomenon that she has tried to make happen. The physicality of the event—the clear bounce of the outer ball off the middle ball, which she watches closely—is the initial trigger. Her effort to articulate what troubles her is supported by her peers, although they do not seem troubled themselves. This suggests social features of the context also played a role (Appleby et al., 2021): The three students have worked together for months and developed a social rapport, evident in their frequent banter and laughter, that supported their attention to and caring about each other's thinking. Of course it also matters that the students were working within instructional labs designed to encourage sensemaking (Etkina et al., 2010). There is evidence here of Esther's framing lab as about their making sense of their data, and in other moments, it is Esther who presses the group with questions.

This moment, in sum, was idiosyncratic. No one could have anticipated these particular dynamics. It is also difficult to imagine a lab design that could have guided Anita to her question. So, what if idiosyncrasy is an ordinary feature of students' problematizing? Perhaps the mixed results in prior accounts of when and how undergraduate students problematize in physics labs reflects the complexity of the dynamics (Descamps et al., 2022; Phillips et al., 2021; Sundstrom et al., 2020). This case, with others, motivates that consideration. Many efforts to support problematizing in the literature involve designing a specific experience of discrepancy into the phenomenon students are to explore. It is clear that these approaches can be successful; we do not propose abandoning them. We suggest, however, that many instances of students' problematizing will arise outside of such specific plans. One implication is that the guided-discovery approach to *problems* has similar challenges to those of the guided-discovery approach to concepts (Hammer, 1997), and so enactments of such curricula should leave room for instructors' discovery of students' productive thinking the designs did not anticipate.

More broadly, instructional labs to support student problematizing would benefit from diversity of approach, including designs to engender idiosyncrasy. This of course argues for student projects, although within introductory courses there may be tension between the various ideas that students want to explore and the shared features of experience in their thinking about similar topics. At another level, labs can pay more attention to student framing of laboratory experiences, including their expectations for how they may be agentive in their learning within the activities. In that regard, Cherbow & McNeill (2022) introduced the possibility that curricula may be *too successful* at anticipating students' thinking, if students come to expect that of the materials: if the course already knows what they are going to ask, why should students bother asking? For instructors and researchers working to prioritize students' agency, the challenge is to designing labs that create space for students' emergent ideas and idiosyncratic questions. Students need opportunities to experience and take up puzzlement of their own.

References

Appleby, L., Dini, V., Withington, L., LaMotte, E., & Hammer, D. (2021). Disciplinary significance of social caring in postsecondary science, technology, engineering, and mathematics. *Physical Review Physics Education Research*, *17*(2), 023106.

Chen, Y.-C., & Qiao, X. (2020). Using students' epistemic uncertainty as a pedagogical resource to develop knowledge in argumentation. *International Journal of Science Education*, *42*(13), 2145–2180.

Cherbow, K., & McNeill, K. L. (2022). Planning for student-driven discussions: a revelatory case of curricular sensemaking for epistemic agency. *Journal of the Learning Sciences, 31*(3), 408-457.

Descamps, I., Jeon, S. M., Hammer, D. (2022). A case of productive confirmation framing in an introductory lab. *2022 Physics Education Research Conference Proceedings*, 137-143. https://doi.org/10.1119/perc.2022.pr.Descamps

Etkina, E., Karelina, A., Ruibal-Villasenor, M., Rosengrant, D., Jordan, R., & Hmelo-Silver, C. E. (2010). Design and reflection help students develop scientific abilities: Learning in introductory physics laboratories. *Journal of the Learning Sciences*, *19*(1), 54–98. https://doi.org/10.1080/10508400903452876

Hammer, D. (1997). Discovery learning and discovery teaching. *Cognition and Instruction, 15*(4), 485-529.

Manz, E. (2018). Designing for and analyzing productive uncertainty in science investigations. *Proceedings of an International Society of the Learning Sciences Conference, 2018* (pp. 288-295). International Society of the Learning Sciences.

Otero, V. K., & Meltzer, D. E. (2017). The past and future of physics education reform. *Physics Today*, *70*(5), 50–56. https://doi.org/10.1063/PT.3.3555

Phillips, A. M., Sundstrom, M., Wu, D. G., & Holmes, N. G. (2021). Not engaging with problems in the lab: Students' navigation of conflicting data and models. *Physical Review Physics Education Research*, *17*(2), 020112. https://doi.org/10.1103/PhysRevPhysEducRes.17.020112

Phillips, A. M., Watkins, J., & Hammer, D. (2017). Problematizing as a scientific endeavor. *Physical Review Physics Education Research*, *13*(2), 020107. https://doi.org/10.1103/PhysRevPhysEducRes.13.020107

Phillips, A. M., Watkins, J., & Hammer, D. (2018). Beyond "asking questions": Problematizing as a disciplinary activity. *Journal of Research in Science Teaching*, *55*(7), 982–998. https://doi.org/10.1002/tea.21477

Smith, E. M., Stein, M. M., Walsh, C., & Holmes, N. G. (2020). Direct measurement of the impact of teaching experimentation in physics labs. *Physical Review X*, *10*(1), 011029. https://doi.org/10.1103/PhysRevX.10.011029

Sundstrom, M., Phillips, A. M., & Holmes, N. G. (2020). Problematizing in inquiry-based labs: How students respond to unexpected results. *2020 Physics Education Research Conference Proceedings*, 539–544. https://doi.org/10.1119/perc.2020.pr.Sundstrom

Watkins, J., Hammer, D., Radoff, J., Jaber, L. Z., & Phillips, A. M. (2018). Positioning as not-understanding: The value of showing uncertainty for engaging in science. *Journal of Research in Science Teaching*, *55*(4), 573–599. https://doi.org/10.1002/tea.21431

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