# Affect, meta-affect, and epistemology in an introductory physics lab

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Radoff and colleagues [1] studied a student's progress in sensemaking to argue it involved *meta-affect* [2], or feelings about feelings. In particular, from the start of the semester to the end, the student went from feeling anxious about feeling confused to finding pleasure in it. The authors described this change as *meta-affective learning* [1] and as entangled with the student's epistemology, in particular her coming to see confusion as inherent in doing physics. Here, we study an episode of uncertainty among three students in a physics lab that shows rich, in-the-moment dynamics of meta-affect and epistemology. We focus on "Abby," who expressed discomfort ("I hate physics") but at the same time showed signs of enjoyment, laughing and persisting in sensemaking. Radoff and colleagues [1] presented evidence before and after a change; we present this episode for insight into how such change may occur.

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## I. INTRODUCTION

DeBellis and Goldin [2] introduced the term *meta-affect* within their research in elementary mathematics education to describe feelings about feelings. If you enjoy the thrill of a roller coaster, that is a feeling about a feeling, pleasure about fear, which, Debellis and Goldin noted, depends on believing "the ride is 'really safe'" [2, p.137]. Students studying mathematics may similarly learn to enjoy frustration, struggling with difficult problems, depending on their beliefs about math and math class, including that "making mistakes is 'safe'" [2, p.137].

Radoff and colleagues [1] found meta-affect in their analysis of a first-year college student's progress in an introductory physics course designed to emphasize students' "learning how to learn," with a particular emphasis on engaging productively with confusion. The student, "Marya," had shown a dramatic change in her affect and approach to learning, evident in her homework and exams. This prompted the researchers to interview her about her experience, which they did immediately following the course and a second time two years later.

By Marya's account and the researchers' observations (two of the authors were her instructors), she had started the course very anxious about her uncertainty in solving problems, connected with an epistemological view of knowledge in physics as "about absolute right or wrong" [1, p.78]. At the end of the semester, Marya explained she had shifted dramatically in both respects, consistent with the evidence in her coursework. She felt excitement in wonderment and exploration, and she saw physics as about finding and engaging with interesting problems to solve. The authors [1] described the change in Marya's feelings about feeling confused as *meta-affective learning*, connected with a change in her epistemology of doing physics—that is, her sense of what knowledge and learning entail.

Radoff and colleagues [1] drew on data from Marya's written work within the course and her two interviews after the course was over. The authors (and Marya) could make claims about her having changed over the semester, contrasting two different 'stable states' of Marya's affect, meta-affect, and epistemology, but with no video or other recorded in-the-moment data, there was little they could say about how that change might have happened. What experiences could have contributed to the shift? What might it look like for a student to be in transition from one stability to another?

Here we examine an episode showing complex in-the-moment dynamics among Abby, her groupmates, and a teaching assistant, what we refer to as "local" dynamics, that give insight into possibilities for longer-term dynamics of student learning. The data is from a larger study focused on students' shifting epistemologies in reformed introductory labs. We present the data with analysis in the following section, then follow with a discussion of implications and future directions.

## II. AN EPISODE OF ENGAGEMENT WITH CONFUSION

### A. Data source and methodology

Abby, Esther, and Anita (all pseudonyms) worked together as a group in an introductory physics lab as part of a course taught by the third author, significantly reformed throughout to emphasize students' learning how to learn, including to engage productively with confusion. They were all first-year undergraduates in engineering, and they identified as women, Esther and Anita as Asian and Abby as White.

Over the course of the semester, there were four lab activities, with progressively reduced structure and each lasting two to three weeks. All were designed to encourage students to engage with uncertainty, both quantitative measurement uncertainty and more generally epistemic uncertainty—confusion or not-knowing. Here, we present students' work on the second lab activity, which builds off of a *FlipIt* pre-lecture video [3] students had watched earlier. The video explains the law of conservation of energy and derives the result that the final velocity of an object that slides without friction from the top of a ramp of height h is $\sqrt{2gh}$. While the lecture describes the object as sliding, the figure shows a ball, which students tended to see as rolling. The assignment was for students to investigate whether the speed of the ball rolling off the ramp is $\sqrt{2gh}$, the same as the speed it would have falling from the same height.

This research study sits within a larger project that studies students' framing in physics labs. The second author collected video data of the students' group work throughout the entire semester, while the first author was a teaching assistant of recitation sections and the third author was the course instructor. All three authors were involved in data analysis after the course ended. Our methods followed Derry and colleagues' work [4]: We viewed the clip, gathered multiple interpretations, and watched it again to challenge and refine our initial interpretations. We repeated this process multiple times and arrived at our findings presented in this paper. We chose the following episode for the salience of affect, meta-affect, and epistemology in the students' interactions, especially in Abby's participation, as they tried to make sense of a discrepancy they saw in their data.

### B. Description with transcript

The group measured final velocities of falling and rolling for a wooden ball and for a rubber, silver-colored ball by retrieving times and distances from slow-motion videos with their smartphones. Their final values were averages of three trials for each ball, the vertical drop and ramp roll.

They found the wooden ball had a lower velocity rolling down the ramp than falling, which they understood as resulting from friction on the ramp. They then found the rubber ball's velocity at the bottom of the vertical drop and the ramp came out to be the same, in alignment with the *FlipIt* result but to them a confusing surprise. Another discrepancy they found was that the wooden ball had a higher velocity than the silver ball, when they had expected no mass dependence. (This was a surprise for us, too: The silver ball, from a computer mouse, had a dense steel core and a light, rubber coating. This gave it a lower ratio $\frac{I}{m}$ than for a ball of uniform density, and so it should have rolled faster down the ramp than the wooden ball.)

Thus they found two discrepancies: (i) the rubber ball's velocities were the same for falling or rolling, but the wooden ball's velocities were different, and (ii) the balls' velocities seemed to depend on mass. For about thirty minutes, they struggled to make sense of these discrepancies. Abby called the results "a bad difference," apparently referring to the velocities of the different balls. She also joked about how the *FlipIt* result might be wrong and commented on how the instructor might be trying to trick them. Esther attended to Abby's comments, weighing their possibility, then Abby turned the conversation again to the idea that friction must slow down the balls on the ramp.

Immediately afterwards, they had the following exchange. (Our transcript notation includes letter capitalization for emphasis, brackets to note any sounds or expressions, and parentheses to give additional context or explanation.)

> **1. Abby:** Ha haaah [laughing/crying], I hate physics.
>
> **2. Esther:** Noooo! You mean you LOVE physics.
>
> **3. Abby:** No, I'm literally a ChemE (engineering major) 'cus I don't wanna have to take physics anymore. [Esther laughs]

Abby said she hates physics with a laugh. Her tone was lighthearted, not in despair, but it was clearly a comment about the challenge of resolving the discrepancies. Esther responded to Abby lightheartedly as well, perhaps trying to help repair Abby's discomfort, or perhaps expressing her own feelings. Abby's discomfort, however, became even more apparent in line 3, as she said that she chose to major in chemical engineering because she wanted to avoid physics, a decision she had made earlier in the year. Evidently her relationship with physics had a fraught history beyond the scope of this moment.

Right after this exchange, the group talked about topics from other science courses, mentioning quantum mechanics and p-orbitals from chemistry, that made little to no sense for them. Then Abby compared these other topics and physics:

> **4. Abby:** But, like, I feel like you can just, like, accept it (information in other science courses) as fact. For this, (introductory physics) it's like "Yeah, the balls are - are - are the same but not the same."
>
> **5. Esther:** [chuckles] The same but not the same
>
> **6. Abby:** It goes WAY more against common sense. But I have - I have ZERO common sense when it comes to chemistry. I don't KNOW.
>
> **7. Esther:** So you just accept it?! [laughs]
>
> **8. Abby:** So I just accept it! [laughs]

Abby's remarks here are epistemological in that they concern the nature of knowledge in different sciences. She saw chemistry as entirely disconnected from her common sense, but physics as connected, which was why she could not "just accept" ideas in introductory physics. She expressed *vexation* over the discrepancy, how the balls could be "the same but not the same"; the discrepancy bothered her in a way she was driven to address. All the while, she seemed to show enjoyment in the moment, laughing and taking a lighthearted tone.

After this conversation, the students spent 30 minutes trying another method of measuring the balls' speeds, but they did not arrive at clear results. The period ended, and other students packed up and left, but Abby, Esther, and Anita stayed, of their own volition, to revisit their first set of experiments.

Abby had an idea as to where they might have gone wrong: They had measured the speed for the ball on the ramp as it rolled along the relatively flat, final portion of the ramp. But they had measured the speed of the falling ball while it was still falling. She wondered whether this difference mattered for their results. She was animated and excited asking for her peers' attention to explain her idea, exclaiming, "Wait, wait, wait, wait, wait!!!" Abby explained her idea, but after discussion, the students decided the different approaches to measuring the speeds did not account for the discrepancy.

Shortly after, the TA suggested they try rolling the wooden and silver balls down the ramp at the same time and see which one gets to the bottom first. The students tried it and saw that the silver ball reached the bottom first, the opposite of their earlier results. They were really struck by this discrepancy, so much so that Abby shook her fists and said, "Yeah, I'm so curious what happened!"

They then considered how their slow-motion video analyses might have affected their measurements. The TA mentioned that another group had used a correction factor to get their time measurements from slow-motion videos and suggested talking with them in the next lab. Abby had also revisited her time measurements in the slow-motion videos. Indeed, she had been in charge of obtaining the time measurements throughout the lab, so she also had taken charge of figuring out how she could make the time measurements more precise. Abby speculated how the other group might have used the correction factor:

> **9. Abby:** You know when you slide on a video you can slide to like the time? I think that, what they, I don't actually know if they did it, but, well, no, it's multiplied by whatever. So, it's like a 5 second video might be 2 minutes, but then it's like, well, to get that 2 minutes, it's probably multiplied 5 seconds, so like, each frame is

> probably multiplied by something, so they probably put down that value [chuckle] to do —

To make the time measurements more precise, Abby suggested a way to avoid the jump between the video frames by using the correction factor in the slow-motion video. She explained how each video frame time was multiplied by the correction factor to get the slow-motion time. Finding this correction factor, she conjectured, would help them get the actual time measurement.

## III. ANALYSIS

### A. Multiple scales of interaction between Abby's affect, meta-affect and epistemology

Abby, Esther, and Anita were confused by several discrepancies during their lab, between measurements as well as between measurements and their expectations. There was evidence throughout of their both recognizing the discrepancies as well as their *feeling* confusion; their experience of confusion was both epistemic and affective. For Abby, the evidence was especially striking, in her comments and tone.

At the same time, there was evidence of her feeling motivated by this confusion, perhaps even enjoying it, in her laughter, in her persistence with the questions, and in her exclamations of curiosity. Following prior work [1, 2], we call these feelings *meta-affect*, feelings about the feelings of confusion.

We described this combination, of feeling confused and feeling motivated by confusion, as *vexation*. Abby did not use this word herself, but she described that state and, in comparing physics with other disciplines, she connected it to epistemology: She explained that in chemistry, she accepted what she learned in class as facts, because she had "zero common sense." If she felt confusion in chemistry, it did not seem to bother her; she expressed feeling neutral, because "I feel like, you can just like accept it." Physics, in contrast, had connections to common sense, and that is why she could not "just accept it," why the results bothered her. She expected the phenomena to make sense, in this case, the speeds of the balls at the bottom of the ramp and the vertical drop. That they did not make sense generated her vexation, which lasted for the rest of the lab session. She expressed discomfort, and at the same time feeling "so curious."

Thus, this is a complex moment of affect, meta-affect, and epistemology. Abby felt confused, animated and motivated by her feelings of confusion, and she connected those feelings with the sorts of knowledge she expected to construct: Physics should make sense. Those dynamics evident in the moment, however, contradict a larger narrative Abby expressed and explained, that she "hates physics," that she chose her major to minimize how much physics she would have to take. Over her career as an undergraduate, she had acted to avoid physics; in the dynamics of this moment, she acted to extend her engagement. Perhaps this is—or has the potential to be—a moment of meta-affective learning, because in this moment, she shifted to productive meta-affect and epistemology of physics, both centering on engaging with uncertainty.

Some of these dynamics may involve Abby's sense of her identity, as someone who hates physics. We wonder what could be going on for her within and beyond this moment. How did this moment fit with her narrative? Was she thinking that she hates physics more because of this moment? She seemed to experience some discomfort that was not only triggered by this moment but also shaped by her prior experiences with physics.

### B. Emergent intellectual agency

Early in this lab session, Abby's engagement was mainly about expressing her confusion and frustration. It was in these moments she declared her hatred for physics, and resisted Esther's encouragement ("you mean you love physics") by describing how she chose chemical engineering to avoid physics. As the work continued, however, Abby did more to drive the group's thinking. She formulated ideas about how to proceed—including to re-examine the group's earlier approach to finding speed, and to plan for next time to use a correction factor in the slow-motion analysis.

In other words, Abby took on more intellectual agency [5, 6], all while showing more excitement and interest. She initiated and coordinated their analyses of the slow-motion videos, both in the moment and in planning for the future lab session. Her contributions were thus influential to the group's epistemic progress; her emergent vexation and excitement shaped the group's goals.

Thus over the time frame of the lab, Abby seemed to have shifted in her feelings about confusion, connected with her view of physics as connected to common sense. These different dynamics of her affect, meta-affect, and epistemology remained stable for the rest of the lab, supporting and supported by her shift of intellectual agency. We only have evidence it remained stable during this lab period; it was a local stability, in tension with a different, apparently longer-term stability of Abby's avoidance of physics.

### C. Peer relationships

There is also evidence that social relationships supported Abby's meta-affective shift. For one, Esther showed strong positive affect and engagement throughout. Moreover, Esther and Anita provided Abby with the space to express her thoughts and feelings. When Abby joked about how the *FlipIt* result might be wrong or the instructors might be trying to trick the students, Esther listened and responded to her by also considering the possibility of these conjectures. When Abby expressed her hatred towards physics, Esther again listened and responded with "you mean you love physics". Anita also chimed in to the conversation when Abby said that chemistry did not make sense, adding topics from other disciplines that Anita also found hard to understand.

The social dynamics among the three students here showed that they could share such thoughts and feelings with each other and be heard by one another. They also demonstrated empathy and a listening stance towards Abby and what she shared with them - and in other cases, Abby reciprocated this social caring [7]. Generally in schools, students seem to experience uncertainty as risk-laden. Krist [8, 9] suggested the importance of students having trusting relationships, with peers and instructors, to feel safe socially. Following Debellis and Goldin [2], we see that safety as enabling the shift of Abby's meta-affect toward feelings of confusion.

## IV. DISCUSSION

Radoff and colleagues [1] presented a case of meta-affective learning, where student Marya arrived at a new stability in her meta-affect that was productive for her engagement with uncertainty. The authors highlighted that her meta-affect was entangled with her epistemology of physics as they have a co-occurring shift. Their study, however, was based on interviews with Marya, without direct evidence of dynamics that might have contributed to her progress.

Abby's case showed in-the-moment dynamics of affect, meta-affect, and epistemology of physics. While we do not have evidence of long-term meta-affective learning for Abby, we suggest that local dynamics may give insight into how a student may progress. For Abby, the moment showed a local stability of her feeling motivated to engage with confusion, because as she said, physics should make sense. That was in tension with her longer-term experience of discomfort in physics. Perhaps Marya's progress came about through her experiencing many such moments, of local shifts in her feelings about confusion and epistemology of physics.

Building on our current analyses of this case, we also have questions for future research on students' meta-affective learning and their epistemologies in introductory physics labs. In part, we would like to understand more about Abby specifically. In videos of Abby working on other lab activities over the semester, the evidence suggests she was working simply to complete the assignment. What made this lab different, for her? Unfortunately, Abby has not so far been available for a follow-up interview. We are hoping to make contact with her in the fall, when she is back from a semester abroad. In this, we are especially interested to examine further the entanglement of her meta-affect and her epistemology of physics both in and beyond the scope of this moment of uncertainty.

More generally, we are interested in the respective roles of the curriculum and of instructors in students' meta-affective learning. The course as a whole was designed to promote positive meta-affect about uncertainty, as Radoff and colleagues also explained [1]. The course, however, in our experience, has had varying levels of success with fostering moments of uncertainty. We would like better to understand that variation, how the course design and instructional responsiveness play roles.

In another paper [10], we analyze an episode focused on Anita's becoming confused over her observation of the group's successful creation of a Newton's Cradle. We intend to bring our analyses of Abby, Anita, and Esther together to understand the local dynamics of their affect, meta-affect, and epistemology in their engagement with uncertainty.

## V. ACKNOWLEDGEMENTS

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