

Digging in: Attending to students' epistemic emotions while computationally modeling in physics

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When physics students experiment with computational models, they encounter new sources of uncertainty: is this surprising behavior of the model a feature or a bug? This added uncertainty comes with the risk of shutting down inquiry. Alternatively, it could be what inspires and facilitates sustained scientific investigation with the model. The outcome hinges on how students respond to epistemic emotions such as uncertainty and confusion. Do they avoid these emotions, or do they dig in? In this paper, we analyze video data of a pair of high school students working with a computational model of global warming. The analysis highlights the epistemic emotions that arise for them. We find this pair responds to surprise and uncertainty by “digging in” with spontaneous scientific experimentation, which in turn leads to conceptual learning, joy, and self-confidence. We discuss the importance of attending to how physics students respond to uncertainty while computationally modeling phenomena.

I. INTRODUCTION

In K-12 science education, instructors and curriculum designers aim to provide students with learning experiences that mirror the work of professional scientists. Researchers are increasingly recognizing the importance of the affective dimension [1] for motivating students' inquiry [2] and giving them a feeling for the discipline [3]. In particular, students' engagement in the practices of scientific sensemaking is intertwined with epistemic emotions - emotions and feelings that relate directly to states of knowledge, such as surprise, uncertainty and doubt - collectively referred to as *epistemic affect* [1] or epistemic emotions [2, 4, 5].

As computational modeling has become increasingly recognized as a key scientific practice, more physics classrooms are incorporating computational modeling as a way for students to investigate phenomena. While existing research on using computational modeling in science education has illuminated its affordances for physics learning [6, 7], little work has examined the role of students' affect when working with computational models.

In this paper, we explore the affective dimension of students' experiences as they work with computational models to investigate phenomena in their physics classrooms. The data come from a pilot study in a physics classroom in which we found positive learning gains in students' understanding of physics concepts and use of computational modeling skills. We analyzed video of student interactions to explore what led to moments of integrated learning of physics and computation. We find that key moments of science learning hinged on how students responded to epistemic emotions of surprise and uncertainty. We present a few illustrative cases in which students were surprised by the behavior of their computational model, which inspired them to spontaneously investigate and make sense of the surprising behaviors on their own.

II. THEORETICAL FRAMEWORK

Epistemic emotions [2,4, 5] or *epistemic affect* [1] refer to emotions or affective states that are directly related to knowledge. Epistemic emotions such as uncertainty, interest, surprise, curiosity, and confusion can set up the motivation for science students to make sense of phenomena [2, 3, 8]. At the same time, epistemic emotions such as self-doubt can present barriers that threaten to shut down scientific sensemaking. For instance, the fear of being wrong can block students from wanting to try to figure out the answers for themselves [9, 10].

In particular, this paper focuses on the prevalence and management of the epistemic emotions of surprise and uncertainty. The philosopher Carruthers [4] considers uncertainty to be an epistemic emotion related to surprise and curiosity, but also a hindrance from succeeding at some

task (e.g., providing an explanation for surprising behavior). Adding computation to a physics classroom can introduce additional sources of uncertainty for students, for instance whether an unexpected outcome of the computational model is a "bug" or a "feature" of the model. This additional complexity runs the risk of making physics more difficult for students [11]. Attempts to integrate computation into STEM classrooms will need to find ways in which these domains can be mutually supportive [7].

III. METHODOLOGY

This paper reports on part of a larger project - a research-practice partnership to integrate computational modeling curricula into high school STEM classes in a large Mid-Atlantic metropolitan district. We focus on a pilot study in which one physics teacher taught a unit on global warming in all four of their sections of approximately 20 students each.

A. Instructional context

The driving question for the 5-lesson unit was: *Can we stop global warming?* Students used and modified a computational model within a blocks-based programming environment [12] to explore mechanisms behind climate change. In lessons 1-3, they experimented with the model to find that the system tends to come to equilibrium, observing that the rate at which incoming solar energy is absorbed by the Earth is balanced by the rate at which infrared energy is radiated away from Earth. They monitored graphs of temperature over time, finding the temperature tended to plateau when the Earth reached equilibrium. Then, in lessons 3-5, they used and started to modify the model to examine how the Earth's equilibrium temperature is affected by greenhouse gasses, reflective surface ice, and human activity.

The students worked together throughout the unit as a pair, splitting their roles between "driving" the model as the student in charge of the computer and "navigating" by asking questions and making sure they are progressing through the worksheet. They were prompted to switch roles at least once per lesson.

B. Data Collection & Analysis

We video recorded students' classroom interactions to gain insight into their processes of learning physics with our computational modeling curriculum. Researchers were present in the classroom to place small cameras and to take observation notes that helped identify potentially significant moments for video analysis. We collected video data of six pairs of consenting students in each class section. We prioritized videos for analysis with the best camera placement, allowing for audible conversations and visible

computer screens. All student names in this paper are pseudonyms.

Our analysis closely follows the interaction analysis methodology outlined by Jordan and Henderson [13]. We created content logs of the video files [13], which were used to select clips where students had extended conversations. Through collaborative viewing [13], we iteratively analyzed clips by discussing interpretations of student conversation and their onscreen work. In particular, we focused on moments in which students seemed to predominantly be in a sensemaking mode [14], when students are discussing their ideas and observations. We transcribed students' sensemaking discussions and looked for evidence of their precursors and outcomes.

We noticed that sensemaking discussions are often preceded by the students being surprised or confused by the behavior of the computational model. We analyzed the discussions from the viewpoint of epistemic affect, attending to both the substance of student speech as well as paralinguistic channels (e.g., volume and tone of voice, gestures such as pointing) to identify epistemic emotions. We keep track of their levels of both uncertainty and confidence with respect to their hypotheses, and to themselves. We note how these emotional states change over time and seek to understand how and why they change.

IV. DATA & ANALYSIS

In what follows, we analyze the conversations of a pair of students, Dora and Natalia (pseudonyms), on the last day of the global warming unit. On this day, Dora was “driving” and Natalia was “navigating”. We split the analysis into three episodes, which come from different parts of the day's lessons. In Episodes 1 and 2, the students are investigating the impact of *albedo* (reflectivity) on Earth's equilibrium temperature. In Episode 3, the students are exploring how human activity (building factories or planting trees) can impact Earth's equilibrium temperature.

Previously in the unit, the pair had seen many times that the graph of temperature vs. time tended to reach a plateau (equilibrium temperature), but even then there were persistent fluctuations above and below the equilibrium temperature.

In each episode, we analyze the students' discussion, pointing out epistemic emotions that arise. We then discuss their response to those epistemic emotions.

A. Episode 1: “It'll like, ACTUALLY flatline”

In Episode 1, the students are investigating the impact of *albedo* (reflectivity) on Earth's equilibrium temperature. The students had been exploring the effect of ice cover on earth's equilibrium temperature in the model. Up until now, the level of ice cover was constant over time. Then, the worksheet prompted them to turn on the “melting ice”

button and investigate what the button does, and how it affects Earth's equilibrium temperature:

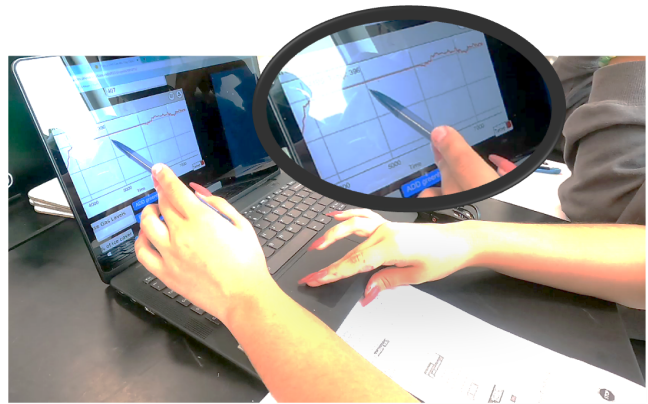


FIG. 1. Dora points out that the graph “ACTUALLY flatline[s].” ALL CAPS in the transcript indicates louder speech.

Dora: You see? It's melting the ice!
pointing to ice on the simulation screen

Natalia: Mmhm

Dora: So it'll, like, ACTUALLY flatline.
**points at very flat part of graph and zooms in* (shown in Fig. 1).*

The first thing they notice is that when the button is toggled on, the ice starts to melt. They also notice that the graph of temperature vs. time not only plateaus, but the fluctuations go away to make a completely flat line, as seen in Fig. 1. This prompts further investigation:

Natalia: Hold up. Click Run/Pause again? ‘Cuz it only happened after you hit Run/Pause-

Dora: ‘Cuz look!
Still pointing at flat part of the graph

Natalia: Click Run/Pause again?
Dora clicks Run/Pause again
 Yeah ‘cuz every time you click Run/Pause it, like, flatlines.

Dora: No, look!
pointing at the where the fluctuations return to the graph after the flatline
Dora keeps clicking Run/Pause, new flatlines appear after the fluctuations

Natalia: See?

Dora: That's weird.
 Natalia: Yeah that *is* weird...Okay, toggle button definitely has some issues.

They were surprised by the flatline. Dora was surprised enough to notice it and call it out as distinct from the usual plateau (zooming in on the graph of temperature vs. time, pointing to the zoomed in portion and announcing "it'll like, ACTUALLY flatline"). Natalia was surprised as well ("Hold up."). Both students admit it is "weird", suggesting surprise over the behavior and uncertainty over the source.

Their response to this surprise and uncertainty was to investigate its source. Natalia wanted to see the behavior again, having noticed it only happened when Dora clicked the button. Seeing it happen again supported Natalia's hypothesis "every time you click Run/Pause it, like, flatlines." Then, after seeing the fluctuations return after a short time following each flatline, Natalia concludes it is a glitch, not a feature of the model: "Okay, toggle button definitely has some issues."

Although they did not use the vocabulary of the scientific method, they were following it implicitly, and spontaneously. They started with an observation, formed a hypothesis, collected data to test the hypothesis, and analyzed the data to form a conclusion. In this case, they concluded this behavior was a bug, not a feature.

The pair's impromptu scientific inquiry was their response to epistemic emotions of surprise (about the "actual" flatline) as well as uncertainty (over the source of the flatline). Thus, this pair's scientific sensemaking was driven by epistemic emotions (surprise and uncertainty).

B. Episode 2: "It actually stops melting"

Episode 2 takes place immediately after Episode 1. Dora found another surprising behavior of the model when she noticed the ice does not completely melt away. While investigating with the model, she set the model's ice cover to 100%. At first the ice melted very quickly before slowing as it approached about 50% coverage. Dora waited for a long time for the rest of the ice to melt and ultimately noted in an elevated voice that the ice stopped melting:

Dora: Well at some point it actually stops melting it off!
points to ice on the Earth's surface
 Natalia: Do we have to write, like, an if-then-because hypothesis statement?
writing on worksheet
 Dora: **continuing to experiment**
 I mean it just probably means it just takes longer to reach an equilibrium level. Cuz, like, look it took it- look how long it takes to get to an equilibrium.
points at graph

Natalia: That's true. I said, "if the ice is melted then the equilibrium temperature would increase because there's no reflective ice."

Dora: It like slows down the time... it increases the time it takes for the Earth to come into an equilibrium.

Natalia: **talking out what she's writing**
 Toggling with the melting ice button causes the Earth to reach an equilibrium temperature at a longer time BECAUSE the temperature increases -

Dora: Slowly

Natalia: due to- SLOWLY...due to the ice being melted.
Drops pencil
 We're done.

Dora was surprised that the ice did not melt all the way ("Well at some point it actually stops melting it off!"). She ran the model three more times before concluding that the melting ice increased the time it took to get to an equilibrium temperature. Meanwhile, Natalia reasoned more mechanistically, concluding that a lack of reflective ice would increase the equilibrium temperature. They ultimately combined Dora's evidence-supported conclusion with Natalia's sense of the mechanism: "the temperature increases SLOWLY due to the ice being melted."

Epistemic affect was driving the pair's investigations once again in this episode. They encountered another surprising behavior, with its source once again uncertain; it could be a bug or a feature. Their response to this uncertainty was to investigate further to make sense of this surprising result. This time, they concluded it was a feature, not a bug.

C. Episode 3: Worst case scenario

Episode 3 happened later in the same class period, when the students were working on a different part of the lesson. At this point, they were exploring how human activity (building factories or planting trees) impacted Earth's equilibrium temperature in the model. Through their investigations, they found that adding factories raised Earth's equilibrium temperature, while adding trees lowered it. The worksheet then prompted them to "describe with a graph what would be the worst-case scenario for this model." First they discuss:

Natalia: How am I supposed to write a graph?
 Dora: *((reading))* "Describe with a graph."
 Um, we're just gonna make like, this, right? **points to temperature vs. time graph on the screen**

Natalia: Yah.
 Dora: Will it just be, like...
 Natalia: This is just, we'll draw increasing.
 Dora: And I'll just casually put a 1000
((laughing)) in temperature.
 Natalia: Yeah.
 Dora: To fully accentuate the-
 Natalia: I'm gonna write no equilibrium
 Dora: I mean it would reach equilibrium.
 High equilibrium.
((reading)) "Try your best to use the
 model to create the worst case
 scenario. Describe what you tried and
 how it turned out."

The pair encountered some uncertainty in their prediction when they seemed to disagree over whether the Earth will reach equilibrium temperature. They proceeded on Dora's assertion that it will reach "high equilibrium" and predict that it will be at 1000 degrees (the temperatures in the model are defined by the movement of modeled particles and so do not correspond to real-world units). Natalia draws another diagram to show the rate of incoming energy absorbed by the Earth is greater than the rate of energy it radiates back out. Then, they use their model to create the worst-case scenario:

Dora: *((looking at Natalia's energy diagram))*
 This looks beautiful. Amazing.
 Catastrophic. *((laughs))*
 Okay, you know how we show that? By
 just...
((adds a bunch of factories))
 ...Oop!
((Laughing at a factory in the sky))
 Natalia: What that hell is that, like, a satellite?
 Dora: You know, this is what I think it's trying to
 tell us but at some point we're going to have
 factories in the-
 Natalia: sky, that's what satellites are for, the
 international space station. *((laughing))*

When adding factories to their model, they are surprised to see some factories show up in the sky instead of the ground. They laugh, but they also do not simply laugh it off. They half-jokingly try to make some sense out of this surprising behavior of the model ("is that, like, a satellite?"), even imagining a future in which we have factories in the sky. They quickly move on and avoid this bug by limiting the number of factories to five:

Dora: Okay, um, one two three four five. We'll
 leave it at 5, cuz 6 makes it that. So it'll be
 five. And then you know what happens?
 Only one tree left. In the world. *((laughing))*

Natalia: No! We have to- No! No trees! Remember,
 no trees!
 Dora: Oh yeah, no trees. Okay...oh!
 Natalia: *((model starts, at first temperature is
 increasing over time))*
 You see, I told you!
 Dora: No, but it's gonna reach eq-
 Natalia: *((gasping as the graph levels off))* We
 guessed it right the equilibrium's at 1000!
 Man, we are just geniuses, actually.
 Dora: I just think we're like, prophets.
 Natalia: You want to know about global warming?
 ask us, okay?

Again, the pair encounter surprise and uncertainty. At first, they are collectively uncertain about their prediction of Earth's equilibrium temperature. They are surprised by the factories in the sky. In each case, these epistemic emotions do not hinder scientific sensemaking; they inspire the group to dig in and make sense of what they are uncertain about. This leads to the culminating surprise that their numerical prediction of the temperature was right on the money, which they respond to with joy and self-confidence.

V. CONCLUSIONS

We analyzed video data of students' classroom interactions to examine how computational modeling can support physics learning. Computational modeling can introduce new sources of uncertainty, especially when the model behaves in surprising ways. We find that this uncertainty can create opportunities for inspiring students' scientific inquiry. Our analysis represents an illustrative case of one productive way students can respond to uncertainty: by investigating until they find out whether the source of the surprising result is a bug or a feature. This work contributes to the Physics Education Research literature by highlighting the role that epistemic emotions play when integrating computation into physics classrooms.

VI. LIMITATIONS & OUTLOOK

This work represents merely an existence proof of how epistemic emotions can inspire students' scientific sensemaking and inquiry while computationally modeling in physics classrooms. Of course, not all student groups will respond the same way to uncertainty. Future research will investigate how this group's investigations changed over time, in comparison with other groups, to explore whether and how the teacher and curriculum supported this group in responding to surprise and uncertainty not by shutting down but by digging in.

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