Review Article

Disciplinary significance of social caring in postsecondary science, technology, engineering, and mathematics

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We analyzed student engagement in physics during a summer course for incoming first-year students, part of a cohort-based learning community designed for students from underrepresented groups in the School of Engineering of a predominantly white institution. The data—video of an episode within the course and interviews of the 11 students one year later about their experiences in the program and the course—support two findings: (i) The students cared for each other, in a social sense, and felt cared for by the instructor, and (ii) the students framed the course as focused on their own reasoning. We argue that the former supported the latter, and we offer this as a conjecture for further study: Social caring can support productive epistemological framing. If this is correct, it would suggest the benefits of aligning what takes place within courses with the socially supportive dynamics of extracurricular cohort-based learning communities.

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I. INTRODUCTION

In an interview at the end of his first year of university, a student described his experiences within a cohort-based program, Bridge to Engineering Success at Tufts (BEST):

> *[T]he cohort that I was in—like, so many of them I can call my best friends, even now. And we're just such a supportive group of people. We still do homework together, we still hang out together, even though that isn't really common from previous cohorts. I feel like we just had—we fostered such a—how do you say—like, a brotherhood, like, sisterhood.*

> *[B]y the end of the six weeks, I feel like we all were able to articulate ourselves in physics in such a different way that it didn't feel like I was doing it to just get the right answer and all that. It's like, "Alright, this is what I think. What do you think?" And then we just keep going back and forth. So yeah, I feel like I appreciate him [the instructor] a lot for that because it made me not see STEM in general as so black and white—just, like, right or wrong. Because I feel like it's so much more than that.*

BEST is designed for individuals from underrepresented groups (including first-generation university students) in the School of Engineering. There were 11 students in that year's cohort, all of whom consented to participate in this study.

The two quotations above reflect two themes we saw across the 11 interviews. First, the students described having formed strong social connections that both supported and grew within the context of their academic work. That is, they showed a sense of community, an explicit goal for BEST, and what we will refer to as *social caring*. Second, they described having shifted in their *epistemological framing*, that is in their expectations about what it means to know and learn, during their first course in physics, the summer before their formal matriculation.

These two themes in the interviews were also evident during the course. They were, in fact, both explicit priorities for the instructor, the second author. First, he intended that the students felt cared for as people, both by him and by each other. Second, he wanted them to learn how to learn physics—that is, he wanted them genuinely reasoning for themselves, drawing on and refining their prior knowledge and experience of the physical world, recognizing and engaging with feelings of uncertainty. He thought of the former as helping the students feel socially "safe" and supported to engage in the latter.

Social caring and science epistemology are both matters discussed in research on learning, although generally within different segments of the literature. That students feel welcome and cared for, that they feel they belong, is a major theme of scholarship concerned with equity and inclusion (e.g., Ref. [1]) and of cohort-based learning communities (CBLCs) like BEST (Ref. [2], p. 4; [3–6]). CBLCs, including BEST, mainly direct their efforts in *extracurricular spaces* (e.g., Refs. [6,7]). That students learn to "do science" for themselves, rather than "do the lesson" [8] has been a mostly separate theme of scholarship in science education. Most designs for disciplinary engagement concern what takes place *within classrooms* [9].

In this article we argue for connecting these two lines of scholarship and attention within postsecondary science, technology, engineering, and mathematics (STEM): Social caring can support disciplinary practices. Using an episode of disciplinary engagement within a reformed physics course at the outset of students' time in university and in their CBLC, we argue that students' experience of social caring within the context of the course and the program helped generate and stabilize their meaningful engagement in scientific inquiry in particular by supporting students in valuing their own and each other's thinking. We propose that social caring in the context of doing science involves attention to and respect for the substance of students' thinking.

We support this claim with evidence from student interviews and from the classroom episode. We also cite support from precedents in the literature, from high school [10] and university [11] mathematics education, as well as from a literacy program for the children of migrant farmers [12]. Finally, we offer a theoretical argument for the connection, in terms of the dynamics of students' epistemological framing [13,14].

The next section presents brief reviews of scholarship on (i) inclusion in STEM and (ii) disciplinary sensemaking. These lines of work have largely been separate, but there are essential connections and overlapping considerations bearing on conceptualizations of science and of learners [15–17]. We then turn to the BEST program and the summer course in physics, to show evidence of interaction between social caring and epistemologies. In the closing section, we discuss some possible contributions of this work to conversations about inclusion and reform in postsecondary STEM.

II. PRIOR WORK ON INCLUSION AND SENSEMAKING

A. Inclusion in STEM

Our data relate to two general forms of STEM inclusion initiatives: (i) extracurricular and course-adjacent opportunities and support for students from underrepresented groups in college and university and (ii) course-level reforms, including redesigned curricula and reformed pedagogical practices.

1. Extra- and co-curricular support for students from underrepresented groups in college and university

Cohort-based learning communities like BEST and their associated support structures (identity-specific community centers, academic support services) comprise some of the largest-scale efforts at STEM inclusion at the post-secondary level. CBLCs, notably Meyerhoff [18] and Posse [19], are designed to promote students' persistence in STEM through various resources and opportunities, including tutoring and study groups, mentoring, professional development, and relationship building with peers, staff, and faculty. Most of these programs act outside of the academic courses themselves, rather than within; some are designed to work adjacent to those courses, such as through specific tutoring or other support.

The *Mathematics Workshop Program* [20] was designed as a co-curricular program for students in calculus. It emphasized group learning through especially challenging problems, explicitly in contrast to *remediation*, and the evidence showed significant improvement in African American students' grades in calculus and persistence in mathematics or mathematics-related majors. Like CBLCs, the MWP and other similar antiremedial programs focus significant attention to fostering a sense of community, along with the intellectual work in doing mathematics.

These accounts attribute the success of these extra- and co-curricular programs in part to their offering opportunities for students to cultivate a sense of belonging (Ref. [2], p. 4; [3–5]) or sense of community [6].[1] We similarly began this work with a sense of the students' experience of community, or what we chose to call "social caring" as we discuss below.

2. Curricular and pedagogical reforms

There has also been work on how to change *courses* to include students from underrepresented groups and those students' resources. Most of this work has focused on K-12; scholars have developed accounts of *culturally relevant pedagogy* [1], *culturally responsive teaching* [21], and *culturally sustaining pedagogy* [22,23]. These approaches take as a premise that students from underrepresented groups have abundant resources (experiences, skills, cultural references) for learning, and they ask what can be changed about the learning environment to make space for and elicit those resources. These approaches generally

[1]The extent to which any particular group coheres, of course, depends in part on the individuals in the group—who they are and what they bring to the group. Some programs, including BEST, explicitly take this into account when they select the students for each cohort, for example, considering the students' promise at contributing to a sense of community.

consider the social and relational aspects of learning and teaching, and they design, accordingly, for student engagement, sense of belonging, and agency (e.g., Refs. [24–26]). Strategies include modifying curricula and pedagogy to make clear contact with students' lives and identities: "Culturally relevant teachers utilize students' culture as a vehicle for learning" (Ref. [1], p. 161), such as by using students' comfort with rap as a "bridge to school learning" (e.g., about poetry), and incorporate local community members and their expertise within the curriculum. There have also been moves to change the power structures of classrooms: Reality pedagogy [26], for example, explicitly involves students in decisions about how class is run. Other scholarship has moved beyond the goal of "inclusion" *per se* to argue the need for expanding what counts as science and engineering (e.g., Refs. [15,27–29]).

B. Science class as a space for sensemaking

There has long been attention in science education research to how students engage in learning. This work has been conceptualized and described variously as focused on "sensemaking" [30], "doing science" [8], "productive disciplinary engagement" [31], "science as inquiry" [32] and disciplinary "practices" [33].

Part of this work has focused on students' *epistemologies* [34,35], their sense of what constitutes knowledge. Research on *epistemological framing* [14] conceptualizes this sense as dynamic and contextual, as we discuss later in the article. Here, we describe the target epistemology, science class as doing science, and its implications for proximate pedagogical goals and practices.

Odden and Russ [30] proposed a definition of sensemaking:

> *[S]ensemaking is a dynamic process of building or revising an explanation in order to "figure something out"—to ascertain the mechanism underlying a phenomenon in order to resolve a gap or inconsistency in one's understanding. One builds this explanation out of a mix of everyday knowledge and formal knowledge by iteratively proposing and connecting up different ideas on the subject. One also simultaneously checks that those connections and ideas are coherent, both with one another and with other ideas in one's knowledge system. (p. 191–2)*

Two features of this definition reflect broad consensus across the literature and inform our analysis of the episode below: (i) Science as sensemaking involves "everyday knowledge"—the knowledge students bring with them from their experiences in the world, and (ii) it means seeking coherent understanding, including to connect everyday knowledge with "formal knowledge" such as presented in a physics course. Arguments for students to experience science as sensemaking have disciplinary origins, including in Einstein's famous remark, "The whole of science is nothing more than a refinement of everyday thinking" (Ref. [36], p. 59).

Pedagogy for scientific sensemaking means tapping into students' resources for doing science, which they have in abundance from experiences of the world [37], including "diverse funds of knowledge" [38] they develop through participation in various epistemic activities [39]. Such pedagogy involves eliciting and attending to students' *disciplinary thinking* and responding in constructive ways. It is thus sometimes referred to as "responsive teaching" [9]. We use the qualifier "disciplinary" here to distinguish this kind of responsive teaching from "culturally responsive teaching" which emphasizes attending and responding to students' *cultures*.

Accounts of disciplinarily responsive teaching (DRT) [9,40] have emphasized the importance of teachers' abilities and inclinations to recognize possible beginnings of scientifically productive ideas. When students genuinely have the freedom for their own sensemaking, they will very often come up with questions and ideas the curriculum did not anticipate—such as thinking of "the sun as living" [41], of a toy car as having "free will" [42], or of liquid "freaking out" [43]. Curricula cannot anticipate everything students might consider or invent, and so teachers must be ready. Often, authors have argued, this recognition and responsiveness means expanding the boundaries of what has conventionally been seen as school science, in particular to challenge the continued emphasis on canonical correctness as the primary objective [44].

C. Convergences

Reforms motivated primarily by disciplinary objectives —that students have opportunities to *do science*—converge with curricular and pedagogical reforms motivated primarily by inclusion. Indeed, in her landmark study of teachers who succeed with Black children, Ladson-Billings [25] emphasized the importance of their recognizing students as able, as having valuable knowledge and abilities, of their making space in class to hear students' thinking and constructively responding to that thinking [25]. Real dialogue, including between students and their teacher, is also part of Freire's model for literacy education [24] which involves a transformation of a course from a place where students are asked to absorb previously determined ideas by authority to a place where they are meant to think and make sense of things for themselves.

Thus, these mostly distinct literatures (of curricular and pedagogical reforms motivated primarily by inclusion and reforms motivated primarily by disciplinary objectives) align in several ways—expecting learners to have productive resources, emphasizing the need for teacher attention, and listening to students' thinking, supporting students' intellectual agency. This suggests convergence in instructional reforms aimed at students' doing science to those aimed at inclusion. Shifting the focus of STEM courses to sensemaking coheres with inclusion because it can expand the space for meaningful contributions, allowing for expression of students' various resources for learning, such as in the "multidimensional" math class described in Boaler [10], provided that instructors can listen to students' disciplinary thinking across cultural differences [16,41].

Social caring is a common focus in inclusion initiatives, in various terms such as "sense of belonging" [2], "social belonging" [5], "network of friends" [7] (p. 16), "family-like nature of the program community" [6] (p. 644), "relational equity" [10], "fraternity" [11] (p. 366), or "kinship" [12]. Only a few of these accounts, however, have considered social caring as connected with student sensemaking and development of disciplinary practices [10–12]. Our central purpose here is to provide evidence and argument in contribution to those accounts: social caring can support (and be supported by) disciplinary engagement. For us, that idea emerged in our study of university students' engagement in physics.

III. A CASE OF UNIVERSITY STUDENTS DOING PHYSICS

A. Context

The Bridge to Engineering Success program at Tufts is a CBLC designed for engineering majors from underrepresented populations and for first-generation university students. Each year, 10–15 students are selected for the program; this year, there were 11, four of whom were women. BEST includes a financial scholarship, courses, other career-related programming, and socio-emotional and academic support from dedicated staff. BEST starts the summer before the students' first regular academic year of university, with two STEM courses, one of which has been calculus and the other of which has been a calculus-based introductory physics course, Physics S11.

Physics S11 is required for physics majors and engineers. BEST scholars take the course in a 6-week format during the summer before their first year of university. They take the pre- or co-requisite, calculus, at the same time. At the time of this cohort, there was no expectation or design in the BEST program that the summer courses change from conventional pedagogy (and indeed that iteration of the calculus course was taught in a conventional manner), but it happened that the teaching assignment went to the second author, V. D., a scholar in physics education research deeply interested in curricular reform and responsive teaching. At the time for him, the latter meant DRT.

Physics S11 met every morning for 2 h in a laboratory setting for easy access to experiments and equipment as students needed them: one of the innovations V. D. implemented was to combine formal "lecture" time and lab in a way that allowed fluid and responsive movement between discussions and experimentation. Students prepared for class by watching "prelecture" videos and responding to "checkpoint" questions in *smartPhysics* (Ref. [45], now called *FlipIt Physics*). In-class activities varied based on students' needs and interests. One common sequence of activities was the instructor facilitating full class discussion around prelecture or homework problems (for which students had provided various arguments in writing the night before) and then small-group work around student-generated questions. Discussion on any single problem in the large group could last from 5 to 45 min.

In these ways, the course reflected several reforms designed to support students' learning how to learn in physics. This was a shift in objectives toward disciplinary practices, that students learn to embrace and articulate uncertainties, formulate their own questions, and work to seek coherence in their own understandings; these significantly reflected the instructor's participation and familiarity with physics education research [46,47]. V. D. was motivated toward DRT [9] out of interest in cultivating students' agency in disciplinary practices.

This year, the instructor, V. D., added another goal for the course, based on feedback from the director of BEST who indicated that in prior years of V. D.'s teaching the course, students largely had not connected with him personally and that had negatively affected their experiences in the course. The feedback was difficult to hear and required some honest self-reflection as to why he had not paid enough attention to the relational aspect of teaching. He consequently made it an explicit goal for that summer to have students feel cared for and supported as people—they should feel "loved," as V. D. put it for himself (cf. Ref. [48]).

B. Data collection and analysis

We analyzed two types of data. The first was a video recording of a class session of Physics S11. This video was part of a larger project, titled *The Dynamics of Students'* Engagement and Persistence in Science (studentsdoingscience.tufts.edu). The *Students Doing Science* project, as we will refer to it here, began with a selection of episodes by a panel of collaborating scientists, including faculty in physics, chemistry, and biology. Project staff presented the scientists with candidate episodes, almost all in the form of video data, and asked them to select "clear instances" of students engaged in scientific inquiry.

The analysis consisted of close, line-by-line narrative accounts of what took place and, to the extent we could infer, what and how students were thinking along the way. The first author took the lead in analyzing this case, presenting an initial pass to the project team and revising with feedback. In this way we constructed a detailed narrative [49] of what took place; for a more extensive account of the project and methodology see Hammer, Gouvea, and Watkins [50]. The project chose eight of the cases to present online, with video; we invite readers to view the online presentation.

The present study grew out of that project and an additional interest to follow-up with the students to learn what influence, if any, the summer course had on how they experienced their first year of university. To that end, the first author invited the students to participate in an interview, one year later; every student consented and participated, for a total of 11 interviews. L. A. started each by asking to hear anything that students wanted to share about their experiences in science and math courses and BEST in general. Later, she played a minute-long videoclip from the episode as a prompt for reflection and reactions.[2] We transcribed and summarized each interview, working to capture main themes and include illustrative quotes. We then looked across the summaries for possible common themes.

We begin with the episode, which we present in four excerpts and then turn to the interviews.

C. The episode of disciplinary engagement

We present four segments of the episode through a combination of narrative and transcript[3] excerpts. For a complete transcript, see the Supplemental Material [51]. For a complete (∼13 min) video of the episode, see the website [52].

The discussion concerns an online *smartPhysics* checkpoint question from the night before, titled "System of Two Masses": "Two objects, one having twice the mass of the other, are initially at rest. Two forces, one twice as big as the other, act on the objects in opposite directions as shown below. Which of the following statements about the acceleration of the center of mass of the system is true?" (Fig. 1). There were five possibilities, multiple choice, along with a space for students to write explanations of their reasoning.

The students came to class split between two of the five options: $a = 0$ and $a = F/3M$ to the left. After some discussion, most students agreed on the latter, which is the canonically correct answer. At the start of the episode we analyzed, Jared articulates his new reasoning, having changed his mind from thinking $a = 0$. He explains that if the two objects move the same distance in the same time, and they have different masses, the center of mass would have to move to stay closer to the larger mass. Jared uses his pen as an imaginary expanding object with unequal masses at either end.

Adolfo goes to the board to draw a diagram of that reasoning. Adolfo's diagram (Fig. 2) shows the two masses,

FIG. 1. The system of two masses in the checkpoint scenario.

"$2M$" and "M" and marks the initial location of the center of mass (c.m.) "x", explaining that it has to be closer to $2M$ than to M.

He then draws a second instance of the system for when the masses have moved apart, marks "x" at the original position and says "It's impossible for it [the c.m.] to be here…" He later moves that "x" to the left.

Mischael, however, sees Adolfo's diagram as supporting his own answer of $a = 0$, saying that "the proportionality of the distance is still the same." We turn now to the transcript, starting with Mischael's explanation (see transcript 1).

Transcript 1

69	Mischael	Okay, if I had—if I had, like, a pencil, right, and I'm balancing it on my fingers, if both ends of the pencil continue to grow, the center of mass will still be where I'm balancing on my fingers. So they're growing at the same rate, but the distance away from—the distance is—is still proportional.
70	Adolfo	I don't know, I don't know if I'm drawing it right.
71	Derrick	((to Mischael)) No, but this side—this side of the pencil is double the mass of this side.
72	Mischael	((to Derrick)) [I know. That's why the center of mass is closer—
73	Kimmee	[But the center of mass is closer to the thing that's heavier. So if it's a pencil—but if it's, like, a pencil, then it's like—((Adolfo redraws the "x" more to the left, i.e., x_f of Fig. 2)) I mean, you're assuming that—like, it's right in the middle. So if you were looking at it from the center of—from the point of the center of mass, it would be growing, like, proportional to each other, from the center of mass. But if you're looking at something, like, heavier ((Kimmee points to her water bottle)) than the other thing, ((Kimmee points to her phone)) and its growing, well, how could it be, like, how could the center of mass be in the same place? It would have to move. Like—
74	Jared	[It would have to move *with the* [[*heavier mass.*
75	Mischael	What do you mean?
76	Kimmee	[So it would be [[closer. Yeah.

1. Segment 1. "the distance is… is still proportional"

Segment 1 begins with Mischael taking up Jared's approach to thinking about the problem in terms of an expanding writing implement, but reasoning that the distance is proportional, he arrives at a different conclusion. Derrick and Kimmee each respond to Mischael,

[2] Reviewers asked us to say why we chose this particular minute, but it was mostly arbitrary. We just selected a clip that included several student voices as opposed to just one.

[3] We use the following transcript notations: Notes, for example about relevant movements, are given in double parentheses, (( )); single parentheses () marks utterances that are indistinguishable; brackets [and [[mark speech that is overlapping. Line numbers here refer to the full transcript, which is available in the Supplemental Material [51]. The students' names are real, used by permission, to be consistent with the video recording online.

emphasizing the importance of the difference in masses on either side.

In her explanation, Kimmee affirms Mischael's reasoning for a pencil, when the c.m. is in the middle, and then contrasts that with the scenario of the checkpoint question, using her water bottle (as a more massive object) and phone (as a less massive object) to illustrate. Other students in the class seem to be following the discussion throughout, as evident in their gazes and gestures. Adolfo is still at the blackboard, revising the diagram he had drawn apparently to represent what he thinks will be the actual new location of the c.m.

2. Segment 2. "as they grow farther and farther apart, won't that become insignificant?"

In an exchange omitted from here, Alejandro starts to speak, but Joel has had his hand raised, and V. D. calls on him (see transcript 2).

Transcript 2

79	Joel	Um, so I think I know almost exactly what Jared's saying—where, like—
80	V. D.	Can you—can you help us with a drawing? ((*Joel goes to the board*))
81	Joel	So if we agree that that's the location of the center of mass, here, right? ((*Joel points to the top* "*x*" *i.e., the* "x_i" *in the top half of* Fig. 2)) [V. D.: Yep] So, at this point—so it's a lot closer to the, uh, larger mass when you start. [V. D.: Yep] And as you start separating the distances, ((*Joel moves his hands apart*) this ((*Joel points to the top* "*x*" *again*)) di—this moves—sorry. If they move away at the same rate, ((*Joel moves his hands apart from each other again*)) then THIS distance ((*Joel points to and brackets* D_1 *in* Fig. 2)) minus this distance ((*Joel points to and brackets* L_1 *in* Fig. 2)) is going to be the diff—only difference in distance between the two masses, right? To the center of mass? And as they mo—as they grow farther and farther apart, won't that become insignificant?
82	Jared	I'm not sure what you mean. [Derrick: Yeah.]
83	Kimmee	I don't follow.

Joel's overall argument is that if the c.m. does not accelerate, then an inconsistency must follow: The equal distances traveled by each object would, when taken to large values, render insignificant the initial difference in distance from each of the masses to the c.m. That is, for a stationary c.m., the ratio of distances (D_1/L_1) would approach 1 as the objects moved farther and farther apart, and therefore the center of mass would no longer be closer to the mass on the left, $2M$. Thus, Joel's reasoning is consistent with what others have been arguing, although Jared, Derrick, and Kimmee have trouble following.

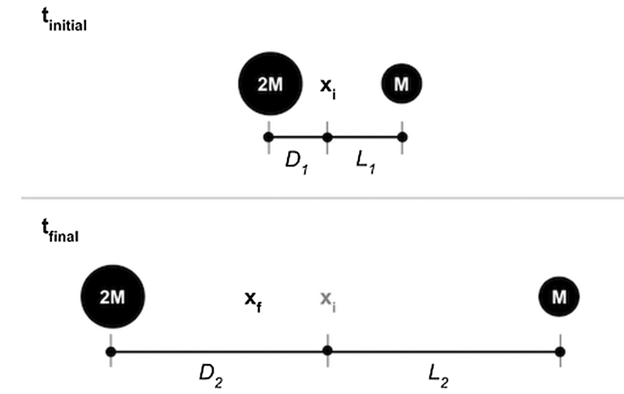

FIG. 2. The diagram Adolfo originally drew. We have modified it slightly for clarity and ease of reference.

Mischael jumps in and starts to explain his thinking in terms of Joel's drawing (line 84):

> *Um, OK so at the beginning, if you take the distance from the 2M to the center of mass, right, and you put it over the distance from the center of mass to M, that—that proportionality will stay the same if they're moving different ((Alejandro raises his hand)) if they're moving —if they're accelerating at the same rate.*

In an exchange we omit, V. D. revoices Mischael's thinking. Then Joel tries again to explain his reasoning, this time by assigning values to some of the distances in his diagram (see transcript 3).

Transcript 3

88	Joel	Yeah, so, if this is, like—this () ((*Joel points to* D_1, *in* Fig. 2)) is, like—is one—one whatever unit, from the center of mass. ((*Joel marks* D_1 *"1"*)) And this ((*Joel points to* L_1 *and marks it "2"*)) is [two
89	V. D.	[two units
90	Joel	then as they keep going farther apart, this could be like—((*Joel draws a new line delineating* D_2 *in* Fig. 2 *and labeling it "1,000,001"*))
91	V. D.	Three units and six units. ((*others laugh*)) Let's make it easy. ((*others laugh*))
92	Jared	Why so big?
93	Adolfo	Yeah, why so, why so big?
94	Jared	Just 10, just 10. ((*others murmur; Joel erases "1,000,001"*))

Joel was trying to express his reasoning again, this time using the large numbers to show the limiting case (1 000 001 is about equal to 1 000 002), but others, including the instructor, still do not follow and protest. That makes Joel stop again.

Segment 2 shows the students attending closely to each other's thinking. First, Joel has been listening to Jared and thinks he can help explain. As Joel tries, the whole class watches and listens, and when they have trouble understanding, several students say speak up. When Joel resumes, it is again clear everyone is still listening. Although they do not follow his intention for using large numbers, the instructor and other students try to help him with their suggestions. Their help is not helpful; Joel abandons his argument. Still, the tone is playful and friendly. Note too that Adolfo, Derrick, Jared, and Kimmee all know Joel agrees with their conclusion, but they are trying to follow his particular reasoning for it.

As well, the segment shows the conflicting lines of mathematical reasoning. One, which Joel tries to explain, involves adding the same number to the distances of both masses from the original center of mass. The other involves maintaining the proportions of their distances to the c.m. V. D. supports the second pattern when he suggests "three units and six units" as the easier numbers for Joel to use in his explanation.[4]

3. Segment 3. "How could it do that if it wasn't moving?!"

V. D. then gives the floor back to Mischael (line 95: "He's saying, he's saying it would be—((*to Mischael*)) you would say it's three and six?"), who then uses three and six to illustrate his thinking: "Say, say it's three and six, right? One over two is the same thing as three over six. It's still proportional." (line 96).

After this segment, there is energetic response from other students, including murmurs and Alejandro pounding his fists on his desk. These responses seem to be a combination of protest, confusion, and amusement. Mischael goes to the board, over spirited objections from others, and uses the numbers there to explain what he means by "proportionality." He argues that the proportionality does not change because "they're moving away at the same rate," and that while the distance between the more massive object and the c.m. may be greater, so will be the distance between the less massive object and the c.m. ("will be even longer").

In an exchange we omit here, Mischael predicts his reasoning would end up wrong (line 103), but he persists, apparently not yet seeing why. Jared says that means that the c.m. must move, "for the proportions to stay the same." Mischael interrupts that "the proportions will stay the same" and the c.m. will be closer to the heavier object. Jared responds, "that's exactly what we're saying," and continues with emphasis: "How could it do that if it wasn't moving?!" The debate is animated but amicable, punctuated by laughter and smiles.

[4]Joel's (and Jared's and Kimmee's and others') reasoning is correct: If the objects move with the same acceleration, starting from rest, they will move the same distances from the original location of the center of mass. The proportional reasoning applies, correctly, to the *new* location of the center of mass —M will always be twice as far from the center of mass as $2M$. Thus Joel and others conclude that the c.m. has to move.

4. Segment 4. "They're disagreeing for weird reasons"

In an ongoing effort to bring in quieter voices, V. D. then calls on Korri, who has had her hand raised (line 123):

> *Um, so, just 'cuz it stays proportional and, like, I'm combining what both of them are saying, but it seems like they're disagreeing for a weird reason. Like, I think that—like, okay—Mischael is suggesting that the proportion is gonna stay the same—it's not gonna, like, percentage-wise, like, go more towards one or the other objects—like, three to six, three here—like, whatever. It's the same distance. Whatever, so—but he's ((Jared)) saying that it has to be accelerating, though, because of, um, you would have to move faster to maintain that proportion. So I that think the—the reason zero is there is it's supposed to kinda trick you into thinking, like, "Oh if the proportions stayed the same then there is no acceleration." But it HAS to be accelerating to maintain that proportion—so if it was going at constant velocity the proportion would be all messed up () the distance won't be increasing the same in time.*

Korri's explanation above is a shift of rhetoric from debate, although her logic is essentially the same as Jared's and Joel's. Thus, she affirms reasoning on both sides of the argument, saying that she is "combining what both of them are saying." She begins by reiterating what she hears, "Mischael is suggesting…" and highlights something she agrees with: The proportionality must be preserved. She then reiterates Jared's argument, that the c.m. has to be accelerating to maintain the c.m. In her telling, "they are disagreeing for a weird reason," suggesting they do not need to disagree. She depicts the answer $a = 0$ as a ploy by *smartPhysics* "to kinda trick you." In effect, Korri puts the students together on the same side of whatever contest is going on, and the checkpoint question (or its author) on the other.

Epistemology and caring.—The panel of collaborating scientists in the *Students Doing Science* project selected this as a clear instance of scientific inquiry, and we agree: The students were considering multiple lines of reasoning, including both formal mathematical and intuitive, and they were working to reconcile an apparent inconsistency. The class had essentially settled on the correct answer; the work they were doing was to ensure everyone followed the reasoning for it. The analysis in that project was to identify aspects of the dynamics of the episode that contributed to the students' doing science:

- The checkpoint question generated two attractive but conflicting lines of reasoning, evident in the split of students' original answers and in the split of arguments during the debate.
- One student, Mischael was persistent in arguing his point, whether in trying to persuade the others, or in trying to understand why he was wrong. He was clearly the proximal driver of the discussion.

- From the laughter and smiles and pace, it is evident the students were having fun with the interaction.
- The students signaled care for one another throughout, in tone as well as in explicit encouragement.
- The class had established expectations that the course was about their sensemaking.

For our purposes in this article, we focus on the last two: the students' care for one another and their expectations of sensemaking. The reader can find more about the other aspects in the online presentation. In this section, we review evidence within the episode of the students' expectations of sensemaking and of their caring for one another.

One form of evidence the students saw the class as about their sensemaking is simply that they were generating arguments throughout, based on their own sense of the situation. Several students used objects at hand to express their reasoning—the pen or pencil, Kimmee's water bottle and phone. Others drew diagrams and constructed mathematical arguments, with symbols or numbers they generated. At no point did any student look to authority—the instructor or the text—for the correct answer. The only reference to authority throughout was Korri's, in her suggestion that the answer $a = 0$ was a tricky ploy by the curriculum.

A second form of evidence is the students' attention to hearing and engaging with Mischael's counterarguments. For most of the discussion, he was the only holdout with respect to the answer. Although Mischael remarked that he knew he was wrong (line 103), he wants to understand why. That Mischael worked to communicate his reasoning, and that others participated with him, shows a shared expectation that the work they were doing together was to make sense of the answer, not just to find it.

Finally, the students also attended to Joel's reasoning. When Joel presented his first argument, (line 81), it was clear he was supporting Jared's reasoning for why the answer cannot be $a = 0$. If the work were to settle on an answer, other students might have been satisfied knowing only that Joel was supporting theirs. But Jared, Derrick, and Kimmee all expressed difficulty following what he was saying. Similarly, when Joel tried again, others in the class attended to the details and tried to help him construct what they thought he was saying.

All of that took place mainly among the students. The instructor participated, but other than calling on students he did little to direct the substance of the discussion. He had certainly worked for student sensemaking in various ways earlier in the course, but the evidence in this moment suggests the students had established their own expectations for what takes place. In other words, the evidence suggests the students framed the activity as about their sensemaking.

In the initial analysis, we described the students and the instructor showing care for one another as contributing to students' general comfort, enjoyment, and productive participation. Throughout the episode, the students and instructor showed care for each other, their ideas, feelings, and well-being, expressing encouragement and empathy for each other's participation. Examples include Jared's checking with his peers about the premise of his argument, Korri's summarizing both Mischael and Jared's arguments, students encouraging Alejandro at the board, shouting "Keep going, keep going" when he starts to doubt his math.

This first impression—that students and the instructor showing care for one another may have contributed to the productive dynamics of the episode—arose through our initial analysis of the episode itself. Later, analyzing the students' reflections in the interviews, we found it difficult to disentangle evidence of epistemologies from evidence of the kind of social care described above. This motivated us to revisit the role that care may have played. We now turn to the interviews.

D. The interviews

Our initial motivation for conducting interviews, one year later, was to find out if the epistemological shift we saw take place during the course had influenced students' learning in other courses over their first year at the university: There was evidence within the course of progress toward V. D.'s goal that the students approach learning—doing science—as sensemaking. We had anecdotal evidence of students reporting, years later, that similar courses had lasting value for them, but these were all students who took the initiative themselves. In this BEST course, we saw an opportunity to interview all the students in this course.

Thus, we designed interviews aimed at eliciting students' epistemologies, or comments about how they framed school and approached learning. In order not to bias the students towards confirming our hopes, we advertised the interview as generally about their experiences in the BEST program and how, if at all, it affected their learning in STEM courses.

The first author, L.A., conducted the interviews, starting with an open prompt: "I'm interested in your experience in your science and math courses this year and how that interacted with your experience in the BEST program." She left space for students to share any initial thoughts. Here and throughout the interviews, L.A. responded with short aural markers of listening and interest, and she asked follow-up questions, for clarification or to encourage elaboration. Towards the end of the interview, L.A. focused their attention on the summer physics course in particular by playing a one-minute video-clip from the episode above on a large monitor for the student to see. During the viewing, she watched the student for in-the-moment reactions, and afterwards she asked them for any thoughts or reactions that they wanted to share about what they had just seen. Again, she left space for the students to speak, listened actively and followed up with questions.

The results did provide evidence of Physics S11 having an influence on the students' learning in later courses. That, however, is not our focus here. Rather, we focus on two themes of evidence: First, the students highlighted something that we came to call "social caring" as central to their experience of the BEST program (both within the context of their courses and beyond). Second, the students spoke of the course as different from what they expected, in ways consistent with V. D.'s goals of a shifted epistemology. Our conjecture is that these themes were connected, in particular that the caring students felt supported their shift in epistemology.

1. The students experienced social caring

The strongest theme from the interviews was of students' experiencing caring, mostly with respect to each other but also with respect to V. D., other instructors, and BEST staff. Recognizing this theme, we struggled a bit with what to call it, settling on "social caring" as our best description of what we heard across the interviews: the students' speaking of people caring about each other as people.[5] Looking to the literature, we found the closest match in bell hooks' concept of "love." She describes love as "revealed through acts of care, respect, knowing, and assuming responsibility" (Ref. [48], p. 246) and as inherent in the concept of community, citing M. Scott Peck's for a definition: "the coming together of a group of individuals who have learned how to communicate honestly with each other, whose relationships go deeper than their masks of composure, and who have developed some significant commitment to 'rejoice together, mourn together,' and 'delight in each other' " (Ref. [48], p. 234–235).[6]

Every student described social caring in one way or another as central to their experience in the program. Here are six examples, from six different students.[7]

> *We had everyone—I had all the other BESTIES who were going through the same thing as me, right? They had questions. They're the same questions I did. We all got together. We would do homework. We would interact with each other, make sure we were all doing OK, make sure we were all understanding what was going on. Same thing with Physics, which is the other course we took. And yeah, we kinda became a community together, studying together, doing homework together, and we got to know each other really well.*

> *It's just nice to always be sure of your support system, I guess, in an academic setting. But also because you have, not even just classmates anymore, they're kinda like your family. 'Cuz I feel like as many friends that I made here, I always go back to them because it's like, we spent the summer together. We kinda suffered through ((L. A. chuckles)) a lot of things together ((L. A. chuckles)) We're a support system, academically and personally.*

> *The summer, while I enjoyed it and I loved it, it was hard. And I don't think I would have been able to get through it if I didn't have my cohort with me. And a lot of the classes I take now I don't think I'd be able to take and get through as easily or as stably as like, if I didn't have my cohort with me. Like, I have these kids, I know they're going through the same troubles I am, and we can always help each other, and we have our certain strengths and weaknesses, yes. But at the end of the day, we are together. And having that feeling, it's a good feeling.*

> *So I guess that's another good thing about—and just something general about BEST, regardless of what class, whether it be math or science, everyone is very inclusive. Everyone is very kind and understanding and, um, yeah, everyone's open to helping one another regardless of academically, socially, and um yeah.*

> *Yeah, like when I needed help in Physics class, I had it on my mind for a while that I was kinda struggling, but the teacher actually reached out to me. [L. A.: Woah] Yeah, and asked if I felt—how I felt about the course material, if I was getting it. But I just found tests hard or things like that so, it felt nice to feel like my professor really did care about whether I was learning or not.*

> *I feel like that's what BEST gave us. It gave us professors who I feel really cared about not only this program but helping us in general. And, yeah, I feel like a lot of us didn't really ever had that. Just people who actually wanted to take time out of their lives to make sure we understood stuff and think about the broader spectrum in terms of what that entails. And I feel like that was what was dope about this program, just so many people who just care so much.*

We present these quotes as examples of the evidence from interviews of the students' sense of community and connectedness with each other in the BEST program. Note that nothing in the interview protocol prompted for comments about relationships and community; the questions asked generally about their experiences.

To be clear, we are not claiming that the full extent of social caring communicated in these quotes existed at the time of the focal classroom episode. Indeed, the interviews

[5]For some educators, the word "caring" has "social" inherent in its meaning, but we are concerned that for some readers, the word "caring" alone would mean something close to "motivation"—students' caring about their grades, their understanding, and so on.

[6]Indeed, we considered using the term "love," but we were concerned that it would not seem like academic prose to PR-PER readers.

[7]Although we have their consent, we have decided not to identify the speakers. It is not necessary for our argument, and we could imagine it leading to some embarrassment.

came after a full academic year of additional experience and bonding, and most of these comments came during the first part of the interview, about students' experiences in the BEST program over the year. We are, however, claiming that students' experience of social caring in the program stood out for them as a primary benefit, and the evidence suggests this sense began in their experiences over the summer.

2. The students experienced Physics S11 as focused on their reasoning, questions, and ideas

There was also clear evidence across the interviews to suggest the course was successful in cultivating students' "doing science" for and among themselves, treating the subject as a "refinement of everyday thinking," drawing on their own experiences and reasoning. This was most evident in students' comments about the video clip, although eight students brought it up unprompted during the first part of the interview. They all saw the clip as representative of the course, and every student commented in some form about the course as focused on student thinking and their collaborative sensemaking. Here are six examples, again from six different students:

> *Before he gets to teach us how to do it, he wants to see how we think we should do it. And we're working through levels of understanding and seeing what students are gonna support this kind of argument for how you would go about solving a problem. And, like, how another student might have a totally different idea for how to approach the same problem. And then after all of that the teacher would kinda explain to us the best way to solve the problem, like what aspects of what argument were right. And I feel like that kinda attitude really promoted all of us —promoted our learning because he was trying to—I guess maybe one of his goals in doing that was trying to show us A. how you could connect your intuition to a subject like physics before you're taught, even. And [B.] that can help you connect what you think you know to what you actually—you know, the transfer…*

> *Awww. This was like every class. Actually, some classes weren't as active because we weren't all arguing with each other. This is actually how nights went too. We would all talk like this most of the time. Aw, I kinda miss the summer. ((laughs)) But yeah. It's just funny 'cuz sometimes when we're talking now, when ____ or ____ was explaining anything, they like talk in the same way they would talk in the summer, so it just takes me back to like the summer, and I'm like, "Oh my god, physics class again?" [L. A.: Can you describe a little bit what that way is that they talk?] Um, so it's very, like—they're very sure of themselves, but also they're not opposed to being wrong. So if there are different arguments, they're like, "Okay, well this is my argument and I'm gonna defend it. But also, I'm gonna take your argument into consideration." Which is a lot how this, I guess, this is, because it's like everyone's talking, we're not trying to talk over each other. But we're trying to listen, we're trying to listen to everyone's perspective and then piece everything together. So that comes in a lot. I think we learned a whole lot from the summer. Because Vesal didn't let us stay quiet ever. Always had to talk. Which is great.*

> *It was basically like we would each try to explain our own understanding and like um—and one thing my teacher, Vesal, said is, "You don't really know something unless you can explain it simply. And you can't prove yourself right unless you can prove everyone else wrong." So it was like—I don't know—I would sit and think, "Oh, it's definitely this, it's definitely this." And then I would talk to my classmates and be like, "No, you're wrong, it's definitely this." But then they would say something, and I'd be like, "Wow, okay, never mind. ((laughs)) Let me rethink some things." And it was just like, I like that discussion, like debating with your classmates, and I don't know, coming to your own um—I don't wanna say, like—coming to your own understanding. Or just have a ton of like epiphanies like, "Oh, wait, they're totally right. It's definitely like friction," or they're totally like, "Aw, I was wrong," or something.*

> *Even if you were wrong, he seemed to value that. And the class, too. He wouldn't tell you what the right answer was most of the time. And the conversation could go on and on… And then at the end finally we'll come to the right answer. So all the wrong answers led us down the path and allowed us to say, "No, not this, no not that." And then (inaudible) finally, at the end, we're able to get through all of them. But I feel everyone's wrong answers were able to be answered. And everyone was able to come to the same conclusion at the end, whether they started there or not. 'Cuz even if you did have an answer, you weren't sure if it was the right one. So somebody's wrong answer might have sounded right. And you're like, "Oh, maybe that," and it got us thinking a lot more, I think, about the subject, to hear the wrong answers as well as the right.*

> *[T]he way he challenged us to think. It wasn't just going into class and he would just write a bunch of stuff on the board, and be like, "Alright, memorize this." It was more like, "Alright, I'm gonna hit this volleyball and this bowling ball with a hammer. Do you think I'm applying equal force?" or "What's gonna happen?" and "What's really happening in the picture?" And everyone has their own thinking, everyone talks a little bit and says, like, "No, I disagree with you," but respectfully. And he lets us talk freely and you realize there's a lotta perspectives in the room.*

> *[W]e all had different opinions, different points of view. And by combining all of our views we concluded to one answer. Something I remember about this class is that there were things that when we concluded to an answer, most of the times we would be right, but not all the time. Sometimes we will conclude to a wrong answer. The way the class works is that understanding was more when you make connections.*

Again, we present these extended quotes as examples of the evidence in the interviews, to help motivate our conjecture. Each touches on the student's sense of the epistemic activity of the summer course, including to emphasize its focus on their knowledge and reasoning. In these ways, the students' comments during interviews supported our interpretation of the episode: Part of what contributed to the students' doing science was that the class had established expectations that the course was centrally about their sensemaking. That is, students framed the work to involve their drawing on their own knowledge and experience, connecting different ideas, and reconciling disagreements. This was a shift, which we describe as epistemological, from their experiences and expectations of a physics course.

IV. OUR CONJECTURE: SOCIAL CARING SUPPORTS A SHIFTED EPISTEMOLOGY

So far, we have reviewed evidence that the students spoke about these two themes—social caring and shifted epistemology. Here we introduce our conjecture that these two themes are dynamically connected, that social caring (including with their classmates outside of the classroom) supported the students' shifted epistemology.

We first arrived at this conjecture in analyzing the interviews: Very often what the students had to say that reflected on epistemology also reflected on social relationships. The second quote above ("Aww, this was like every class…") is an example. The student spoke of students hearing and responding to each other's arguments, the work to "piece everything together," while showing and expressing caring—beginning with the affective tone of "*Aww*,"—and their respect for each other during the discussion.

During our initial study of the interviews, we spent time trying to understand whether "because it's like everyone's talking, we're not trying to talk over each other. But we're trying to listen, we're trying to listen to everyone's perspective" was evidence of epistemology—our initial interest—or was it simply evidence of social caring. As we made our way through the data, we came to the idea that our repeated experience of difficulty in disentangling evidence of epistemology from caring was telling us to shift our analytic focus to the entanglement itself.

In this section, we will first present more of the evidence from interviews that led us to the conjecture. We will then turn to the dynamics of framing.

A. Evidence from interviews

Students often talked about their experience of social caring within the BEST program and their collaborative sensemaking in Physics S11 effectively within the same breath. For example, the fifth quote above includes

> *And everyone has their own thinking, everyone talks a little bit and says, like, "No, I disagree with you," but respectfully. And he lets us talk freely and you realize there's a lotta perspectives in the room."*

This is at once commenting on the relationships (as "respectful") and on the activities (disagreeing, talking, listening, realizing) which are ultimately part of sensemaking.

Here we provide four more examples from the interviews, again all from different students.

> *Yeah, I'm still really close with the people in my cohort. Like, we have study groups. We just come together and study on our own. And we would just debate even topics that aren't relevant to class, like, "Is water wet?" or random things and I don't know, it's great. Oh, another thing was you feel like you don't really know—or a good way to evaluate if you know a topic is if you can teach it to someone else. So we were all kinda trying to help each other out and teach each other and talk about concepts and different things and be like, "Oh yeah, there's this, this, and that." We still all come together and study together and everything.*

The student is at once describing the nature of the relationship amongst their peers (as "close") and the nature of their joint activity: working to understand and help each other understand the natural world, even on topics not directly related to class. Their speaking of "a good way to evaluate if you know a topic" is epistemological.

> *It took me the six weeks and then probably like a month or two into like the actual semester to finally like, I don't know, accept everyone into my—into me but um, yeah. Oh, I say that because like everyone in the cla—everyone in my cohort was—it was a very comfortable experience 'cuz these open-ended questions—most of us were wrong most of the time, and the teacher was very like—he was concerned more about our understanding and the way, the path we took to get to that understanding less than actually getting the right answer right off the bat. So I found it easy to participate 'cuz there's only 11 of us, although we all just met one another, it felt very inclusive right off the bat.*

The student describes the interplay between their sense of connection with their peers and the intellectual focus or climate of the course as set by the instructor. That the student described the teacher (V. D.) as "concerned more about our understanding" is evidence of how they framed the activity; that they describe the class as "comfortable" and "inclusive," "although we all just met one another," is evidence of how they experienced it socially. The student also links the social with the intellectual explicitly: "it was a very comfortable experience 'cuz these open-ended questions."

> *After I got over the fear of, like, "Oh, crap. I'm dumber than everyone," we all just got together. And we would fight these problem sets together…[W]e would all discuss with each other. We'd be like, "Alright, how do you think this problem is done? Why is this wrong? I'm not getting the right answer here, can you help me out?"*

The student above links a sense of connection with their peers (as united against the problem sets) with the work of disciplinary sensemaking ("Why is this wrong?").

> *…I felt like I was a little less motivated sometimes in my bigger classes. Because I knew what a small but hard—like small-sized but difficult class was like. [L. A.: Yeah.] So I almost always wished, "Wow, if my class was like this, and I knew my peers, and we talked about our ideas more with each other, and like talked about like the right and wrong parts of what we were thinking, like and worked through problems like that, I feel like I'd understand more and have to remember less in my classes.*

The student explicitly connects a kind of epistemic activity that could take place—talking about "the right and wrong parts of what we were thinking"—with the social connection of knowing their peers.

Again, our initial interest was to study the students' epistemologies. At first, we were challenged in that effort by comments such as these, which seemed to be as much about the students' experiences of social connections. Here, we cite them as evidence for our claim that these students' social caring supported their productive epistemological framing and our conjecture that this dynamic may have more general significance. In the next section, we describe how an account of epistemological framing provides theoretical support for the conjecture.

B. The dynamics of framing

The interview data suggest there was disciplinary significance of the BEST students' experience of social caring. Here we argue that significance makes sense: You may listen to someone because you care about them, and it is an act of caring to hear and understand what they have to say, and/or you may listen to someone because you care about their ideas.

The construct of *frames* came out of research in anthropology, linguistics, and sociology to describe "structures of expectation" [53] about what is taking place, evident in speech and behavior. Consider, for example, the student's saying in their interview, "Even if you were wrong, he seemed to value that," referring to V. D. The statement is evidence, first, of a baseline frame (structure of expectation) in which a physics teacher would not ordinarily value a student's being wrong, and second, a shift from that baseline in the student's understanding of this course.

Or consider the student's remark at the opening of the article: "I feel like we all were able to articulate ourselves in physics in such a different way that it didn't feel like I was doing it to just get the right answer". There is evidence both for the positive statement, "we were able to articulate," and for the contrast he expresses—his saying "in a different way" and "I didn't feel" are evidence of his awareness of default expectations for what would ordinarily take place. There is also evidence in people's actions. When V. D. sits to the side rather than stands at the front, it is evidence (for the students as for us) of his expectations for the activity.

Frames, like schemas, constitute "active developing patterns" (Ref. [54], quoted in Ref. [53], p. 16). As well, those patterns' activations as structure influence and are influenced by the situations and activities learners experience. We follow prior research on framing in PER in using the term *framing*, to emphasize these dynamics [55–58]. As in that work, we have been centrally concerned with understanding what can support the activation and stability of students' productive *epistemological* framing, that is their productive framing with respect to epistemic activity.

Our conjecture in this article builds on prior work showing entanglement of social behavior and epistemological framing, in collaborative groups during introductory physics [56] and among students and the teacher in a middle school science class [59]. The latter study focused on the entangled dynamics of two modes of activity in a classroom, one focused on student agency and reasoning, with the teacher sitting at the back of the room, and the other focused on the teacher's social and epistemic authority, with him standing at the front. The present article also builds on a study showing synergy between an epistemological framing and affect [60]. A student in a reformed physics class shifted in her epistemology in a way that supported and was supported by a shift in her affective response to uncertainty.

Here we propose that the experience of social caring supported students' framing their scholarly activity as focused on their sensemaking: Caring cues listening; listening sustains the epistemic activity. And we expect the support is mutual: Framing the activity as focused on each other's thinking would cue listening; listening would contribute to experiences of caring. Thus, with this construct of framing, we see social caring and engagement in scientific inquiry as a single dynamic. Stability in the activity of sensemaking arises from this dynamic because in any given moment, a student might listen to another out of caring, out of concern for the substance, or both.

V. DISCUSSION AND IMPLICATIONS

In summary, this was originally a study of whether a course designed to promote productive epistemologies had an effect on how the students approached learning in subsequent studies. The students in the course we chose were part of BEST, a cohort-based learning community, about to start their first year at a primarily white institution. We collected data during the course as part of the larger project [61] and interviewed the students the following summer. In analyzing the interviews, we found it difficult to disentangle evidence of epistemology from evidence of their experience of social caring, which motivated us to shift our focus.

Of course, feeling welcome and safe is helpful in many circumstances. Some scholarship has claimed, for example, that experiencing the threat of prejudice and stereotype can cause Black students to underperform. By this reasoning, helping students feel safe can reduce their feelings of stereotype threat, freeing students to direct more of their attention to the task at hand [62]. That is, if students feel socially comfortable, they can be more relaxed and focused on the intended work. In this article, we have argued for the possibility of a different, additional mechanism: Students' experiences of social caring may have specific disciplinary significance, through stabilizing their framing the activity of science as focused on their thinking.

First, we offer this as a contribution to research on epistemologies [34,63]. To be clear, we do not claim or believe that social caring is either necessary or sufficient for productive epistemological framing. Rather, we expect complex interactions among a variety of "elements of the activity system" [64], including "the type and extent of student authority present in a classroom", the "provision of relevant resources," and the instructor's relative focus on students' reasoning vs. the canonical correctness of their answers [30]. Our core finding is that social caring was *a supportive element* in this cohort of students' disciplinary engagement, and this motivates our conjecture that this finding may be applicable in other contexts as well. Our main point here is that interactions often seen both within class and outside of class as "off topic" may actually contribute to dynamics supportive of disciplinary substance.

Second, we offer a possible contribution to program design and postsecondary education reform. Social caring has long been an emphasis of CBLCs [18,19], including BEST, designed to promote academic success and persistence of students from underrepresented groups. As we discussed in the introduction, these programs generally operate as support systems outside of students' coursework. CBLCs have mostly assumed that instruction and disciplinary activity will take place as they have—with conventional curricula and pedagogy. Indeed, the selection by the BEST program of *this reformed version* of Physics 11 was not by design; it just happened that the person hired to teach the summer course was V. D., who approached and ran the course in a reformed way. This study suggests the possibility of synergy between the community emphasis of BEST and the epistemological aims of the course (i.e., cultivating students' disciplinary agency). It has motivated an adjustment to BEST, to make this reformed version of Physics 11 a deliberate part of the program, as well as to pursue reformed pedagogy in the mathematics course that students also take during their first summer.

Third, we suggest that this finding builds on the alignment we described in the introduction, between calls for reform and responsive teaching based on disciplinary considerations [9] and calls based on cultural considerations [1,21–26]. Our conjecture here would extend the alignment: Social caring has been an emphasis in culturally responsive teaching [21] (p. 92), but it has mostly been missing from work focused on disciplinary practices, with exceptions noted in mathematics [10,20] and literacy [12] education, all of which took place in contexts of attention to educational equity. Our study extends that perspective into university physics.

VI. CLOSING THOUGHT

A few years ago, Scherr and Robertson [65] suggested that canonical curricula and pedagogies of physics privilege western, white, male participation. Their article prompted an outraged letter to the editor [66], calling their ideas "nonsense" and contending that the changes the authors proposed meant sacrificing essential features of the discipline. We have witnessed concerns by some postsecondary faculty members about the present episode and others like it—that it would be clearer and more efficient for the instructor to present or validate the correct explanation.

We argue, with Scherr, Robertson, and other authors [67] that the goals of broadening participation are not at odds with but rather supportive of disciplinary rigor. If disciplinary practice means thorough, careful study of arguments, then, in the case we presented, social caring may have supported disciplinary practice. And if inclusion means the valuing of what each individual student brings to the doing of science, then, in the case we presented, a reformed science course designed to center students' own thinking may have supported inclusion. We locate the incompatibility rather between inclusion and a form of school science that emphasizes the reproduction of a narrow set of facts.

Calls for change in the curriculum and pedagogical thinking can sound outrageous, but that phenomenon is not particular to research in education; it is a hallmark of intellectual progress. Physicists are familiar with ideas seeming outrageous that had or come to have central roles in progress, from accounts of phlogiston or caloric (which today may seem outrageous), to the speed of light as independent of reference frame, to the nondeterministic, nonlocal theory of quantum mechanics. Of course, most outrageous ideas do not stand up to study, but the history of physics has shown, time and again, that productive new thinking can involve fundamental revolutions of thought [68].

Our closing thought is this: As we see social caring supportive of disciplinary progress in the classroom, perhaps it will also prove to be supportive of progress in the community. Ideas can seem outrageous, not worth serious attention and effort to grasp, but caring and respect for the *people* who are thinking those ideas might contribute to our stability in productive inquiry.

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