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Respecting tutorial instructors' beliefs and experiences: A case study of a physics teaching assistant

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Effective physics instruction benefits from respecting the physics ideas that introductory students bring into the classroom. We argue that it is similarly beneficial to respect the teaching ideas that novice physics instructors bring to their classrooms. We present a case study of a tutorial teaching assistant (TA), Alan. When we first examined Alan's teaching, we focused our attention on the mismatch between his actions and those advocated by the TA instructors. Further study showed us that Alan cared about helping his students and that his teaching was well integrated with his beliefs about how students learn physics and how teachers can best assist students. Learning about Alan's beliefs and motivations changed our thinking about what might constitute effective professional development for Alan and other TAs. We advocate a new perspective on TA professional development: one in which TAs are seen as partners in the endeavor of educating students and one that seeks to find and build upon productive elements in their beliefs.

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I. INTRODUCTION

As teaching assistant (TA) supervisors, we often find that we focus on the aspects of TAs' teaching that are inconsistent with our expectations about reform teaching. However, when we examine TAs' teaching with more knowledge about their experiences and beliefs, we find that their actions here are not ignorant but rather informed by reasonable thought-out epistemological beliefs and expectations for teaching.

Effective physics instruction benefits from respecting the physics ideas that introductory students bring into the classroom. In what follows, we will argue that it is similarly beneficial to respect the teaching ideas that novice physics instructors bring to their classrooms. We advocate a new perspective on TA professional development: one in which TAs' ideas about teaching are taken to be rich, sensible, and potentially productive.

As we conceive it, a respectful approach to TA professional development (PD) has two primary aspects: (1) treating TAs with courtesy and (2) looking for productive seeds in their beliefs and practices. By the first, we mean that TA instructors should treat TAs as partners in the endeavor of educating students—as thoughtful young professionals who care about doing their jobs well and whose decisions about teaching have a reasonable basis in their beliefs and past experiences. The second aspect is that TA instructors benefit from identifying their TAs' epistemological and other views upon which professional development can productively be built.

This paper presents a case study of one TA, Alan, which shows how improving our understanding of his beliefs and motivations changed our thinking about what might constitute effective professional development for him. We do not attempt to present particular elements of a program for TAs nor do we advocate a significant reallocation of resources within TA training programs. Instead, we are calling for a different approach to be used within existing programs by providing an example of how this perspective could be applied.

II. PREVIOUS RESEARCH ON TA PD

A. There is only limited research that could inform TA PD

Although graduate students have been partially responsible for physics undergraduate instruction for decades, little published research addresses the nature or effectiveness of professional development offered to graduate students who are TAs in physics or other science departments. Some TAs participate in workshops focused on topics such as classroom management.[1,2] TAs can take courses that are department specific and offer instruction in pedagogical content knowledge and constructivist learning theories.[3–6] Surveys or interviews are sometimes used to demonstrate changes in beliefs or conceptions, but because the TAs' classes are not regularly observed, there is no way to see how or if these courses affect TAs' teaching.

B. Professional development offered to science TAs is rarely responsive or explicitly focused on treating TAs as partners

Since TA PD research has frequently assessed effectiveness through surveys, interviews, and written assignments administered at the end of the PD program,[4,5,7–9] it is difficult to know whether the PD has been responsive to the ideas and experiences TAs bring in. While it is possible that some PD instructors have modified their instruction based on the ideas they hear from TAs during instruction, we can find no explicit discussion of this phenomenon in the literature.

There is also little evidence to address the question of whether TAs are treated courteously (i.e., as partners in educating students), but informally we observe that faculty often consider TAs to be either blank slates or bearers of misconceptions. Work that exemplifies the type of courtesy we advocate is found in Speer's study[10] of the fine grained differences between two mathematics TAs' belief and practices, in which the TA instructor works to develop a shared understanding of the TAs' beliefs and practices with each TA. Seymour[11] discussed ways to encourage respect (which she terms collegiality) among TAs and TA instructors and used a case study to demonstrate how increased collegiality resulted in increased TA engagement and support for reform teaching practices.

III. DATA AND METHODS

A. Larger project: Understanding graduate TA tutorial teaching

The data discussed here were collected as part of a larger project that sought to characterize and explain the teaching practice of physics graduate students who were assigned to teach tutorials in introductory physics courses. During their discussion sections, the TAs taught using tutorials developed at the University of Maryland (UM). Tutorials are worksheets that support students' conceptual development through collaborative learning.[12]

The Maryland students using these tutorials are mostly juniors and seniors majoring in the health and life sciences. A significant portion of the students are premed students. More than half are female, and there is wide ethnic diversity.

During the semesters we collected data, the tutorial TAs were mostly first-year and second-year physics graduate students. All the TAs we observed were male. Almost half spoke English as a second language, but all except one was fluent.

During the fall semesters of 2006 and 2007, we asked all the tutorial TAs to participate in this study. Those who consented were interviewed at the beginning and end of the semester they taught. Interviews were audio taped and transcribed. In addition, we selected about a dozen classes to be regularly taped based on researcher convenience rather than classroom or TA attributes (though we ruled out nonconsenting TAs' classes). We also videotaped two weekly PD meetings.

B. Alan: A TA with well-articulated ideas about teaching

1. Choosing Alan

The particular TA selected for this case study, Alan (a pseudonym), is typical with respect to many of the demographic characteristics discussed above. He was a first-year graduate student with no previous experience as a classroom instructor but had tutored students in math and physics. He was a non-native speaker of English, but his English was excellent. He often participated in the discussions held in the weekly tutorial preparation meetings. Also, as we have found with other TAs,[13,14] patterns in his teaching seemed connected to his views about teaching and learning expressed in interviews.

Alan was one of the six "focal TAs," who we studied in greater detail than most of the UM TAs who participated in this project, based mostly on availability of classroom videotapes. We chose him for this particular study because he was exceptionally articulate in his interviews and during PD meetings. It was important to him to convey his ideas about tutorials to the interviewer: he brought a tutorial book with him to his first interview so that he could point out specific examples of curricular decisions with which he disagreed.

We taped Alan in two classes each week, yielding 48 hours of classroom video. Each class had two four-person tables that were taped by stationary cameras. So, Alan was recorded for a small fraction of each hour when he interacted with a recorded student group. Of the 48 hours we taped, we have watched and analyzed 14 hours of classroom video, which included approximately 40 interactions between Alan and students. For this paper we selected episodes that we thought illustrated different aspects of Alan's classroom behaviors and represented his teaching overall.

2. Analyzing Alan

When characterizing Alan's teaching, we did not try to fit his work into predetermined categories. Instead, we watched multiple episodes of his interactions with students, seeking to describe and generate plausible explanations for his actions. We continued to watch episodes until we reached saturation, at which point we could explain new observed behavior by what we had already learned about Alan from his interviews and from previous video observations.[15]

We used the data from Alan's two interviews to generate our descriptions of his beliefs. When we refer to Alan's *beliefs*, we mean his declarative knowledge about teaching and learning in the context of introductory physics. While others have carefully distinguished beliefs from goals and knowledge, these distinctions are not critical for our argument.

To create descriptions of Alan's beliefs, we read through the transcripts of the interviews and identified excerpts that seemed to reflect Alan's views about teaching and learning physics. These statements were often about his own role as an instructor, the strengths and weaknesses of the tutorials, and what his students "should" be doing. We organized these statements into larger categories that we termed beliefs. For example, Alan's desire for his students to spend more time on quantitative problem solving and his statement that physics provides "extremely powerful machinery" to calculate precise results are both evidence of his belief that quantitative calculations are an integral part of physics.

Identifying Alan's beliefs from his interview data and generating plausible explanations for his practice occurred in tandem. We then used both of these analyses to create narratives of how Alan framed individual interactions with groups of students and how his beliefs supported these framings.

C. Professional development that Alan experienced

Alan was expected to attend three different types of professional development during the semester we observed him.

Physics education researchers ran all three programs. The first was part of a three-day orientation offered to all incoming physics graduate students. The portion devoted to teaching preparation lasted about 6 hours. It introduced the idea of physics education as a scholarly activity and provided practical advice about grading and classroom management. The second was a weekly preparation meeting attended by all tutorial TAs. During this hour, TAs would spend about half the time discussing issues that had arisen in the previous week's classes and half the time working through the tutorial for the upcoming week. Alan also attended ten weekly teaching seminars that all first-year physics TAs were required to attend.

The weekly tutorial preparation was originally intended to be an hour in which TAs worked on the upcoming tutorial in small groups, as their students would. This is the model used at other universities that use the tutorials developed by the University of Washington Physics Education Group.[16] The tutorial supervisor during the year Alan taught was one of the authors (Scherr). Noting that this group of TAs often grew restless after working on the tutorial for half an hour, she modified the weekly schedule so that the TAs spent the first half hour discussing issues from the previous week's teaching and the second half hour working through the tutorial. This allowed for a guided discussion of issues that were important to TAs (because they raised most of the ideas themselves), such as specific student difficulties the TAs noticed or what they thought students should be learning in tutorials.

IV. ANALYTIC FRAMEWORK

People do what they do because it makes sense to them based on their past experiences. Our framework attempts to embed a deep respect for novice instructors' existing beliefs and prior experiences, seeing them as the essential material from which expert conceptions of teaching are constructed. Members of the physics education community have long taken this perspective regarding learners' physics ideas,[17–21] with the benefit that we can identify ideas that can be the basis for effective constructivist instruction.[22] Our analytic framework extends this fruitful perspective to professional development.

A. Conceptual and pedagogical resources

In a familiar example, in response to questions about a large truck hitting a small stationary car, many students respond that the truck must exert a greater force on the car than the car exerts on the truck. If we were to think of this response as stemming from a stable, coherent, incorrect conception, then we might use it as a basis for inferring that students do not know or do not believe Newton's third law and that they believe instead that more massive or more active objects exert larger forces in collisions.[23,24] A resources-based account, however, suggests an alternative interpretation: students trying to explain the fact that the *car reacts more* frequently map "reaction" to "force" (which is, after all, the quantity often prompted by the question) and conclude on the spot that the force on the car must be greater.[25] This answer, though incorrect, contains the seeds of expertise: the car *does* react more, after all, if we interpret the reaction as being its acceleration rather than the force it feels. What is more, although the force on the car is the same as the force on the truck, the force on a *person in the car* is greater than the force on a *person in the truck*. Since in this scenario it is compelling to imagine oneself inside one of the vehicles, students may thus be answering an important question correctly, though not the question that was asked. Physics instructors can therefore reinforce students' existing conceptual understanding, while helping them discriminate among closely related concepts and questions.

A resources framework can be used to model pedagogical knowledge as well as conceptual understanding. If we see TAs teaching in a manner that we judge unfavorably, we strive not to see that as indicating knowledge that TAs lack or monolithically wrong ideas that TAs hold about teaching. Rather, we try to identify resources that the TAs have for teaching, which may be being misapplied in predictable ways in certain teaching situations. For example, some TAs ask questions that may be inappropriately broad (such as "How does circular motion occur?") or unhelpfully rapid. We see these TAs as comparable to physics students who say that the force by the truck is larger in a collision: although the specific application of the idea may be unhelpful in the situation at hand, it may yet contain the seeds of expertise. Broad questions, for example, are consistent with an intention on the part of the TA to leave the student room to develop their own line of reasoning, and rapid questions can model a line of reasoning for the student. Professional development for TAs can reinforce these laudable aims while helping the TAs discriminate among situations in which various teaching strategies—many of which are already in their repertoire—are likely to succeed.

B. Epistemological framing

A TA such as Alan, who has many pedagogical resources, decides what to do in a particular teaching situation based to a great extent on his understanding of the nature of the situation. *Framing* is a construct developed in anthropology and linguistics to describe how an individual or group forms a sense of "What is it that's going on here?"[26–28] To frame an event, utterance, or situation in a particular way is to interpret it based on previous experience: to bring to bear a structure of expectations about a situation regarding what could happen, what portions of the information available to the senses require attention, and what might be appropriate action. Both students and TAs naturally use information from their prior experiences in school to inform their framing of present course activities. For example, if students' and TAs' prior experiences have emphasized rote learning, even activities intended to promote intuitive sense making may be interpreted as occasions to fill out a worksheet. That does not mean, however, that students do not have sense-making capabilities or that TAs do not care about sense making. Only by helping the students and TAs epistemologically reframe their activity—change their sense of "what is going on here with respect to knowledge generation" in physics discussion section—can we fully tap into the students' and TAs' resources for doing and supporting sense making.[29]

A group's framing of an interaction stabilizes when the individual ways of framing (epistemological and otherwise) reinforce each other. We will see below, for instance, that Alan often frames *assisting students* as *giving them information*. His students' behavior helps to stabilize this framing: they expect help, listen attentively, ask questions to clarify what he is saying, and direct their attention to him. These actions reinforce Alan's idea that unambiguously answering their question is the right move. So, the stability of the framing stems not just from Alan's beliefs but from those in-the-moment interactions with his students.

We identify framings by examining verbal and nonverbal interactions, including linguistic signals and body language.[19,30–33] Having identified a possible framing for an interaction, we look for confirmatory and disconfirmatory evidence within the interaction and also across other similar interactions in our Alan video, iteratively refining our story. As a final step, we triangulate our framing attributions with the beliefs expressed in interviews; however, we do not assume that the TA's classroom behaviors will be fully consistent with those beliefs.

Framing plays two distinct roles in this paper. First, we use framing analysis to characterize Alan's interactions with students, as just described. Second, the point of this paper is to show how we, as researchers and TA professional developers, reframed our analysis of Alan's teaching during this project and to encourage others who work with TAs to reframe their PD along similar lines. When we began analyzing Alan's teaching, our unspoken answer to the question "What is it that we are doing here?" was "We are looking for places where Alan's teaching needs to be improved." This led us to concentrate on what Alan was doing wrong. When we reframed our analysis, the answer to the framing question became "We are respectfully making sense of why Alan does what he does." In contrast to the previous answer, this way of framing our activity focuses our attention on why Alan's teaching practice is reasonable to him. Thus, our reframing of our analysis caused us to shift our attention from Alan's "teaching errors" to Alan's underlying beliefs and motivations and the productive seeds in his beliefs and behaviors.

V. CONTRASTING OUR INITIAL ANALYSIS WITH A RESPECTFUL ANALYSIS OF ONE TA'S TEACHING

In this section we discuss how our view of Alan changed as we learned more about his beliefs. First, we present two episodes of Alan teaching tutorials and our early interpretations of his teaching when we primarily focused on the ways his teaching failed to meet our expectations. We then describe Alan's beliefs about physics and how it should be taught, drawing on his interview data. Lastly, we reexamine the tutorial episodes to show how a respectful interpretation can help us better make sense of his teaching decisions. Section VI will discuss how this could be used to improve the PD we offered him.

A. We'll start with a new question. Suppose the truck's mass is 2000 kg while the car's mass is 1000 kg, and suppose the truck slows down by 5 m/s during the collision. Intuitively, how much speed does the car gain during the collision? (Apply the intuition that the car reacts more during the collision, keeping in mind that the truck is twice as heavy.) Explain your intuitive reasoning.

B. Does your answer to part A agree with Newton's third law? To find out, we'll lead you through some quick calculations.

1. Suppose the car and truck remain in contact for 0.50 seconds before bouncing off each other. Calculate:

i. the truck's acceleration during the collision.

ii. the car's acceleration during the collision (assuming your guess about its change in speed is correct).

FIG. 1. An excerpt of the tutorial on Newton's third law.

A. Critique of Alan: Interpreting Alan's actions in terms of our values and beliefs

1. Episode 1: Alan constrains the conversation and fails to elicit student ideas

This episode occurred during the third tutorial of the year, which helps students reconcile the idea that two colliding objects (truck and car) each feel the same force (Newton's third law) with the "common-sense" idea that the car reacts more. The tutorial begins by asking students to use their common sense to generate a guess about which vehicle experiences a greater force during a collision. After doing so, they apply Newton's third law to the situation and observe two carts with force probes colliding as a demonstration of Newton's third law. The tutorial then poses the questions excerpted in Fig. 1. A correct answer to part A is that the car gains 10 m/s because it weighs half as much as the truck and therefore reacts twice as much. In part B, the students are asked to calculate the truck's acceleration and the car's acceleration. The truck's acceleration works out to be $a=\Delta v/\Delta t=(5\ \text{m/s})/(0.5\ \text{s})=10\ \text{m/s}^2$.

The TA-student interaction begins when Student 3 raises her hand and calls Alan over to ask about the truck's acceleration. Alan asks them what the definition of acceleration is and then what the change in velocity and change in time are. The students calculate the acceleration and Alan suggests that they can use the same method to find the car's acceleration.

1 Alan: Hi, what's going on?
2 S3: Um, what's the, what happens to
3 the truck's acceleration during the
4 collision?
5 Alan: Okay, so you want to compute
6 this acceleration during the collision,
7 right?
8 S3: Right.
9 Alan: So, what is the definition for
10 acceleration? If you don't know
11 anything, just try using the definition.
12 What's the definition of acceleration?
13 S4: [inaudible] over time
14 S3: Distance…
15 S2: [inaudible] Over feet time
16 squared
17 S3: The change in velocity over time.
18 Alan: Right. So it's change in velocity

19 divided by the change in time. Or the
20 time that it took for the velocity to
21 change. So in this case, do you guys
22 know from other things they've said,
23 how much the truck's velocity
24 changed?
25 S2: Yeah, five-
26 S1: Is that five…
27 S3: five meters-
28 Alan: Five meters per second-
29 S2: Yeah.
30 Alan: -Right, so it changed five meters
31 per second. And how long did it take
32 for it to change?
33 S3: A second. Sss.
34 S2: Half a second.
35 S3: Point five.
36 Alan: Half a, half a second, right? So
37 now you know the change in velocity
38 and the change in time. You can get
39 the acceleration from… Right?
40 S2: Like I said-
41 S3: So its-
42 S1: Ten.
43 S3: Ten. Is that ten?
44 Alan: Yup. Yeah, five divided by a half
45 is ten.
46 S3: Ten, ten meters
47 Alan: Ten meters per second squared
48 is the acceleration. Do you see how I
49 arrived at that?
50 S1: Yeah.
51 S2: Yeah.
52 S4: Take five meters and divide it by
53 the time.
54 Alan: Okay, so then the next thing you
55 can also do using the same idea.
56 S1: All right.

When we first watched this episode, we focused on Alan's decisions with which we disagreed. For example, the questions he asks constrain the conversation, so that the students have fewer opportunities to bring up difficulties or questions they have. Each student participates in the conversation to varying degrees, but Alan's conversational turns are the longest. Alan's gaze is usually on one of the students, but their gazes are mostly on Alan or the papers on their table, not on each other. Thus, the students' attention is not on each other's ideas.

Alan also fails to elicit students' ideas in this episode despite the tutorial's emphasis on eliciting and refining students' common-sense thinking. When S2 asks her question (lines 2–4), he uses that question to diagnose what their problem is and he does not ask anything else to check if his assessment is correct. He also does not seek student ideas that he could build on: he does not ask what the students have already tried or whether there is some part they do understand.

Alan makes additional assumptions when determining whether the students understand what he is doing. After his explanation, he asks if they understand how he calculated the acceleration (lines 48–49) and leaves soon after they say yes. The students may follow what he did, but Alan does not have a lot of evidence of the depth of that understanding because he allowed few opportunities for students to make mistakes or discuss their thinking.

I. "Timmy's fallen down the well!"
To rescue a child who has fallen down a well, rescue workers fasten him to a rope, the other end of which is then reeled in by a machine. The rope pulls the child straight upward at a steady speed. The child weighs 250 N, which means gravity pulls him downward with 250 N of force.

[Two pages of the tutorial are omitted.]

5. It makes sense that, if the rope force remains greater than the gravitational force, the child keeps speeding up; and if the rope force becomes less than the gravitational force, the child slows down. By this line of intuitive reasoning, what happens to the child's motion if the rope force *equals* the child's weight, *i.e.,* if the rope force "compromises" between being greater than and being less than the child's weight? Explain.

FIG. 2. Two excerpts of the tutorial on Newton's second law.

2. Episode 2: Alan directs the conversation and neglects student ideas

The fourth tutorial Alan taught helped students reconcile the common-sense idea that force causes motion with the Newtonian idea that a net force is needed only to *change* an object's velocity. The tutorial considers a child on a rope being reeled up at steady speed from a well. The students are led to see that some of their common-sense ideas conflict with Newton's second law. They then consider what would happen, once the child is already moving, if the upward force of the rope were greater than the child's weight or less than the child's weight. In the excerpt below, the students are working on the next question, shown in Fig. 2. A correct answer to question 5 is that if the rope force "compromises" between being less than the child's weight (which makes the child slow down) and being greater than the child's weight (which makes him speed up), then the child will "compromise" between slowing down and speeding up: he will move at a constant speed.

As Alan approaches, S1 calls him over and asks him whether a child who is not accelerating would experience no force and no movement. Alan discusses the forces and accelerations of an object in a series of examples: first, a stationary object that has equal forces, which does not move; then an object feeling an upward force greater than gravity, which would accelerate; and finally one which is being pushed up with the same amount of force as gravity, which would not accelerate. Alan points out that in the final situation, the object will move at a constant speed.

1 S4: That's what we were ask-, this is
2 the same question as here.
3 Alan: Hmmm? Yeah, okay, go, so ask
4 your question.
5 S4: So net force is zero.
6 S1: So, there's no acceleration? And
7 there, does that mean there's no force
8 too? So does the child stay still?
9 S4: There's no net force.
10 Alan: Well-
11 S4: Like-
12 Alan: [inaudible]

S2: It doesn't stay still, it moves at a constant velocity.
S1: It's still moving?
S4: But it could be either, like if it were, if it wasn't moving, if the kid wasn't moving, and this equaled this, then he still wouldn't move. Like, it just means that there's no change in velocity. Sorry, go ahead.
Alan: So, no, no. Okay, so, so if um, how shall I put this? Suppose something is sitting still. Suppose I try to push, pull up on it, push up on it. With a force, with a force that's less than is holding it down. The force of gravity.
S1: It wouldn't go anywhere.
Alan: It wouldn't go anywhere, right? Suppose I push up with exactly the same force, it still wouldn't go anywhere.
S1: Yeah.
Alan: The force on it is zero, its acceleration is zero, it's not moving, right?
S1: All right.
Alan: However, suppose I push up on it with just a bit more force than necessary to lift it. Just a bit more force than the force of gravity. It's going to accelerate.
S1: Uh-huh.
Alan: And then suppose I get lazy and I start pushing only as hard as gravity's pulling it down.
S3: [inaudible]
Alan: So, I got it moving. Its acceleration changed from zero to say one meter per second.
S1: Mm-hmm.
Alan: In a, in over a second.
S1: Uh-huh.
Alan: And then I only started pushing just as hard as gravity is pulling it down. At this point it's not going to accelerate any more. Which means that it's going to keep moving with the speed it had before I stopped accelerating it.
S1: Okay.

a. Alan focuses exclusively on answering S1's question. This episode begins when S1 calls Alan over in the middle of a group discussion about whether the child can be moving if the net force on him is zero. Alan asks what her question is and then he works on answering the question she has asked. In doing this, he ignores the other students' ideas. One example of this occurs at the start of the episode. When S1 calls Alan over, he immediately approaches and leans over the table to read their papers. After S1 asks her question, Alan straightens up and steps back, directing his gaze at them rather than at the paper (line 10). At this point he is interrupted and he continues to stand about a foot away from the table. When S4 indicates that she is done speaking (line 21), he steps closer to the table and stands in front of S1. During S4's explanation, Alan has separated himself both physically and mentally from the conversation; he has stepped away and he does not respond to any of the statements between the interruption and when he speaks again. Alan has interpreted his job during the encounter as answering a question, so he spends the rest of the time answering it.

Discussing the previous episode, we noted that Alan failed to elicit student ideas. His misstep here is greater, from our perspective, because he is ignoring ideas that the students have voiced. In this case, S4 discusses her idea that no force just means no change in velocity (lines 16–21), which is correct, and could be expanded to include the idea that if the child were already moving he would stay moving. In addition, S2 asserts that the child is moving at a constant velocity (line 13–14). Alan does not seem to notice either of these potentially useful ideas. After Alan leaves, S2 also notes that her idea was the same as Alan's.

Alan directs this conversation by providing a series of examples to demonstrate the steps in his reasoning. His final conclusion is the answer to S1's initial question "Does that [no acceleration] mean there's no force too?" The fact that Alan is guiding the conversation comes through in the length and type of conversational turns. He introduces all the examples and receives a confirmation after each one. The students support his framing of this activity: S1 affirms that she follows each step, and S2 and S4 remain quiet, sometimes looking at Alan and sometimes looking away, which is consistent with the group's shared understanding that Alan's explanation is aimed mainly at S1. Once Alan begins his series of questions, no student introduces an idea or asks a question even to clarify.

When Alan directs the conversation so strongly, it prevents him from doing things we would like him to be doing. Alan does not provide an opportunity for the students to give him feedback about whether he has correctly identified their difficulty. There is also no chance for the students to demonstrate whether they understand the idea by applying it. Alan is conveying, through his actions, that tutorial is a time when students can get help answering questions. We, in contrast, want the students (and Alan) to see the tutorial as a time when students construct knowledge together, even when the TA is present.

b. Alan misjudges students' skill level. Alan's actions also convey a different understanding of his role than what we would prefer. We want tutorial TAs to see their job as that of a guide, figuring out the students' ideas and helping them make connections between their current thinking and the physics concepts. Alan, by contrast, elicits little information about students' thinking before or during his interventions. As a result, he may in some cases credit students with more skills or propensities than they have, for seeking coherence and for connecting mathematical equations and operations to physical meaning.

B. Alan's values and beliefs about tutorials

We began to appreciate Alan's thoughtfulness as an instructor when we understood his ideas about teaching and learning. This section will explain some of his beliefs that we think most influenced his teaching in the clips presented here: his assessment of the tutorials' ineffectiveness, his view of his role, and his belief that an instructor should be generous when assessing understanding.[34]

1. Alan thinks that tutorials should help students with traditional problems

Alan was concerned that the tutorials' conceptual focus was not providing the help his students needed. He felt that his students could often understand the concepts and do computations, so the problem was in putting the two together: "I don't think it's the math that's holding them back. It's the translation of intuitive ideas into algebra and then also just dealing with intuitive ideas and putting them together in various ways." Thus, the tutorials were not helping students develop a skill that he recognized as one needing a great deal of instructional support.

The tutorials' focus on conceptual reasoning also prevented Alan's students from being exposed to the predictive nature of physics computations and the cohesiveness of the theories. More than once he complained that tutorials presented equations as if they simply came into existence rather than showing how they stemmed from more fundamental laws. He also felt that students were not seeing one of the most important features of physics, the ability to quantitatively predict what would happen to physical systems.

Alan's prioritizing quantitative reasoning aligns with the ways his students were assessed. Tests and homework emphasized quantitative problem solving. Alan noticed this mismatch, saying, "I'm seeing a lot of frustration from my students, about the homework and what they're being graded on and the fact that this [tutorials] is not [like their tests]." Alan viewed the mismatch between what the tutorials were asking the students to do and what the students were being graded on as unfair. Alan's concern that tutorials did not prepare students for their tests was separate from his belief that tutorials did not teach important aspects of physics as a discipline. However, both supported the same conclusion that tutorials did not meet students' needs.

2. Alan treats his students as epistemologically sophisticated equals

Alan compared his role of a tutorial TA to that of a "fifth group member who… has taken the course before… and who happens to know everything, you know, and so you can ask him." This analogy is consistent with the method of guidance Alan uses. Alan might explain a problem to a fellow graduate student and then expect that she would work to really understand that solution herself; he expects his tutorial students to do the same.

Alan often drew upon his past experiences as a learner when deciding what is appropriate and useful for his students. For example, he explained that it is frustrating for students when a teacher expects them to be wrong. At that point, he discussed memories of his correct answers being marked wrong in high school because they were not in the form the teacher wanted. He also noted that, once he has wrestled with a problem, he is ready for direct instruction and would feel annoyed if the instructor provided only hints and guidance. While Alan knew that his students were novice physics learners, he drew on his experiences as someone who excelled in physics when determining what would help his students learn. In brief, he treated his students as he would want to be treated.

3. Alan thinks teachers should give students the benefit of the doubt

Alan's assessment that students can be frustrated when tutorials expect they will answer incorrectly is part of a larger belief about how he should treat his students. Alan thinks it is important to give students the benefit of the doubt, a theme we see in many of his statements. When a student asks a question, he thinks the teacher should assume that student has already thought carefully about the problem. Alan also objected to the tutorials' common tactic of eliciting a common-sense idea that will need to be reconciled with a physics concept. He cited an example:

> "And then the whole rest of the tutorial assumes that they screwed up. So basically, it assumes that they, I mean, they were stupid… I'm seeing that every time I do the tutorial, there's at least one group every time, who doesn't make the stupid mistake. And then they feel, actually, kind of offended."

In Alan's view, such an assumption not only demeans a student who originally had the correct answer but can also cause her to be confused about something she initially understood.

Through our interviews, we came to see Alan as a TA who thought deeply about the tutorials he taught and had identified substantive differences between his expectations and those of the tutorials. He was frustrated that students using tutorials could not connect qualitative and quantitative reasoning as well as he expected. He strove to help students so they did not unnecessarily struggle. Lastly, he held a principled view that it is wrong for instructors to assume students do not understand.

C. "Co-construction" as an alternative to confrontation

One pedagogical approach to changing Alan's beliefs might be to challenge his beliefs by presenting him with evidence that some are not appropriate or useful in the classroom. This would be similar to the "elicit-confront-resolve" (ECR) approach that has been used with students.[35] If a TA has such a well-established belief that it is evidenced in both his behavior and his reflections about teaching, then that belief should be stable enough so that a TA could explicitly compare the belief to evidence. This would allow him to discover the belief's shortcomings.

There are several difficulties using ECR in TA PD. One is that the subject matter is students, not the physical world. In physics, we can devise, for example, an experiment-based instructional sequence to convince most students that, for example, charges are not "used up" in a bulb.[36] By contrast, teaching involves maneuvering through situations that involve numerous variables, including different students, varying topics, and individual instructor differences. This makes it difficult to present evidence that TAs' particular beliefs and behaviors are problematic. For example, when TAs are confronted with evidence that lecturing is less effective than facilitating collaborative active learning, it may be difficult for them to determine whether the shorter "minilectures" they would give in tutorial are also likely to be ineffective. Some TAs we have talked to agree that lecturing in large classes is ineffective but also state that tutorials provide the opportunity for students to hear short focused explanations addressing their particular difficulties. More generally, it is almost always possible to "explain away" evidence that one's teaching is ineffective. A second reason to reconsider using ECR in TA PD is that it can be difficult to treat TAs as partners in the endeavor of educating students while simultaneously confronting their beliefs as "wrong." Confrontation makes it more difficult to establish an environment of openness and trust in which TAs can discuss their difficulties and rethink their teaching practices without becoming defensive.

We are suggesting an alternative to ECR, called co-construction. We use the term to refer to professional development in which the TA instructor and the TAs seek to understand each other's ideas about teaching with the stance that everyone can learn from each other. People *can* change the way they think about teaching and learning, but we think that confrontation is an inappropriate instructional strategy. We want to emphasize that co-construction allows for disagreement among participants. We do not advocate giving approval to each and every TA behavior. However, ECR does not provide an avenue for authentic disagreement and argumentation. Rather, it marches TAs along a line of reasoning carefully structured to show the inadequacies in their beliefs. Co-construction provides a means for TAs and TA instructors to authentically discuss differing positions, with the goal of improving teaching practice.

D. Courtesy to Alan: Interpreting Alan's actions in terms of his values and beliefs

In this section, we reexamine the two episodes of Alan's teaching presented above, with the goal of understanding how his actions align with the beliefs that we have just discussed. In Sec. V E, we will then show how this understanding can help us identify productive resources that Alan has, which can be used as a basis for more responsive PD.

1. Reinterpreting Episode 1: Alan helps his students get "unstuck"

Alan's efforts to help these students solve the acceleration problem align with his beliefs about what should be happening in tutorial. Because Alan is concerned that tutorials do not allow students to translate conceptual ideas into algebra, he is demonstrating how to do that. He is helping them do a quantitative problem, which is a part of physics he particularly values and which will help prepare students for typical homework problems. This action fits with his belief that it is important to assume students who have asked for help are ready to benefit from direct instruction and that he should not assume students are confused about basic conceptual distinctions such as velocity versus acceleration.

In this episode, Alan gets feedback from the students indicating that his behavior is expected and desired. Like Alan, the students know that quantitative problems form the bulk of their homework. S3 has indicated that the students need help. Alan is providing this help with an explanation, and they endorse this by answering questions when he asks them, focusing their gaze on him and not introducing any other ideas. In this way, a shared framing of the situation becomes stabilized: the students ask for help to get unstuck, and Alan provides it. Thus, the students are satisfied that they have an answer and Alan is satisfied that he has helped them.

2. Reinterpreting Episode 2: Alan gives a direct answer to a challenging question

Alan's behavior in the episode makes sense given his beliefs. He sees his job as helping his students complete the tutorials, here by helping S1 understand why something can have no net force acting upon it and yet be moving. Alan considers this a challenging question, as evidenced by his pause before answering and by his detailed multistep explanation. Moreover as discussed above, he believes he should assume that the students have wrestled with the ideas themselves before asking the instructor, rendering the students ready to benefit from direct instruction and leading to frustration if they do not receive it.

In light of these beliefs, Alan's actions are a sensible and sensitive response to the students' needs. He helps his students by providing a detailed explanation. The answer involves multiple steps of reasoning, reflecting the conceptual difficulty of the question. He periodically checks in with S1 to make sure she is following the explanation, and Alan gives that student the benefit of the doubt about being able to assess whether she understands the explanation.

In contrast to the previous episode, the students in this episode vary in their support of Alan's framing. Although Alan sees his job as answering a question, only S1 acts in a way that encourages him to do so. S1 shows Alan that she is listening to his minilecture with affirmations. By contrast, S4 interrupts Alan to express her reply to S1's question (lines 11 and 16–21), and neither S2 nor S4 talks to him except to apologize for interrupting him. However, S2 and S4 provide only minimal feedback to Alan that they do not endorse his actions; his failure to pick up on those cues reflects his attention to S1, whose question he is answering.

Our reanalysis of Alan's actions renders them more understandable and sympathetic. In both of the episodes, Alan acts in alignment with his beliefs that connecting qualitative and quantitative reasoning is important, that students should have their question answered and which students should not unnecessarily struggle. We see that Alan is striving to teach the parts of physics that he thinks are important and that will help students succeed in the class. His intentions are admirable. Still, his teaching differs from what the tutorial developers intended. Section V E will discuss the productive seeds in Alan's beliefs and actions upon which PD can build.

E. Productive seeds for professional development

We know the professional development that we gave Alan had little effect on him because neither his beliefs nor his actual teaching changed over the semester. As we have shown, Alan's teaching is rooted in his beliefs about what physics should be taught and what help is appropriate for his students. He is unlikely to embrace PD that admonishes him to discard these beliefs. What we can do, however, is offer PD that builds on productive seeds in his beliefs and thereby encourages beliefs and practice that are more appropriate to reformed physics instruction.

1. Alan's view of his students

One area in which we see productive seeds is Alan's view of his students as having resources for epistemologically sophisticated learning, in contrast to the instructional view that students are dim or unmotivated. In particular, the way in which he checks his students' understanding is consistent with an assumption that they are capable of monitoring their own understanding. This is better than a teacher's stance that only the teacher can judge student understanding. We agree with Alan that students are capable of monitoring their understanding and engaging in sophisticated learning behaviors (constructing causal stories, seeking coherence, etc.); however, we think students do not always deploy these resources in physics class because they do not consistently frame their activity as sense making. In order to make Alan's generous estimation of his students' abilities more productive, we might show video of students shifting between sense making and "getting through the worksheet" and engage Alan (and other TAs) in discussions of when and how the students are engaging in sophisticated learning.

2. Alan's view of his job

We can also identify productive seeds for PD in Alan's desire to "do right" by his students. In both episodes, Alan has interpreted his job in the moment as answering a question, and he does not leave until he feels the students understand the answer. While we do not agree that his direct instruction was necessarily effective, his teaching decisions align with his desire to help his students. Responsive professional development would build upon Alan's desire to help his students do well by, for instance, engaging him in reflective discussions with other TAs about how to help students become better learners.

3. Alan's view of small group activities

We also see a productive seed in Alan's assessment of traditional discussion sections, in which TAs typically work problems at the board in front of students. He says that they are only occasionally helpful for students, such as when they have prepared by completing the homework before the section. "I'm not surprised that people don't learn much from it. You just kind of tune out. Um, making [the students] do it would be good." Instead of a TA lecturing, he agrees that group work is more effective because students can build on each other's good ideas and catch each other's mistakes. We can see that Alan is already convinced that traditional discussion sections offer limited opportunities for student learning. His recognition of the need for reformed methods of instruction and the usefulness of group work for student learning are productive resources; PD can focus on how to help student groups work more effectively.

Looking at Alan this way allows us to see beliefs he has that could be the basis for more effective professional development. Section VI examines what changes could be made to make Alan's PD responsive.

VI. RESPONSIVE TA PROFESSIONAL DEVELOPMENT

Responsive PD is made possible when TA instructors create opportunities for TAs to express their beliefs and opinions and then tailor the PD to address them. In addition, TAs need to feel that they are responsible for their teaching and that their contributions are valued. Literature on TA and teacher PD offers suggestions to help achieve these goals. In a report advising universities on how to better prepare graduate students to become faculty, Adams[37] called for more varied and extensive teaching experiences and PD programs that incorporated experienced TAs as resources. She suggested following the accepted apprenticeship model for training graduate students in research, in which progressively less scaffolding is provided as more responsibility is conferred. Research specifically addressing science TAs has recommended that departments provide discipline-specific pedagogical content knowledge[38] and increase the use of formative assessment that TAs receive regarding their teaching.[39,40] Others emphasize providing TAs with the opportunity to integrate pedagogical ideas into their teaching by offering PD as they teach.[3,9] TA instructors could help TAs identify ways to improve their teaching by observing TAs' instruction and providing feedback.[41] Close has reported that directing instructors to interview peers with the purpose of understanding their ideas rather than questioning to make a point focuses the instructors' attention on teaching as making sense of students' ideas.[42]

None of these activities are *inherently* responsive. They become responsive when they are chosen in response to the beliefs and resources the particular TAs have. In Alan's case, if a TA instructor was observing him to provide feedback, the PD could be made responsive by changing the primary focus of the feedback session from the instructor advising Alan to the instructor eliciting Alan's explanation of *why* he made particular instructional moves. As we have discussed elsewhere,[14] the beliefs that underlie a behavior cannot be "read off" from the behavior itself because different kinds of beliefs can underlie behaviors that look similar. Thus, feedback given to Alan needs to respond not only to behavior like his tendency to assume students understand when they provide the correct conceptual answer but also to respond to his belief that instructors *should* give students the benefit of the doubt rather than assume they are incorrect.

Now that we better understand Alan's beliefs, we think that a part of responsive PD for Alan could be meetings in which Alan and a TA instructor meet and watch video episodes of students in the classroom (as used by Speer[43] and recommended by Roehrig *et al.*[44]). In order to "cultivate" Alan's productive seed that students are capable of monitoring their own understanding, we might show him different clips of students working when the TA is not assisting them and ask him how accurately the students seem to be evaluating their own understanding. Our purpose would be to give Alan the opportunity to observe and reflect on a wider spectrum of student metacognition than what he observes directly as the TA. Similarly, we could build on Alan's desire to "do right" by his students by showing him the same video clips, but this time focusing his attention on whether the students have a correct conceptual understanding. This would be done to allow Alan the chance to see and become aware of a wider range of student understandings. If these modifications were suggested after he had watched his students working on the tutorial, we would hope to this would encourage reflection about what difficulties he sees his students having and how the tutorial could address those difficulties.

There are many reasons to think that such an approach would have the potential to help Alan improve his teaching. He cares about his students and wants to help them learn. He has demonstrated an ability to be reflective about his students' learning during his interviews. He thinks student group work is a productive activity, so watching videos of student work should be an authentic (to him) way to explore how they learn. All of these are resources that he can draw upon when improving his own instruction.

VII. CONCLUSION

Initial implementations of our professional development program had been focused on pedagogy, not on the TAs. Thus, we paid attention to how to "fix" the TAs' behaviors and beliefs rather than attending to the substance of their ideas. The shift we are advocating here is not in the object of the TA developer's attention—on the TAs' ideas and behaviors—but on the filter through which those ideas and behaviors are viewed. If TA instructors are paying attention to TAs in order to assess and correct TA instruction, then it is much harder to understand the TA's motivation and harder to provide PD that is responsive to the particular TA's relevant concerns and productive seeds in their beliefs. Our analysis does not lead to a list of necessary elements of a responsive PD program; instead, it argues that a different more co-constructive perspective toward TA professional development can improve the responsiveness of current PD programs. To be clear, the way we first characterized Alan's teaching was not incorrect; we were identifying pedagogical decisions to which we objected. However, our focus on what Alan did wrong instead of the reasons why he did it caused us to miss opportunities to provide him with useful PD.

Although we analyzed Alan's interviews and teaching in depth, we do not expect that we would have to do this hundreds of times in order to identify the most common beliefs and experiences that TAs draw on. As with students, there are probably common patterns of thought. However, as with students, we cannot just guess those patterns; we have to carefully observe and interpret their practices and listen to their beliefs and experiences to learn about their ideas so that we can offer PD responsive to those ideas.

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