

# Building Knowledge for Teaching: Three Cases of Physics Graduate Students

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**Abstract.** Over the past two decades education researchers have demonstrated that various types of knowledge, including pedagogical content knowledge, influence teachers' instructional practices and their students' learning opportunities. Findings suggest that by engaging in the work of teaching, teachers acquire knowledge of how students think, but the education research community has not yet captured this learning as it occurs. During an investigation of whether novice physics instructors can develop such knowledge via the activities of attending to student work, we captured instances of knowledge development and have identified several mechanisms that supported instructors in building this knowledge. We analyzed data from interviews with physics graduate teaching assistants as they examined and discussed students' written work. During those discussions, some instructors appeared to develop new knowledge—either about students' thinking or about the physics content—and others did not. We compare and contrast three cases representing a range of outcomes and identify factors that influenced the development of new knowledge.

**Keywords:** teacher knowledge, pedagogical content knowledge, graduate students

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## INTRODUCTION

From research on mathematics and science teachers, it appears that particular types of knowledge used in teaching correlate with reform-oriented teaching practices and with student achievement [1, 2, 3]. In addition to knowledge of content, knowledge of student thinking, a subset of pedagogical content knowledge (PCK) [4] has been found to play prominent roles in teachers' practices. Findings suggest that via their work, teachers acquire knowledge of how students think, but researchers have not yet captured this learning as it occurs.

We sought to capture the genesis of knowledge for physics teaching through task-based interviews with physics graduate students as they examined student solutions to physics problems. During discussions, some graduate students appeared to develop new knowledge—either about student thinking or about the physics content—and others did not. We compare and contrast three cases that represent a range of outcomes. Our analysis suggests a specific mechanism that aims to account for how two of the instructors built new knowledge during the interview. In particular, for these instructors, the context of interpreting student work cued specific physics content knowledge that had not been cued while they solved the problem.

Utilizing that knowledge, these instructors generated precise and accurate interpretations of student work which were then used to develop more general claims about students' understanding of underlying physics concepts.

## METHODS

One-on-one task-based interviews were conducted with seven physics graduate students currently serving as teaching assistants for introductory physics courses. Participants' physics teaching experience ranged from one semester to seven years.

During the interviews, participants considered several kinematics problems drawn from literature on student difficulties [5, 6]. For each problem, participants were asked to (i) solve it and give reasoning, (ii) discuss what one would need to know in order to solve it, (iii) generate and discuss possible student approaches, and (iv) examine and discuss prepared examples of student work.

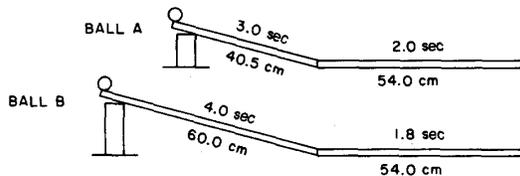
From the seven interviews, we selected three for cross-case analysis [7]. One interview was selected for closer analysis based on its *inherent interest* to our research questions. During this interview, Jamie developed an increasingly specific and accurate diagnosis of a known common student difficulty. The

other cases were selected for their *contrastive value*. Sam developed better understanding of the underlying physics by attending to student work and Alex struggled to make progress in understanding the problem or student thinking.

To conduct the analysis, we drew on research findings about student thinking about these problems [5] and methods for fine-grained analysis of teacher thinking and practices [8, 9]. Particular attention was given to moments when participants utilized content knowledge to either make sense of a problem or to interpret student work. Participants' statements about their own understanding or about students' understanding were compared and contrasted *within* individual cases and *across* the cases to generate and explore hypotheses about roles that physics content knowledge played in developing new knowledge.

## THE RAMP PROBLEM

In this paper we focus on just one of the kinematics questions used in the interviews. It was adopted from Trowbridge and McDermott's [5] investigation of student difficulties with acceleration. In the problem (Figure 1), two balls roll down ramps starting from rest. Students are asked to compare the accelerations. Based on the data, Ball A gains 27 cm/s in 3 s ( $9 \text{ cm/s}^2$ ), while Ball B gains 30 cm/s in 4 s ( $7.5 \text{ cm/s}^2$ ).



**FIGURE 1.** The question asks students to compare the acceleration of the two ball's using the definition of acceleration, not by using formulas such as  $\Delta s = \frac{1}{2} a (\Delta t)^2$ .

The problem is particularly challenging because it invites two kinds of mistakes. One mistake is to only consider the velocities. This can result from failing to distinguish between the concepts of acceleration and velocity. A second mistake is to calculate speed using  $v = x/t$ , and then acceleration using  $a = v/t$ . While this results in a correct comparison, the thinking behind it fails to distinguish between change in velocity and average velocity. These distinctions play important roles in all three cases discussed below.

## THREE CASES

We present the three cases and discuss them in light of the following questions: Can novice physics instructors develop new knowledge while attending to

students' written work? If so, what kind of knowledge develops and how does that development occur?

### Case One: Jamie Develops PCK

At the time of the interview, Jamie was only a few weeks into teaching for the first time. Jamie was the only participant who had little difficulty solving the ramp problem. After solving it, when prompted to generate examples of student work, Jamie stated:

So the first thing they might do is they might say that, acceleration is meters per second squared. And they might just be...well it's only being accelerated on this side [along the ramp], so I'm going to ignore what's on this side [along the flat track]... And I'm gonna say, this one is 40.5 over 3 times 3. And this one is 60 over 4 times 4. So, then I'd say like, 'A' is greater acceleration.

This quote illustrates how Jamie generated an example student solution, in part, by considering the units of acceleration as a piece of subject matter knowledge a student might know and apply to the problem. When asked about what the approach would mean in terms of understanding, Jamie states the following:

[It] would mean that the student understands the units of acceleration, but that would be about it. [The student] doesn't understand how acceleration, velocity, distance, and time are inter-related, and how to go from those pieces of information.

Jamie makes a rather broad diagnosis of the student difficulty, naming each of the four major kinematical quantities as among the things the student is having trouble relating. Later in the interview, however, Jamie offers a different diagnosis of the same student work:

They are doing something different, because they are not finding a final velocity, which you have to use. They are finding an average velocity... So this is what this students' approach doesn't understand: the difference between change in velocity and the average velocity. What's missing from this student's understanding is that to find our acceleration, what we need is the change in velocity not the average velocity.

Whereas before, Jamie characterized the difficulty quite broadly as not being able to relate position, velocity, acceleration and time; Jamie later locates the difficulty more specifically as being between change in velocity and average velocity. This is more specific in two senses. First, Jamie narrows the space of possible quantities the student is having trouble relating. Second, it is more specific with respect to physics content, with Jamie now specifying three different velocity-related quantities in his diagnosis.

Jamie's diagnosis is also more *accurate* in the sense of being increasingly aligned with the statements made by the authors of the original research using the problem:

[Students would] calculate the average velocity on the incline, and then use this value, instead of the instantaneous velocity at the end of incline, to find the acceleration. This confusion made successful solution of the problem impossible. Moreover, discrimination between instantaneous and average velocity is essential for a numerical interpretation of  $\Delta v$ , which in turn is crucial for an understanding of acceleration. (Trowbridge & McDermott, 1981, p. 248)

We claim that Jamie's statements made near end of the interview convey insights into student thinking that Jamie did not appear to know earlier in the interview. While not a part of our analysis here, these new insights did not come easily. Rather, they were the result of an extended effort by Jamie to determine whether, in fact, the student work was valid.

While not initially armed with knowledge of the student thinking, Jamie demonstrated strong content knowledge during the interview. Jamie's case, thus, is an existence proof that even novice instructors may be able to develop teaching-related knowledge through activities of attending to student work.

### **Case Two: Sam Develops Content Knowledge**

Sam was in the second year of a teaching assistantship. Sam's initial attempts to solve the problem included common student difficulties:

The way I'd try to do it is to compare their average velocity. If they start from rest and reach some average velocity, they are accelerating. And if they reach that average velocity... Well, if it's a greater velocity,... This isn't really an acceleration. This would be an average velocity of 13.5 and 15. So then if they start from rest, and B reaches a greater average velocity, then I'd be tempted to say it's accelerating more.

Sam's initial thinking about the problem is incorrect. While Ball B does have a greater average velocity along the ramp, this occurs because the ball accelerates for more time. Sam doesn't explicitly consider the time to speed up. In addition, Sam states that the ball "reaches" an average velocity, when it is (arguably) more appropriate to speak of the ball reaching a final (instantaneous) velocity. In this sense, neither Sam's calculations nor ways of talking about the problem clearly distinguish between the concepts of average velocity and instantaneous velocity.

Later, Sam's thinking is quite different:

So what we are interested to figure out is initial and final velocity. And so, previously, I had thought you couldn't find final velocity, but the amount of time it takes to traverse this distance is the amount of velocity you get when you are finished accelerating. So if you know the initial velocity, which we know, and you [find] the final velocity, then we know how the change in velocity worked. So I think that looking at it this way, looking at the change in velocity and the amount of time it takes. What I had left out. Or what I thought I couldn't find was final velocity, and I just found some velocity. Which isn't quite right.

Sam's shift in thinking is significant in two respects. Sam's later approach is now correct, taking into account the amount of time the ball accelerates. More importantly, Sam's pattern of talking about the problem becomes increasingly differentiated with respect to velocity concepts, distinguishing and relating instantaneous and change in velocity.

Early in the interview, Sam demonstrated gaps in understanding of the content. While working on the problem directly, Sam was unable to resolve these issues. Sam's new thinking occurred after he had been engaged in the work of interpreting a piece of student work that was incorrect. While forming his interpretation, he appeared to make key connections that enabled him to go back and solve the problem.

### **Case Three: Alex Struggles with Problem**

Alex was a fourth year teaching assistant. Like Sam, Alex struggled with the ramp problem:

This is my velocity down the ramp. And then I did the distance over the time for the straight part. And then. Let's see. I guess I did the average acceleration for the whole segment. I did the straight part minus the ramp and it took five seconds to go from here to here. That gave me  $2.7 \text{ cm/s}^2$ . I guess that's my average acceleration for the whole time.

Alex's approach is incorrect. Like many incorrect approaches, it fails to distinguish among different velocity concepts. Alex, in essence, finds an arithmetic difference between final velocity and average velocity, rather than a change in instantaneous velocity.

In the interview, Alex goes on to construct other ratios in which a "velocity" is in the numerator and "an amount of time" is in the denominator, referring to them as different average accelerations. Later in the interview, while attending to examples of student work, Alex seems to apply this same framework to evaluate what the student has done:

They took the ramp distance over the ramp time, and then they divided by the ramp time again to get centimeters per second. So they did, acceleration is

velocity over time, and they applied that. So they came up with some sort of average acceleration.

In essence, Alex viewed this student work through the framework that acceleration is “velocity” over “time” with it being possible to calculate different accelerations. Although able to correctly interpret the steps taken, Alex was unable to learn something from that interpretation, which might have served as a jumping off point for learning something new about the physics content or the significance of student thinking with respect to content.

## DISCUSSION OF CASES

The three cases illustrate the range of outcomes we observed during our investigation. While Jamie and Sam did articulate new insights during the interview, we cannot claim that these insights necessarily represent new stable forms of knowledge that would be brought to bear in other contexts. We are, however, still concerned with understanding *how* Jamie and Sam were able to learn something new from the activity of attending to student thinking. We see in these cases the beginnings of processes that support stable knowledge development, and thus hope to better understand the conditions, contexts, and practices that enable it.

Based on our more extensive analyses, we hypothesize two specific processes that supported the beginning of such new knowledge development:

- First, for both Jamie and Sam, the activity of interpreting student work elicited content knowledge that had not been put to use while solving the problem or generating student work.
- Second, Jamie and Sam developed specific and accurate interpretations of student thinking, which were then used as the basis for making more general claims.

In Jamie’s case, we see a shift from describing the student work as “using units” to “taking an average velocity.” This re-description required the application of knowledge about average velocity—knowledge that Jamie did not appear to use while solving the problem. Jamie was then able to leverage this interpretation to make a more general claim that the student work represents difficulty understanding the difference between average velocity and change in velocity.

In Sam’s case, we also see content knowledge used to interpret student work, which hadn’t been used earlier. Specifically, Sam interpreted a student calculating the velocity on the straight track as finding the final velocity. Initially, Sam had thought the velocity at the bottom of the ramp was irrelevant (since it isn’t accelerating), but Sam eventually made key connections while examining an incorrect piece of student work. Based on this insight, Sam was able to

generate a more general statement about what the error in his own understanding had been.

Alex, on the other hand, utilized the same content knowledge to approach solving the problem and to interpret student work. Both contexts elicited the same knowledge base. Ultimately, the nature of this knowledge was not only insufficient for understanding the problem but also insufficient for gaining traction in understanding the nature of the student difficulty.

These cases provide us with some insight into the interactions that can occur between content knowledge and knowledge of student thinking as instructors engage in teaching-related tasks. The participants not only interpreted student work through the lens of physics content knowledge, but those interpretations were generative of new knowledge. The specific mechanisms of this learning have only been loosely sketched in this paper. Ultimately, we hope these and other findings can shed light on how teachers learn while engaged in the work of teaching and can also inform the design of professional development activities to support such learning in novice teachers.

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