# Content Knowledge for Teaching Energy: An Example From Middle-School Physical Science

R. E. Scherr, A. D. Robertson, L. Seeley, and S. Vokos

*Department of Physics, Seattle Pacific University, Seattle, WA 98119*

**Abstract.** “Content knowledge for teaching” is the specialized content knowledge that teachers use in practice – the content knowledge that serves them for tasks of teaching such as making sense of students’ ideas, anticipating conceptual challenges students will face, selecting instructional tasks, and assessing student work. We examine a middle-school physical science teacher’s interactions with a group of students for evidence of content knowledge for teaching energy (CKT-E). Our aims are to develop our theory of CKT-E as well as criteria for its observational assessment. We identify CKT-E as potentially including elements of canonical energy models, elements of alternative energy models, and a repertoire of instructional tasks or activities that exemplify or support instructional goals.

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## INTRODUCTION

“Content knowledge for teaching” is the specialized content knowledge that teachers use in practice – the content knowledge that serves them for tasks of teaching such as making sense of students’ ideas, anticipating conceptual challenges students will face, selecting instructional tasks, and assessing student work. We examine a middle-school physical science teacher’s interactions with a group of students for evidence of content knowledge for teaching energy (CKT-E). Our aims are to develop our theory of CKT-E as well as criteria for its observational assessment.

As a result of this investigation we identify CKT-E as potentially including elements of canonical energy models, elements of alternative energy models, and a repertoire of instructional tasks or activities that exemplify or support instructional goals. We identify observational criteria for CKT-E including teacher statements about energy in a pedagogical context, teacher-initiated changes to an instructional task, teacher addition of distinctive content to student statements in the process of revoicing, teacher mischaracterization of a student idea, and teacher proposal of a model encompassing student ideas.

## CONTENT KNOWLEDGE FOR TEACHING

In the 1980s, Shulman [1,2] offered researchers, teachers, and teacher educators a new lens through which to view the knowledge that teachers enact in practice. Shulman argued that the association of teacher competence with “pedagogical knowledge” and/or “content knowledge” was insufficient to capture teachers’ professional expertise. He defined an additional category of teacher knowledge, “pedagogical content knowledge,” which “goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*” [1]. In addition to “pedagogical knowledge,” which consists of strategies such as wait time, and “content knowledge,” which consists of a teacher’s canonical knowledge, PCK includes, for example, knowledge of common student ideas and representations or analogies that are productive for learning specific topics.

Although Shulman’s work provided a new framework for teacher knowledge, it did not explicitly explore the specific PCK that is entailed in teaching a particular subject. Ball and colleagues subsequently built on Shulman’s work by defining and cataloguing “mathematical knowledge for teaching” (MKT), defined as the “mathematical knowledge needed to perform the recurrent tasks of teaching mathematics to students” [3]. Ball and colleagues divide Shulman’s content knowledge into two domains: common content knowledge and specialized content knowledge [3]. Together, these encompass the content knowledge that teachers use in practice; the latter refers to the mathematical knowledge unique to teaching (e.g., looking for patterns in student errors or deciding whether a student’s unique solution approach will work in general), whereas the former refers to mathematical knowledge used across settings (i.e., that is not specialized to teaching, such as knowing that a square is a rectangle or that 0/7 is equal to 0). They likewise divide pedagogical content knowledge into two domains: knowledge of content and students

(KCS) and knowledge of content and teaching (KCT). The former blends knowledge of mathematics and knowledge of students. Ball and colleagues give examples of KCS that incorporate knowledge of the average student – such as when a teacher uses the literature on common student ideas to anticipate where her students will likely struggle with particular content – and examples that incorporate knowledge of a teacher's unique students – such as instances when a teacher hears and interprets her students' emerging mathematical ideas. KCT blends knowledge of mathematics and knowledge of teaching. For example, a teacher displays KCT when she evaluates advantages and disadvantages of representations used to teach a particular idea.

Ball describes their approach as the "development of a practice-based theory" for MKT: she and her colleagues worked "from the bottom up," conducting "extensive qualitative analyses of teaching practice" [3,4]. To define MKT, they watched classroom video and asked themselves: "(1) What are the recurrent tasks and problems of teaching mathematics? What do teachers do as they teach mathematics? (2) What mathematical knowledge, skills, and sensibilities are required to manage these tasks?" [3,4]. In doing so, they explore "the *territory* of mathematical knowledge for teaching," rather than seeking to infer "any *individual's* overall level of knowledge, classroom practice, or learning" [5,6]. In what follows, we begin to explore the territory of content knowledge for teaching energy (CKT-E) in physics by asking these same questions in a physics context.

## METHODOLOGY

We take the perspective that the universal properties of an event or phenomenon emerge from the specifics of a particular case, rather than from the patterns that emerge across cases [7]. We identify cases of CKT-E in video records, observe them naturalistically, and generate claims based on this naturalistic observation. We follow practices common to video research and interaction analysis [7,8]. Cases of CKT-E illustrate and refine our understanding of general teaching and learning theories and phenomena, developing of our theory of CKT-E.

We analyze an episode from video records of an eighth-grade classroom in a public middle school in the Pacific Northwest. The video data was collected as part of a professional development activity in which participating teachers' classrooms were videotaped for discussion with peer teachers and researchers. The episode was selected because of the high level of interaction between the teacher and the students and the high visibility of students' science ideas. The discussion below highlights three short segments of interaction from within the twelve-minute episode.

We follow Ball's lead in building on Shulman's work in the context of physics, specifically energy. We first seek a practice-based account of CKT-E; we wish to understand the nature of CKT-E before we attempt to assess an individual's overall level of CKT-E or the relationship between CKT-E and other variables. This work is part of a larger project to develop and validate a set of coherent measures of CKT-E for use in professional development and evaluation of secondary teachers.

## MOMENTS INDICATING CONTENT KNOWLEDGE FOR TEACHING ENERGY (CKT-E)

Students in this episode have just begun their study of energy by watching a movie showing various phenomena: a bus driving, a bicyclist pedaling, leaves blowing in the street, and so on. After the movie, students work in small groups on a worksheet that asks them to state how energy is involved in each of the phenomena in the movie. When the students have completed the worksheet, the teacher leads a whole-class discussion of their responses to selected worksheet items.

### "For something to have energy, does it have to have gasoline in it?"

In this first segment, some students claim that they know a bus driving down the street has energy because it is in motion. Other students object that the bus itself does not *have* energy; instead it *uses* energy. Mark identifies and highlights the disagreement for discussion. (Superscripts are line numbers.)

1 **Student:** We already know it has energy cause it moves. We know it has energy.

2 **Mark:** What do you mean? I don't think, that's not an assumption that everyone is working with.

3 **Student:** (inaudible)

4 **Mark:** You made a claim there, you said that well obviously it has energy because it's moving.

5 **Student:** Yeah.

6 **Mark:** That was a claim. Does everybody agree with that claim?

7 **Students:** No

8 **Student:** That's not what I meant. There is an engine in the bus.

9 **Mark:** Guys, this is a line of reasoning that we need to work through, like, what does it really mean to have energy, for something to have energy, does that mean it has to have like gasoline in it, does that mean that, that's what it means to have energy.

[10]**Brianna:** So, well I think like the bus doesn't have energy itself. It uses energy to help power it. But in itself the bus cannot have energy

[11]**Mark:** So the only thing that has energy would be like, the fuel, so you're saying the gasoline is the energy

[12]**Brianna:** Is the energy

[13]**Mark:** And then that energy is kind of used up by the bus to move. But the bus itself

[14]**Brianna:** Does not have energy.

[15]**Mark:** Does not have energy?

[16]**Brianna:** Yeah.

The idea that energy is indicated by motion is a typical learning target for students at this level. The fact that Mark highlights opposing views about this learning target suggests its instructional salience to him: "energy is indicated by motion" is part of Mark's CKT-E. In bringing this disagreement to the class's attention, Mark brings out not only the specific conceptual issue of energy and motion, but also the larger question of "what it really means for something to have energy," showing awareness that there can be competing conceptualizations of energy. This awareness is not merely content knowledge (CK) for Mark: it is content knowledge brought to bear for a task of teaching (CKT), specifically, to have students identify indicators for the presence of energy in an object. He asks whether having energy means having fuel, suggesting that his CKT-E includes knowledge of this common alternative model [9]. Brianna's response suggests agreement with the idea that energy is fuel ("it uses energy to help power it") and the idea that inanimate objects (such as the bus "in itself") do not have energy.

Opportunities to infer Mark's CKT-E in this segment are associated with particular kinds of interactions that take place. Specifically, Mark highlights a disagreement among students and marks it as instructionally important. He adds distinctive content to student statements in the process of revoicing them (introducing the issue of "gasoline"), supporting our attributing the associated content knowledge to him rather than his students. He hints at a model that will encompass student ideas ("what does it really mean for something to have energy"). It is likely that other episodes including these kinds of interactions would offer opportunities to observe and assess CKT-E.

## "Does a ball rolling down a hill have energy?"

In this next segment, which occurs a couple of minutes later than the previous one, a student explains his idea that the mere presence of fuel is insufficient; some activity is required. In response, Mark suggests a new physical situation for the students to consider, one in which there is activity but no fuel.

[47]**Mark:** Guys, guys, let's listen to Christopher please.

[48]**Christopher:** If you put fuel on a bus and let it sit there it's not going to do anything. You need to actually make it move.

[49]**Mark:** So just having the fuel doesn't necessarily mean that it has energy? So it has to be doing something to have energy? I do want to skip down to the example of like the rolling basketball, and I'm going to change the situation a little bit to, well what if we had put a basketball like on the top of a hill and we just let it roll down. So I didn't do anything, and then I just set the ball there. So what we witness is the ball rolling down the hill. Does that have energy?

Christopher states that just putting fuel on a bus "isn't going to do anything"; Mark seems to interpret Christopher's statement as suggesting that (1) having fuel is not equivalent to having energy and (2) energy is indicated by activity. Both of these interpretations go beyond what Christopher said, which supports our attributing the knowledge that they represent to Mark, rather than Christopher. Mark's next move is to ask the students to consider a new scenario, one in which an object is in motion without being powered by any obvious external agent. These moves add to the evidence of the previous segment that Mark's CKT-E includes the alternative ideas that energy is indicated by motion or by the presence of fuel, as well the idea that energy is attributable to inanimate objects. We infer Mark's CKT-E by his selection of an instructional scenario that more effectively highlights these issues (an inanimate object that rolls spontaneously downhill). Mark's repertoire of such tasks is another element of his CKT-E.

## "We might need to start dealing with different types of energy."

In the segment below (taking place a few minutes after the last segment), students respond to the basketball scenario by proposing another scenario that they treat as analogous, in which the basketball is replaced with a deceased person. Mark uses the occasion to introduce the idea that we may need to distinguish different types of energy.

[119]**David:** If there's like a dead person, I don't think it would have energy, but you could roll it down a hill

[120]**Danielle:** You could burn it

[121]**David:** And I don't think the person had any energy.

[122]**Mark:** Hold on, hold on. It sounds like one of the issues that's coming out is that we might need to start dealing with different types of energy. There might be different things going on with different types, and that could be an issue.

David states that a dead person would not have any energy, yet would still roll down a hill, perhaps in reference to the claim that energy is indicated by motion. Danielle points out humorously that the person would still be combustible, suggesting that the person does have energy. Mark, reaching the end of the class period, uses this occasion to suggest that they may need to distinguish between different types of energy that an object may have, indicating that his CKT-E includes the knowledge that energy has different forms associated with different observable quantities. For example, most material objects can be burned, indicating the presence of chemical energy. Mark's statement suggests a need to consider separately the questions of whether the person (or bus) has energy associated with its motion, with its combustibility, with its possession of fuel, and with its status as living or nonliving. We infer Mark's CKT-E by his introduction of a new concept, one that helps organize the students' discussion and is aligned with learning targets for energy in middle school (that it has forms).

## OBSERVATION OF CKT-E

Some of the CKT-E we infer from this episode is in the form of elements of canonical energy models, such as "energy is indicated by motion," "energy is indicated by the presence of fuel," and "energy has a variety of forms." Other inferred CKT-E is in the form of elements of alternative energy models, such as the ideas that inanimate or nonliving objects do not have energy. Still other CKT-E is in the form of instructional tasks and activities that exemplify and support learning goals: we infer from Mark's behavior that he has a repertoire of such tasks and activities.

We add to Ball's work by articulating not only what constitutes CKT-E (as Ball did for MKT), but also where in teacher practice one may locate CKT-E. On the basis of the above analysis, we particularly expect to observe CKT-E when the teacher makes distinctive statements about energy in a pedagogical context; when the teacher adds distinctive content to student statements in the process of revoicing them (or even mischaracterizes a student idea – not observed in these episodes); when the teacher changes an instructional task; and when a teacher proposes a model encompassing student ideas.

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