Does the dog in the car have kinetic energy? A multiage case study in the challenges of conceptual change

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Kinetic energy is usually the entry point for the study of energy in physics and is often perceived as unproblematic. We present evidence, however, that some learners who seem to have accepted the concept, from elementary school students to college physics majors and in-service teachers, nevertheless do not consistently attribute kinetic energy to moving objects that are being pushed or carried by other objects. Factors that seem to contribute to this idea include that the passive object is not moving "on its own"; the lack of attributes, like wheels, that suggest the ability to move on its own; and the perception that it would stop immediately if the driving object were to stop or disappear. We interpret these observations in terms of a model of a conceptual change via assimilation rather than accommodation and suggest some possible instructional implications.

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I. INTRODUCTION

Young children have ideas about "energy" which are quite different from the scientific concept associated with that word [1–5]. They associate energy primarily with human beings, other living things, and perhaps objects that appear to move on their own. These prescientific understandings are, in Solomon's words, "messy, contradictory and obstinately persistent," [1] even as they offer productive resources for building a more consistent and canonically correct understanding of energy [4–8]. Even after formal physics instruction, similar ideas emerge in students' attempts to explain the role of energy in real-world situations [2–4,9,10]. Nevertheless, traditional physics instruction in high school and college typically does not acknowledge or seek to engage productively with these preexisting ideas, instead simply presenting, developing, and practicing energy concepts as they are understood in physics.

Kinetic energy often provides the entry point to a scientific understanding of energy. Even young children readily accept the idea that an inanimate moving object, such as a rolling ball, has energy by virtue of its motion [1,5,11]. Introductory physics texts at the high school and college level typically begin their discussions of energy with kinetic energy. This paper, however, presents evidence from learners, across a wide range of ages and levels of physics education, to illustrate the persistence of one particular noncanonical idea about kinetic energy: That when a passive object is being pushed or carried by an "active" one, only the active one has kinetic energy. Physics educators, at all levels, should be aware that this conception can and often does persist, even when students show a good understanding of kinetic energy in the case of single objects. While we do not have data to support specific interventions, we suggest that it may be helpful to include in instruction cases, and opportunities for open-ended discussion, that elicit and address this idea. More broadly, this case presents an example of the well-established challenges, for both instructors and learners, in fostering and achieving conceptual change from noncanonical "common sense" understandings to the more consistent, and ultimately more productive—but often counterintuitive—scientific perspective.

II. EVIDENCE FOR PERSISTENCE ACROSS AGE GROUPS

We present evidence of learners' ideas about whether a passive object being pushed or carried by another, active object has kinetic energy, from four different populations, as summarized in Table I. The populations vary widely in age, from elementary school students to adult teachers, and in the level of formal physics education, from a few units in elementary school up to advanced college physics classes. The numbers in each group also vary widely, and the questions posed, and types of response collected, were not identical. These differences mean that the results from the different groups are not directly comparable, but they also show that the ideas in question show up in learners'

TABLE I. Summary of populations studied. MC = Multiple choice; OR = Open response. See text for details.

Population	Number	Instructional context	Question	Type of data
Elementary students (G4–5)	153	*Focus on Energy* curriculum	Block-Push	Written, MC and OR
College students, previous physics in high school	20	Class on physics of sustainable energy	Block-Push	Written, MC and OR
College students, previous college-level physics	6	Class on physics of sustainable energy	Truck-Crate	Written, MC only
In-service teachers, G48, varied physics backgrounds	Approximately 20	Professional development workshop and Professional Learning Community meeting for *Focus on Energy* curriculum	Box on skateboard and block push	Open group discussion

responses to different physical scenarios, and when questions are posed in different ways, and the more open-ended responses provide insights into the kinds of thinking that underlie those ideas and to potential avenues for addressing them.

Figure 1 summarizes some of our evidence for the persistence of the idea that a passively moving object does not have kinetic energy of its own. The figure shows the results when students in the first three categories in Table I, with various levels of physics education, answered questions about whether an object does or does not have energy when it is moving under the influence of another object that is pushing or carrying it. (We did not collect quantitative data for the in-service teachers.) The fraction of respondents saying that the passive object does *not* have energy decreased with higher levels of physics instruction, from 51% among the elementary students studied ($N = 153$), down to less than 20% among the students who had taken college-level physics ($N = 6$), but it was present to some degree at all levels studied. Notably, 40% of the (college) students studied who had completed a course in high school physics ($N = 20$) said that the passively moving object did not have energy.

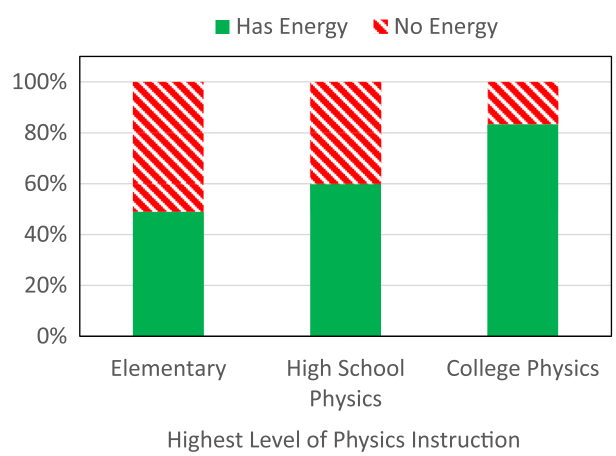


FIG. 1. In questions involving the kinetic energy of an object being pushed or carried by another object, a fraction of students answered that the passive object does or does not have energy as a consequence of its motion, for three levels of prior instruction. While the results are suggestive, they should be viewed with caution. The elementary school data come from 153 students in nine Grade 4 or 5 classes. The data for higher levels come from much smaller numbers of college students, 20 who had taken only high-school physics, and 6 who had taken physics in college. The last group was also responding to a somewhat different prompt. See Table I and the text for details and discussion.

Given the small numbers, and relatively narrow population of students in the samples, the quantitative values for the college students, for either level of past instruction, should not be taken as necessarily representative of the larger population. Nevertheless, these results, along with those students' open-response answers (see below) suggest that confusion or uncertainty about the kinetic energy of a passively moving object persists in at least some students who have had significant secondary and even postsecondary physics instruction.

In the following sections, we will examine the responses of each group in greater detail, seeing how some students' conception of energy retains aspects of preinstruction ideas, even as they have apparently accommodated the principle that all moving things have energy. We will also offer qualitative evidence of the persistence of this idea among in-service elementary and middle-school teachers, during or after a professional development workshop specifically about energy. These data, coming from open-ended group discussions, provide richer insights into learners' conflicting ideas, and some clues regarding the kinds of examples and arguments that they found instructive or persuasive.

A. Elementary school

The elementary school data come from a sample of 153 students in nine Grade 4–5 classrooms, in suburban schools

FIG. 2. Image from the block-push probe video, showing the battery-powered "car" (right) slowly pushing a wooden block at a constant speed to the left.

in Massachusetts, that were using an experimental energy curriculum, *Focus on Energy* [11,12]. Through a series of structured activities and discussions, the classes had arrived at an understanding that objects in motion had energy and that the amount of energy was related to the speed of the object. They had applied this idea to objects such as a rolling ball, a small object launched from a springboard, and a spinning propeller. The issue of energy in a system of objects moving together, however, had not been discussed. They were then given the "block-push probe," in which they viewed a short video that showed a battery-powered "car" pushing a wooden block slowly across a tiled floor (see Fig. 2) and then completed a written assessment. (The video is included in Supplemental Material [13].) For each object (car and block), the students were asked to select one of two options: whether the object *does* or *does not* have energy. In each case, they were then asked to explain in their own words why their answer made sense to them. (This probe was not used for grading the students but to gather insight into their understanding.)

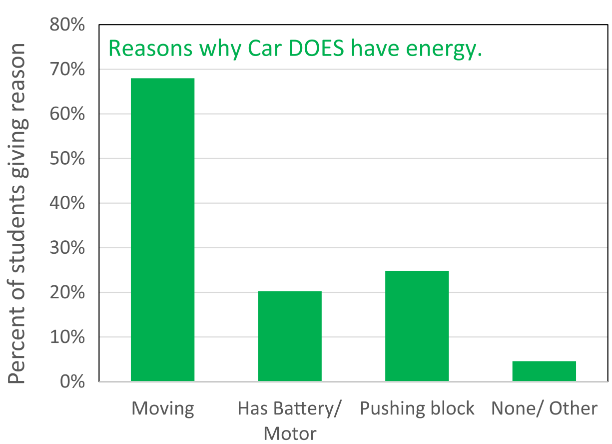


FIG. 3. Reasons given by elementary school students ($N = 153$) for their conclusion that the battery-powered car *does* have energy. While two-thirds mention that the car is moving, a significant fraction gives other reasons. Totals sum to more than 100% because some students offered multiple reasons.

All 153 students answered that the car had energy. Figure 3 summarizes the reasons they provided in their open-response explanations. About two-thirds (68%) said it had energy because it was moving, indicating that a large majority of the students had accepted that motion in itself was evidence of energy. However, 25% said it had energy because it was pushing the block, and 20% because it had a battery or a motor. These answers suggest the persistence of early conceptions that energy is associated with the ability to act on other things or with having an internal source of that ability to act [3–5].

The wooden block in the video is manifestly moving at the same speed as the car. The students, however, were equally divided as to whether the block had energy (49% yes, 51% no). Figure 4 shows the reasons they gave for their answers. While their answers regarding the car indicated that a large majority appeared to accept the idea that motion was, in and of itself, evidence that an object had energy, their responses about the block, suggest that understanding was more fragile than it appeared. Many did not carry it over to the case of an object that was in motion *because it was being pushed by something else*. Indeed, even among the two-thirds of the students who specifically mentioned the motion of the car as a reason for concluding that it had energy, 38% (19/48) nevertheless answered that the moving block did *not* have energy. As one explained: "It's in motion yes but it's not moving by itself. It is moved by force from the car!"

Some students (8%) actually asserted that the block was *not* moving—although it clearly was. We speculate that they interpreted or redefined "moving" to mean "moving on its own." One student, for example (who said the car was moving), wrote "The block didn't move. It's just staying

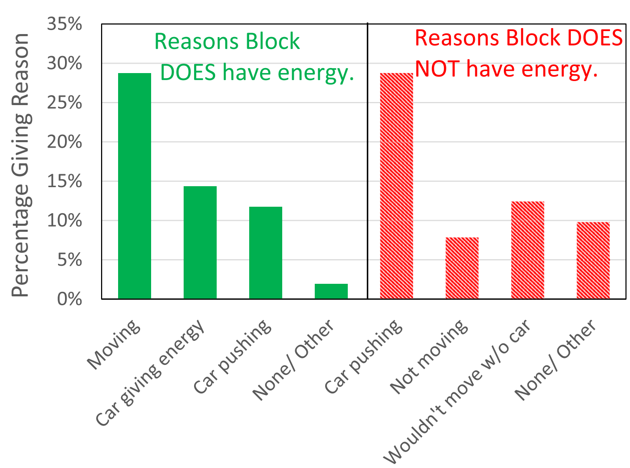


FIG. 4. Reasons given by elementary school students for their conclusions regarding whether or not the wooden block has energy. Reasons for concluding the block *does* have energy are shown on the left side, in green (49% of students); reasons for concluding the block *does not* have energy are shown on the right side, in red hatching (51% of students). Totals do not add to 100% because some students offered multiple reasons.

there with the car pushing it." Another offered "the block is being pushed, not moving by itself."

Other students gave explanations that evoked preinstruction ideas of energy as an inherent property of certain kinds of objects or as an enabling agent that makes things happen: "Blocks don't move." "A block can't get energy just sitting there." "Wood does not let energy flow." "If it had energy it wouldn't need that car to push it." "The wooden block doesn't have anything that gives it energy, so if you don't have energy then you can't move." One student claimed the block does have energy, because "blocks are made of wood and wood comes from trees, and trees have energy because it is a live breathing thing on earth." A few students mentioned the fact that the block had "no wheels to move itself."

B. College students

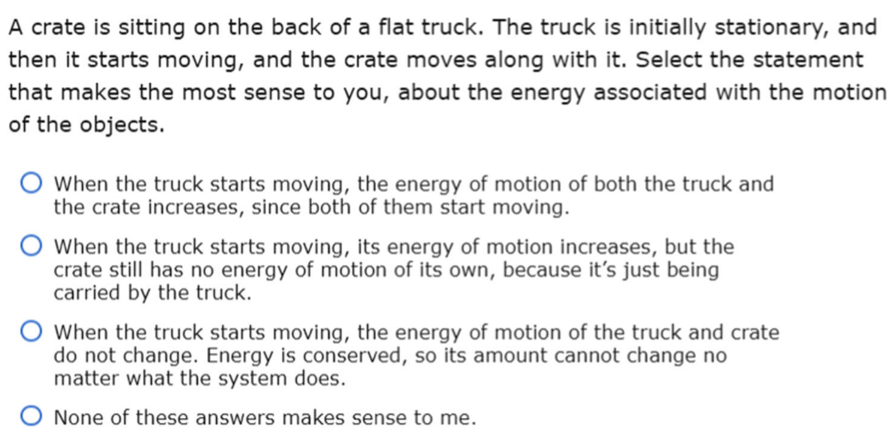
It is probably no surprise that elementary school students, in their first weeks of learning about energy, and prior to any formal training in the physics and mathematics of the concept, would retain aspects of their preinstruction conceptions. To see whether these conceptions persist after more advanced physics education, similar questions were asked of two groups of college students. These students all attended Tufts University, a highly selective private research university, and were enrolled in one of two classes on the physics of sustainable energy. Twenty were enrolled in a class open to nonscience students and had taken physics in high school, but not in college (two took physics in grades 9 or 10; the remaining 18 in grades 11 or 12). Six others were enrolled in a more advanced version of the class and had taken physics in college, beyond the introductory level. Both groups were asked (slightly different) questions related to the energy of motion of passive objects, as part of an ungraded survey completed by all students at the very beginning of the course. Their answers thus represent their understandings after their prior physics instruction but before any additional instruction about energy.

Since the number of students is small, drawn from a single institution, and represents students who chose to enroll in a physics course specifically about energy, their answers cannot be taken as representative of any broader population. Nevertheless, their responses show the persistence of prephysics ideas about kinetic energy among some college students after conventional physics instruction. Indeed, given the selectivity of the school, and their choice to enroll in the class, these students might be expected to have, if anything, stronger than average physics preparation. Further, as we discuss below, the framing of the question posed to the students with previous college physics experience may have been more likely to cue the canonical physics answer than that posed to the elementary and high-school physics students. For these reasons, these data may underestimate the prevalence of these ideas in a broader population. Additional research would, of course, be needed to test that speculation.

The students with only a high-school physics background were asked essentially the same Block Push probe questions as the elementary school students. As Fig. 1 shows, 60% (12/20) of these students answered that both the car and the block had energy, but 40% (8/20) indicated that the car had energy but the block did not. Explanations given by students in the latter group included:

> The car is doing work by pushing the block, but the block is not doing anything itself.
> I think that the box does not have energy because it is not moving of its own volition and therefore is not exerting any energy.
> Because the car is the one with the motor pushing the block forward. The block is resisting the push of the car.

These explanations echo those given by the elementary school students, suggesting that for a substantial minority of these academically accomplished students, high school physics instruction had not fully supplanted early associations of energy with "volition" and the ability to "do


A crate is sitting on the back of a flat truck. The truck is initially stationary, and then it starts moving, and the crate moves along with it. Select the statement that makes the most sense to you, about the energy associated with the motion of the objects.

- When the truck starts moving, the energy of motion of both the truck and the crate increases, since both of them start moving.
- When the truck starts moving, its energy of motion increases, but the crate still has no energy of motion of its own, because it's just being carried by the truck.
- When the truck starts moving, the energy of motion of the truck and crate do not change. Energy is conserved, so its amount cannot change no matter what the system does.
- None of these answers makes sense to me.

FIG. 5. The Truck-Crate question given to students who had taken college-level physics.

something itself." In the second response above, energy is described as something "exerted," possibly suggesting a conflating of energy with force or drawing on the idea of energy as an "enabler" that makes things happen.

The students who had taken college-level physics—most were physics majors who had taken multiple courses beyond the introductory level—were instead asked the slightly different question shown in Fig. 5. We expected that physics majors would be likely to know that the objects could have other forms of energy, such as potential and thermal energy. To avoid those complications, and to focus attention on kinetic energy, the question asks about the change in energy due to the change in the truck's and crate's state of motion, as well as specifically referring to "energy associated with motion." This question did not have an open-response component; the students were not asked to provide further explanation of their thinking. (If a student had selected the last answer, they would have been prompted to offer an answer that did make sense to them, but this did not occur in our sample.)

While the sample size of six is very small, it is reassuring that almost all ($5/6$) attributed energy of motion to the crate. Even in this group, however, one student still selected the second option, that the crate has no energy of motion of its own because it's just being carried by the truck. This student's answer suggests that the early ideas about energy seen in elementary school students can persist even in some students who have had multiple college-level physics classes and have a high level of interest in physics.

It is also possible that the better performance of these students, compared to those who had only high school physics, reflects in part the framing of the question. As we will see from the discussion among in-service teachers, some learners are more hesitant to attribute kinetic energy to objects that are moving very slowly and that would not perceptibly remain in motion if the active object stopped (like the block in the block-push video). The context of a crate on a truck—where it's easy to imagine the crate sliding forward if the truck stopped abruptly—may therefore be more suggestive of the canonically correct response than the block-push scenario.

C. In-service teachers

We have also observed evidence of uncertainty about the energy of passive objects among in-service elementary school teachers participating in professional development for teaching the above-mentioned *Focus on Energy* curriculum. For this group, we do not have quantitative measures, but we have video recordings of extended, open-ended discussions in which the teachers expressed and collectively worked through their thinking, offering deeper insight into their struggles. We also do not have specific information about their prior physics training. It is likely that few, if any, had taken college-level physics but all presumably had received some education in physical science in middle and/or high school.

In one session, a group of teachers, as part of a weeklong workshop on energy, was presented with a possible formative assessment task for their students, posing the question: "Does a box sitting on a moving skateboard have motion energy?" In a video of the session, one of the teachers, George, after reading the question, turned to the teacher next to him, Lauren, and said "Oh. [laughs] Oh, man. Oh, no." and, a bit later, "My God!". The question had clearly taken him by surprise, and he didn't seem to know what to think. A few moments later, after the teachers have spent some time thinking, he turned to Lauren again and said "I say no."

Speaking to the whole group, Lauren expressed her own struggles with the question, bringing up many of the same concerns raised in the students' answers above.

> Lauren: My struggle, which I'm sure students would have as well, is if you were to yank (makes a strong upward motion with both fists) the skateboard out from under, the box isn't going to move anymore. … So I'm kind of, like, struggling with that, like, would it be moving without the skateboard? But it's still moving. And if it were to like, run into something, like, if the skateboard were to run into something, the box would go (shoots her arm forward), so kind of … (trails off, looking doubtful).
> Mike: Can I ask something? I totally got the part about how the skateboard hits something and the box keeps going and that makes [unintelligible]. I still don't think I've got the piece about [unintelligible].
> Lauren: If there was, like, a trapdoor under the skateboard and the skateboard just, like, dropped through, but the box didn't, the box would stop moving. But, things with motion energy stop moving all the time. [Unintelligible]
> Mike: It's like, if the skateboard goes over an open manhole?
> Lauren: Yeah.
> Leader: But the manhole closes up right before the box gets to it.
> Lauren: Maybe the box is too big to fall, like it's a skateboard-sized hole.
> Leader: But wouldn't it continue to move until …?
> Lauren: The box?
> Leader: Yeah.
> Someone else: Yeah, momentum.
> Lauren: I don't know. How fast is the skateboard going?

Here we can see Lauren wrestling to reconcile a physics concept of energy with her own preexisting ideas.

She understood, from prior instruction and/or what she had learned in the workshop, that objects in motion have energy—"but it's still moving"—but she was clearly not comfortable with that idea unless it's moving on its own: "would it be moving without the skateboard?" To resolve the dilemma, she imagined a series of thought experiments in which the skateboard is somehow removed from the scenario and in each case tried to imagine whether the box would keep moving. "on its own." At the end of the excerpt, she raised the issue of how fast it is moving. Perhaps if it is moving fast enough, we can imagine that it would keep sliding "on its own," and in that case perhaps it is okay to attribute energy to it. After all, "things with motion energy stop all the time."

A short time later, Henry offered a series of related examples, apparently in support of the idea that box does have energy.

> Henry: Well if you're on a skateboard and your skateboard hits a rock, your skateboard stops, what do you do (makes a gesture of falling forward)? Or you're on a bicycle and your front wheel hits something [unintelligible] what do you do (another gesture suggesting going over the handlebars)? Why is that? Or if you're on the skateboard and there's something off the ground at the level of the box, that stopped the box, that would definitely have to stop the box with some opposing force, right? So this is all one system. […]
> Lauren: If you're a passenger in a car that's moving, you're still moving.
> George: Or on an airplane.

It appears that Henry's examples may have persuaded Lauren, but it is not entirely clear whether the logic of his examples—in most of which the objects are moving fast enough that it is clear they would keep moving if the skateboard, bicycle, car, or airplane suddenly ran into something—would carry over to a case like the block-push probe.

Similar concerns were expressed by a different group of teachers participating in a professional learning community (PLC) meeting. They had completed the summer training workshop—in which one of the principles they agreed upon was that motion is an indicator of energy—and were in the midst of teaching the *Focus on Energy* curriculum to their elementary-school classes. In the PLC meeting, the authors led a discussion of the block-push scenario, including an example in which one of the discussion leaders walked with a coffee mug across the room and showed that the mug could push a piece of paper out of the way. This was intended to suggest that the moving mug had energy, even though it was being carried by a person. Megan, however, was still not fully convinced. She contrasted the block push with another activity in the curriculum, in which a twisted rubber band had been used to spin a propeller.

> Megan: I still struggle with that the block has motion energy. Cause I still think the car pushing it is giving it the energy.
> Leader: Well, it is. [Laughter] Now it's got it.
> Megan: But the thing is that it's constantly pushing it, right, (placing fists together and pushing one with the other) where the propeller, you see it and then the propeller seems to be spinning on its own (gestures with a spinning finger), where the block doesn't seem to be moving on its own.
> Judith: I agree.

Like Lauren in the previous example, Megan and Judith seemed to struggle to reconcile the principle that motion itself is sufficient evidence of energy with their strong intuition that energy belongs only to an object that is "moving on its own," even if only for a time.

A little later, one of the discussion leaders offers another thought experiment:

> Leader: What if we made the little battery-powered car push a rolling thing along, and then we stopped it, and this might keep going? Would that do it?
> Megan: Yeah, that would do it for me.

In the first group, Lauren mentioned that the box, even though it is moving, would not be moving without the skateboard. Here, Megan contrasted the block with the propeller that spins "on its own" after the rubber band unwinds (and Judith agrees). Lauren, Henry, and Megan all attended to the question of whether the box or block would keep going if the skateboard or cart stopped, and, in Megan's case, that issue was also related to whether or not the block had wheels that would allow it to roll. These teachers' comments echo many of the issues raised by the young children and by the college students.

III. DISCUSSION: A CASE OF (INCOMPLETE) CONCEPTUAL CHANGE

We frame the learning of energy in the context of physics as a case of conceptual change [14–18]. It has been long and firmly established that students are not blank slates, but come to the study of physics—at any level—with firmly held, though often loosely defined, common sense ideas that are highly situational; often inconsistent, both internally and with canonical physics; and frequently resistant to change by instruction, yet manifestly adequate and useful in normal life [19,20]. Valuable reviews are given by McDermott and Redish and Docktor and Mestre [21,22]. Posner *et al.* [16] argued that individual learners, like the scientific community writ large [23], are more likely to *adapt* new information or concepts by assimilating them into their existing conceptual frameworks, via modest adaptations either of the preexisting framework or of the new information and ideas, rather than by making a more radical "accommodation" that fundamentally replaces or reorganizes those frameworks.

Much of the research into students' common-sense conceptions has focused on introductory mechanics, and, to a lesser extent, electricity, magnetism, and a few other topics [21]. Energy concepts have been less studied. Even young children know and use the word energy, and have definite ideas about what it means—such as which things have or don't have energy [1–6]. These ideas have some overlap with the concept of energy as it is understood in physics, such as associations with motion, heat, and electricity, but they also have crucial differences, such as the association with life or volition and, perhaps most important, the lack of an idea of conservation. We have little understanding of how learners accomplish the conceptual change from their preinstruction concept of energy toward adopting a concept of energy as it is understood in physics—except that, with conventional instruction, most learners do not accomplish that transition [24–26]. Research has tended to focus on big and presumptively difficult ideas, such as work, potential energy, chemical energy "in" foods and fuels; energy conservation; and dissipation and degradation [2,9,10,27–30].

Kinetic energy seems to have been implicitly assumed to be unproblematic—and indeed, our results support such an assumption, *as long as one is only concerned with the motion of individual objects*. In the case of the composite systems considered here, if the active and passive components of the system are moving in tandem, it makes little practical difference whether the system's total kinetic energy is divided between the two objects or attributed entirely to the active component—consistent with the common sense association of energy with things that move on their own—although attributing kinetic energy to each component separately is certainly more conceptually coherent. As Lauren, Henry, and Megan recognized, however, once one of the components is stopped or removed from the system (e.g., by dropping through a manhole), the issue can no longer be avoided.

In limiting their assignment of kinetic energy only to some moving objects under some conditions, many of the learners represented in our data appear to have only partly integrated the physics concept of kinetic energy into their overall understanding of the concept of energy. Their process of conceptual change regarding energy and motion is incomplete, even though they seem to have accepted the canonical association of energy with motion.

Posner *et al.*, in their analysis of conceptual change in science, posit that for accommodation (i.e., full cognitive integration) of a new concept to occur, there must be *dissatisfaction* with the previously existing conception, and the new conceptual understanding must be *intelligible*, *plausible*, and *fruitful* [16]. From our results with both schoolchildren and adult learners, it seems that the idea that moving inanimate objects possess energy is *intelligible*, and, at least under some circumstances, *plausible*. After only a few activities, all of the elementary students studied accepted that the slowly moving car had energy, and most of them explained their answers by saying that the car was moving. For many, however, the kinds of questions raised in these examples, involving systems in which one object is being carried or pushed by another, raised dissatisfaction or discomfort with the attribution of energy to the passive object. The plausibility of that idea seems to be in doubt. Lauren expresses this clearly: "So I'm kind of, like, struggling with that, like, would it be moving without the skateboard? But it's still moving."

For Lauren, and many of the other teachers and students, associating motion energy with an inanimate object seems to be plausible when the object moves, at least for a while, without the action of an external agent; when it moves fast; or when it has an attribute, like wheels, that is associated with the ability to move. The idea seems least plausible for something like the slowly moving wooden block. The students' answers, and the teachers' discussions, reflect a variety of strategies to assimilate the principle that moving objects have kinetic energy with their preexisting ideas about the nature of energy. Some seek to limit the principle to certain kinds of objects (such as those with wheels) or certain kinds of motion (such as high speeds), or even by redefining the concept of motion itself as applying only when the object is moving on its own. These adjustments allow the learned concept that motion implies kinetic energy to coexist, however tenuously, with a strongly held sense that an object like the wooden block does not, or perhaps can't, have energy.

The more challenging task of fully accommodating the general principle that *all* moving things have energy may not appear *fruitful* as long as the two objects in the system stay together, but many of the students, as well as the teachers quoted above, spontaneously raised the question of what happens to the block if the car stops pushing it or to the box if the skateboard falls into a manhole. These examples seem to create the necessary *dissatisfaction* with the preexisting idea that the passive object does not have the energy of its own. If the formerly passive object continues to move on its own, after the active component is removed from the system, then the passive object must now have kinetic energy, and it might then make sense to say that it already had that energy when it was being pushed or carried. Megan, for example, says "that would do it for me," when it is suggested that the block could have wheels that would allow it to keep moving. For Lauren, whether the box on the skateboard would keep moving and thus deserve to be assigned its own energy, depends on how fast the system is moving. It is yet another step, however, to generalize that conclusion to a case in which the passive object would not appear to keep moving. Henry seems to suggest that his examples of the skateboard or bike suddenly stopping are enough to answer the question in general, but it is less clear that Lauren, George, Megan, or Judith, was ready to take that additional step toward full accommodation.

IV. TENTATIVE IMPLICATIONS FOR PHYSICS INSTRUCTION

The plasticity exhibited by these learners in applying what physicists take to be universal principles presents an instructional challenge for physics instructors in high school and college. The authors were frankly surprised by the resilience of the idea that an object that is moving under the influence of an external agent does not have kinetic energy of its own, and we did not systematically assess instructional strategies to address it. The most we can offer are tentative suggestions, based mainly on our observations from the teacher workshops.

As noted above, multiple teachers spontaneously raised the issue of what would happen if the active agent were abruptly stopped or removed, and the open-ended, lightly guided discussions seemed to be productive for many participants. As the speed decreases, and the passive object becomes more inert (e.g., no wheels, high friction), these scenarios seem to create, for some learners, a growing tension between the desire for a consistent answer to the question of the passive object's energy—regardless of the details of the situation—and an intuitive sense that energy should not be attributed to something like the inert, slow-moving wooden block in the block-push scenario. In a classroom environment, such a discussion could be stimulated by a clicker question or small-group activity. In our examples, neither the leaders nor the participants explicitly highlighted this tension between the goals of having a consistent, general model of energy and of having a model that fits comfortably with common sense notions of energy. Perhaps drawing explicit attention to these conflicting goals, in an all-group discussion, would both help clarify the immediate issue and provide an example of model-based scientific reasoning.

This paper explores a rather small point of understanding about kinetic energy, but it illustrates a larger point about conceptual change: Even in the case of concepts—like kinetic energy—that appear straightforward to experts and seem to have been readily accepted by students, that apparent acceptance can represent assimilation rather than accommodation. That is, the canonical understanding may be adopted only contingently, in certain contexts (especially those, like textbook and exam problems, that come overtly labeled as "physics"), while other situations may prompt a reversion to preinstruction, common-sense understandings.

Moreover, often instructors are unaware—until they come up—of the situations that will provoke this kind of cognitive tension between physics principles and common-sense conceptions. The authors were surprised at how difficult it was for some adult learners to accept the idea that the passive object in these scenarios had kinetic energy, and at the many (irrelevant, to us) factors—such as the speed of the system or whether the passive object had wheels—that came into their thinking. The learners themselves may be equally unaware of the cognitive conflict until confronted with a situation that raises it. It seems clear from George's reaction to the skateboard question that the conceptual difficulty it presented was totally unexpected. During the course of multiple workshops with different groups of teachers, moreover, no one raised such a case when the teachers were collectively agreeing upon the principle that moving objects have kinetic energy. For some teachers, simply referring back to that earlier conclusion was enough to resolve the conflict, but others clearly continued to struggle. It is up to instructors, then, to make a point of posing realistic cases that extend or explore the concepts we're teaching, to see where they may run into resistance from strong preexisting ideas.

V. LIMITATIONS AND FUTURE DIRECTIONS

The evidence presented here indicates that, for at least some learners in some contexts, the idea that an object being carried or propelled by another agent may not have kinetic energy persists even after conventional physics instruction. Because of the small numbers of individuals involved, our limited information about their prior physics instruction, the narrow range of instructional contexts, the specific scenarios discussed, and our relatively superficial access to their reasoning, a great many questions remain, even about this specific idea. How prevalent is this idea? How much is it affected by formal physics instruction? What kinds of scenarios are most likely to evoke it? How are the learners thinking about energy as they seek to reconcile their intuitions about the (lack of) energy of passive objects with what they have learned about kinetic energy? What instructional approaches are most effective in helping them fully accommodate the scientific concept of energy? Each of these could be the subject of future research, whether in the form of broad surveys to assess prevalence in various populations and scenarios, investigations of possible instructional interventions, or in-depth interviews to probe more deeply into the thinking that underlies this idea about kinetic energy.

VI. CONCLUSION

Does a dog in a moving car have kinetic energy? Yes, but for some learners—including some college students who have studied physics—maybe only because it is alive, because it has legs, or because it would be thrown forward if the car braked hard.

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