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Talking to Learn Physics and Learning to Talk Physics

Danielle B. Harlow & Valerie K. Otero

University of Colorado, Boulder, CO 80309-0249
Danielle.Harlow@colorado.edu

Abstract. Many words are used in physics differently than they are used in everyday speech. Thus, physics learners must develop conceptual understandings of physical phenomena while learning to use words in new ways. This simultaneous construction of physics concepts and discourse requires that students talk about partially understood concepts using partially acquired vocabulary. Our analysis shows that the development of physics discourse and conceptual understanding, while intricately related, are separate processes.

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INTRODUCTION

When asked, "If a single force continues to act on a cart, what will happen to the cart?" Deb and Amy, adult students in a physics course, answered, "It accelerates." They even challenged other students' claims that a force acting on an object would cause an object to move at a constant speed. Later, in an experiment in which they attached a small fan (providing a constant strength force) to a low friction cart, Deb and Amy incorrectly predicted that the cart would move at a constant speed.

PER researchers have made progress in explaining why such contradictory statements are common [1]. We add to this ongoing dialog by investigating the phenomenon through a language-based approach. We argue that considering the learning of language and conceptual understanding as separate yet simultaneous processes may help us explain why contradictory statements are an expected part of learning physics.

The Role of Language

According to linguists (e.g, [2]), individuals acquire patterns of talking that correspond to different communities that they participate in. Thus, in science classes, students not only gain new understandings about how the world works from a science perspective, they also learn to *talk science* [3]. They develop new vocabulary (and new meanings for common words) and learn to combine this new vocabulary into sentences which are considered meaningful in the science community. Lemke [4] considered the ways students appropriate the language of physics and found that students are usually expected to pick up the language implicitly from their textbooks and teachers. One teacher in his study, however, taught his students to associate the word *voltage* with the word *across* and the word *current* with the word *through*. Lemke claimed that this direct instruction about which preposition to use with voltage and current helped students construct correct sentences about circuits.

While we do want students to be able to talk about physics with confidence and accepted terminology, we also want them to develop conceptual understanding; we want our students to *talk and think* physics. In the above example, it is unclear whether these students understood the ideas of voltage and current any better than before, despite being able to construct intelligible sentences about circuits.

While conceptual understanding and language skills often develop simultaneously, one does not necessarily imply the other. Knowing that physicists say, "a force causes acceleration" and "force is not transferred during an interaction," is different than developing a conceptual understanding necessary to predict with confidence that if a fan unit (which provides a constant force) is placed on a low-friction cart, the cart will continue to speed up rather than move at a constant speed. In this study we argue that the development of physics discourse and conceptual understanding are different processes that depend upon one another for successful physics learning. The remainder of this paper examines the discourse and conceptual development of *force* for two students in a physics course.

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DATA AND ANALYSIS

We examined video data taken from a physics course using the *Physics for Elementary Teachers (PET)* curriculum [5] which was offered as a two-week (60 hours of class time) intensive summer class. The PET curriculum consists of small group activities and discussions and whole class consensus discussions. We video taped one small group (Deb and Amy) during all activities and discussions. This allowed us to follow the conceptual and language development of these students for the duration of the course. In this study, we examined the students' development of the discourse and conceptual understanding of *force* in a portion of an activity.

Developing Discourse

When initially asked why a ball moves across grass after it has been kicked, Amy and Deb discussed their answer and then wrote, "The ball continues to roll because of the force of the energy" as their answer. Research has shown that many students make statements similar to Amy and Deb's, using the words *force* and *energy* interchangeably and using the word force to talk about something that is transferred from one object to another, causing motion [6]. Interactions and Forces, the second unit of the PET curriculum, is designed to help students understand forces as pushes and pulls and to distinguish the idea of force from motion and energy. To this end, students conduct experiments such as pushing a low-friction cart on a track and recording its motion and feeling the pressure from the cart on their fingers. They compare speed and force graphs produced with a computer simulator which show that there is no net force acting when the cart is moving at a constant speed.

The episode we discuss below begins with the students being asked about the force on a cart when a short quick push was given. The first question asks, "Do you think the force of the hand was transferred from the hand to the cart during the interaction and then continued to act on it after contact was lost?"

At this point in the course, despite having the word defined on the first page of the unit and conducting the activities described above, force is a puzzling concept to the students. In fact, we found that students used the word *force* in 20 different ways during this one activity. They use the word force not only in ways that a physicist would use *force*, but also in ways that physicists would use the words *energy*, *acceleration*, *velocity*, *momentum* and *motion* and sometimes the word *force* in the students' dialog could be replaced by the phrase *a mysterious entity*.

How can these students answer the question of whether force is transferred? The answer depends on what the words *force* and *transfer* mean to them and their understanding of what these words mean to physicists or at least to their teacher. As shown in the following transcript, the students began their discussion stating that force was transferred.

97	Deb	((Reading)) do you think the force of the hand was transferred from the hand to the cart during the interaction and then continued to act on it after the contact was lost?
99	Amy	I guess. Because look ((points to computer graph)) *some force is there because it keeps moving*

Amy claimed that force was transferred because of the evidence from a speed graph that *the cart was moving*. Further into this conversation, Amy and Deb considered that force and motion might be different concepts and that the words might have different uses.

102	Deb	Well, what is the relationship between force and motion?
104	Amy	((writing)) Some force OR movement is occurring because the cart
105	Deb	Right ((writing)) some force is
106	Deb	Can you just have motion without force? I guess is the question. So is it really motion that is moving it? When you're not pushing it with your hand?
107	Amy	Ahh is it motion? Is it force? Or both?

Deb and Amy wondered if *force* and *motion* are the same thing and if one can exist without the other. They even considered that *motion* might move the cart. Later in the activity Deb used the curriculum-driven question, "At what point did the push stop acting on the cart?" to rethink her use of the word force.

118	Deb	((reading)) At what moment do you think the force of the hand stopped acting on the cart?
119	Deb	See I don't think it did and so that would mean that it wasn't motion- well that would mean that it was both. Because I don't think that the force of the hand stops acting on the cart when it's traveling, you know, when it's traveling on its own. The force is still
120	Amy	The force is still with it
121	Deb	So then it would be both. I think it's both here.
122	Amy	But it says, "at what moment"
123	Deb	((reading)) "Do you think the force of the hand stopped acting on the cart?"
124	Deb	I don't think there was a moment. I don't think it ever did stop.
		((7 lines deleted))
132	Deb	The question doesn't seem to indicate that that's an optional answer, you know? Cause it doesn't say, "At what moment, *if any*,"
		((3 lines deleted))
136	Deb	I think [force] continues, don't you? Why would it stop? Well, see I don't know enough about forces
137	Amy	I don't know enough
138	Deb	Does it just stop after you?
139	Amy	Right. Or is it a different kind of force?
141	Deb	And then does it become motion? Then maybe it becomes motion. There's a force of hitting the cart, then it becomes motion
143	Amy	Either the force continued or the force stopped and the motion took over

When Deb and Amy were asked *at what moment* the force of the hand stopped acting on the cart, they were prompted to conclude that the force is not transferred. Although Deb said that she didn't think it ever stops acting, the question does not ask her, "When, *if at all*, does the force stop acting?" therefore she must identify a point in which the force stops acting. Later, Amy considered that *energy* rather than *force* might be transferred from the hand to the cart.

178 Amy Here's our, well we need an answer. Is it energy, force or both or neither? I don't think it's neither. We think it's, is energy transferred? Or is force?
179 Deb it's not neither
180 Amy ((whispers)) I think it's energy
181 Deb What do you think is transferred
182 Amy ((excited))I think energy is transferred ((bangs hand down))
183 Deb from the hand to the cart
184 Amy It's not a force. The force is the initial thing. I think. ((with more conviction)) I think energy is transferred.
185 Deb You don't think it's both?
186 Amy No. ((shakes head)) I don't.

Amy and Deb agreed that energy is transferred during an interaction and that force is not. They stated their ideas in a whole class discussion and even convinced other students that force is not transferred.

Through their curriculum-guided discussion, Amy and Deb appropriated more accepted ways of talking about force. The graph below illustrates the development of the students' use of the word force during the 10 minute conversation discussed above. Each line of the transcript in which the word force was used (unless students were reading the question) was assigned a value based on how accepted their use of the word would be to a physicist listening to them at that time. Phrases such as, "the force continues after the hand has left the cart" were coded as 1 and phrases such as, "the force stops after the interaction" were coded as 3. Statements in which the students explicitly stated that they did not know what the word force meant were coded as 2 (Interrater reliability=96%).

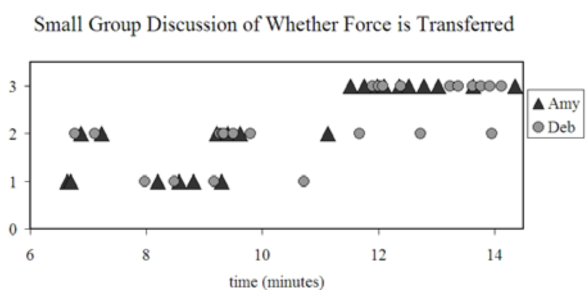

Figure 1. Graph of students' use of *force*.

The graph shows that by the end of the discussion, Amy reliably used the word force in ways that would be accepted by physicists and Deb no longer was using the word incorrectly though she still expressed confusion. They learned not to say that force is transferred and that force and motion are different words with specific uses. Amy and Deb developed an understanding of how to use the word *force* with respect to transfer.

Conceptual Development

Thus far we have only considered the students' development of proper use of terminology. We examine Deb and Amy's conceptual development in this section. Despite goals of conceptual understanding, in many physics courses, acquisition of vocabulary is often what seems to matter. If students can *talk* about ideas in accepted ways, it is often assumed that they also have conceptual understanding.

Deb and Amy made phenomenal progress during this activity. Learning how to use the word *force* is a difficult and important task. However, whether they have actually understood the *concept* of force is unclear. The following day, they expressed their uncertainty about the difference between force and energy.

1692Amy Is energy and force the same thing?
1693Deb That's one of those things we were talking about yesterday.
1694Amy Let's clarify these vocabulary words so we know.

One way of directly comparing vocabulary use to conceptual understanding is to determine if students can talk about phenomena without the specialized vocabulary. A subsequent activity provided an opportunity to explicitly compare the students' use of the term *force* to their conceptual understanding of force. Instead of focusing on the idea that force is not transferred during an interaction, the following example focuses on an activity in which they are discussing how a continuous force impacts an object's motion. Earlier in the course, they learned that force causes acceleration by examining motion detector graphs and computer simulator produced graphs. Evidence for conceptual understanding of this idea would be that Amy and Deb expect that an object that is pushed will speed up whether or not the vocabulary of force and acceleration is used.

In the activity, Deb and Amy predicted what would happen when a fan is put on a low-friction cart twice, once using formalized physics vocabulary and once in concrete everyday words.

966 Deb (reading) If a cart is at rest and a single force acts what's happened?
967 Amy It moves! (reading) "If a single force continues to act on the cart what will happen to the motion?" It will accelerate!

As shown in the transcript above, the question is asked first in terms of force vocabulary. Deb and Amy correctly predicted that a continued force will make the cart accelerate. However, when they were asked to imagine a low friction cart at rest on the track and describe how it would behave if it were pushed with a constant strength push, they answered, “It would continue moving at the same rate,” and drew a graph like the one below:

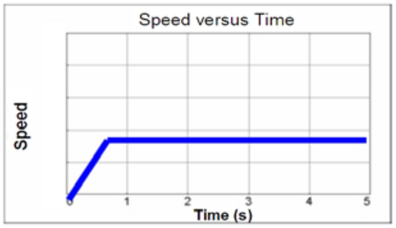

FIGURE 2. Amy and Deb’s graph of speed vs time

When they conducted the experiment, Deb and Amy noticed that the cart sped up. Deb observed the actual speeding up of the cart on the track and Amy noticed that the graph of speed verses time on the motion detector showed increasing speed. Both expressed surprise. Following is an excerpt from their conversation after the experiment.

1530	Deb	We said if an object is pushed continuously, it will move at a constant rate. That's wrong
1531	Amy	Well it depends on what's pushing it - oh wait a moment
1532	Deb	But the fan was just pushing it and it sped up
1533	Amy	Oh you're right
1534	Deb	So we were proven wrong right?
1535	Amy	It'll increase in speed

After seeing that their ideas did not match their observations, they corrected their graph and their answers. Even so, much of the following class discussion focused on this observation. While most students initially stated that a force makes things accelerate, they had trouble believing this observation.

Difficulty in believing that an object will continue to speed up should not be unexpected. Based on students’ experiences (in a world with friction), they expect to have to continue pushing on object to keep it at a constant speed. What is more surprising is their earlier statement that friction makes things accelerate.

Amy and Deb develop a better conceptual understanding throughout the unit. Eventually, they routinely expect that if a cart is pushed, it will speed up, unless an opposing force is acting on it - both when using physics terms and when talking in everyday terms. However, at any given time, their conceptual development did not necessarily match the way they used terminology.

The above example demonstrates that the correct use of science terms is not necessarily evidence for conceptual understanding. Deb and Amy learned to associate the word force with acceleration before they believed that a force caused acceleration. The converse may also be true. We could talk about the concepts they already understand but do not yet have the science vocabulary to talk about them.

DISCUSSION AND IMPLICATIONS

Discourse and concepts are *not* the same things. We cannot assume that the acquisition of one implies the other. In physics courses, individuals must develop both discourses and conceptual understandings and they must link these together. This is not a new idea. Vygotsky [7] claimed that people have both experience-based knowledge and scientific knowledge (knowledge gained from books and school). While experience-based knowledge may be more strongly held and difficult to change, it is easier for people to articulate their understanding of their highly vocabulary-based scientific knowledge. These two types of knowledge develop together. As individuals develop vocabulary that allows them to articulate their experiential knowledge, they can further develop their understanding which, in turn, allows them to refine their use of terminology.

The terminology of physics is not just a matter of vocabulary; it is a tool through which we and our students make meaning. Thus, it is not surprising that students often make apparently contradictory statements. They are learning the language and the concepts at the same time. While they may be talking with newly acquired vocabulary, they may also be reverting to old uses of the words to talk about new concepts. Appropriating science discourse and conceptual understanding are equally important and further research is needed to understand the relationship between discourse and understanding.

ACKNOWLEDGMENTS

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