What Is Speed: A Young Chinese Adult Non-Scientist's

Epistemologies and Her Understandings of Speed

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Abstract

In science education studies, researchers have thoroughly investigated the epistemologies held by students who are learning science. These research findings, however, have yet to be applied to individuals who are not currently enrolled in science classes. Additionally, these studies have primarily focused on individuals from Western cultures and who are native English speakers. In this paper I examine an individual to see whether the research claims in relation to students' epistemologies still apply to someone with different characteristics. Overall, I aimed to investigate whether Hammer and colleagues' claims concerning learners' epistemologies (e.g., Hammer, 1994; Hammer, Elby, Scherr, & Redish, 2005) can be more widely applied than their previous research has indicated by extending these claims to individuals who lack advanced science training, have had different learning experiences, and who grew up speaking and learning in another language and culture. The findings show that previous theoretical frameworks can be used to explain the epistemologies of the individual examined in this study. The case suggests that these theories may apply to individuals regardless of the learner's science background, language, education experience, and cultural background. More cases should be examined with learners with different academic backgrounds and from different cultures if we want to provide more compelling evidence for this claim.

Introduction

In science education studies, researchers have thoroughly investigated the epistemologies held by students who are learning science. These researchers have come to the consensus that students' epistemologies, their understandings of the nature of science and the learning of science, can be categorized, and that different epistemologies affect how students approach science problems in different ways and understand science concepts differently.

These research findings, however, have yet to be applied to individuals who are not currently enrolled in science classes. Additionally, these studies have primarily focused on individuals from Western cultures and who are native English speakers.

In this paper I examine an individual named Klara to see whether the research claims in relation to students' epistemologies still apply to someone with different characteristics. Klara's characteristics are unlike those examined in previous studies: 1) she has not taken a single science course in the past 8 years; and 2) her education until the end of her undergraduate career was in her native country China. In 10th grade, Klara took algebra-based physics for one year, where the concept of velocity[1] was addressed. After that class, however, she had no further schooling in science. At the time of the interview, she was 25 years old and studying Museum Education in graduate school. Given these characteristics, I wanted to examine whether the frameworks about learners' epistemologies described in prior studies by Hammer and colleagues

[1] In Chinese, "velocity" and "speed" are the same word, so there is no verbal difference when the subject says "speed" (an everyday word describing how fast an object is moving) and when she says "velocity" (a physics term for the vector describing how fast and in what direction an object is moving). When translating the conversation, carried out in Chinese, into English in this paper, I use the word "speed" whenever Klara spoke. By doing this, I am assuming that because of her novice background in physics it is unlikely that she would use the physics term.

(e.g., Hammer, 1994; Hammer, Elby, Scherr, & Redish, 2005) still applied to individuals such as Klara. To this end, I examined two main research questions:

1) What epistemologies of science does Klara exhibit during the interview?

2) How do Klara's epistemologies affect her understandings of science concepts?

Overall, I aimed to investigate whether Hammer and colleagues' claims concerning learners' epistemologies can be more widely applied than their previous research has indicated by extending these claims to individuals who lack advanced science training, have had different learning experiences, and who grew up speaking and learning in another language and culture.

Theoretical Framework

Epistemological Beliefs and Epistemological Resources

Scholars in this field have developed two perspectives regarding learners' epistemologies: a *beliefs* perspective and a *resources* perspective. Hammer, Elby, Scherr, and Redish (2005) contrast these two approaches in interpreting learner's epistemologies, emphasizing that *epistemological beliefs* are unitary and stable, whereas *epistemological resources* are fine grain-sized, sensitive to context, and subject to shift due to various triggers in the situation, such as the instructor's prompts, for example.

In his early work on epistemologies of college students taking introductory physics courses, Hammer (1994) claimed that college students held epistemological beliefs that can be characterized along three dimensions linked to the structure, content, and learning of physics. Using Hammer's terminology for different types of epistemologies along the dimension related to the structure of physics, if a student sees it as a system with coordinated components, his/her belief is categorized as "Coherence." If a student sees the structure of physics as loosely related fragments, his/her belief will be categorized as "Pieces." In the second dimension related to the content of physics, if a student sees physics as a collection of terms and equations and these verbal and mathematical symbolisms are used for answering questions and solving problems, this belief is categorized as "Formulas." If a student believes that physics equations must have underlying conceptual explanations, then this belief is categorized as "Concepts." Along the third dimension related to the learning of physics, a student's belief can be categorized as "By Authority" if s/he believes that learning physics is receiving information from the teacher or the textbook, or as "Independent" if s/he believes that learning physics involves constructing one's own understanding.[2] When students hold epistemological beliefs, these beliefs are, according to Hammer (1994), unitary and consistent across context. These beliefs make students approach physics problems in particular ways: to make sense of phenomena and try to explain them in everyday language, or to pull out formulas from a textbook and plug in numbers and get the answer.

In his later work, Hammer, together with his colleagues, proposed an alternative way of interpreting students' epistemologies—from a *resources* perspective (Hammer, 2004a; Hammer et al., 2005). From this perspective, students are seen as activating sets of *epistemological resources*. These resources include the

> ones for understanding the source of knowledge (*Knowledge as transmitted stuff*, *Knowledge as fabricated stuff*, *Knowledge as free creation*, and others); forms of

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[2] In his work, Hammer (1994) also found some intermediate beliefs that cannot be definitively categorized into any of the above 6 basic groups along the 3 dimensions. For example, Weak Coherence/Weak Conceptual represents the beliefs that physics should be a coherent knowledge system and the formulas should have conceptual meaning underpinning the formulas, but the responsibility to make the system coherent and the formulas meaningful lies with the experts, not with the learners themselves (Hammer, 1994).

knowledge (*Story*, *Rule*, *Fact*, *Game*, and others); knowledge-related activities (*Accumulation*, *Formation*, *Checking*, and others); and stances toward knowledge (*Acceptance*, *Understanding*, *Puzzlement*, and others). (Hammer et al. 2005, p. 8)

Compared to epistemological beliefs, epistemological resources are more numerous, less formalized, and in much smaller units. They are loosely connected, sensitive to context, and subject to change easily. Here I elaborate on this resources perspective by giving a hypothetical example. In a traditional lecture class, students may activate epistemological resources including *knowledge is facts and rules*, and *learning is accepting what the lecturer delivers*. Activating these resources, students choose to approach problems by looking up textbooks or their notebooks for the facts and rules they consider relevant to the problem and solving the problem based on them. However, in a hands-on, project-based learning activity, students activate other epistemological resources, such as *knowledge includes both the product and the process of exploration and investigation*, and *learning is communicating ideas and experiences*. These activated resources cause students to approach problems by applying their findings (empirical correlations between two variables, for example) from the project and making multiple rounds of trial-and-adjustment until they are satisfied with the result.

The connection between the *beliefs* perspective and the *resources* perspective is that if a resource, or a set of *resources*, appears to be consistently applied across different contexts, and shifts or variations are not identified, then that set of *resources* can be, at least functionally, equal to a particular stable *belief* or a particular combination of *beliefs* (Hammer et al., 2005).

In the present study, I wanted to look at Klara's epistemologies through her responses during the interview: does she hold stable epistemological beliefs (and if so, what are they?), and/or does she activate epistemological resources?

Stability of Ideas and the Mechanisms of Stabilization

Within the field of educational studies, one goal of studying and modeling learners' epistemologies is to find out the roles they play in conceptual learning, thus to inform pedagogy. There are many kinds of roles that epistemology can play in learning. The present study mainly focuses on examining a claim that Hammer and his colleagues made: epistemologies can help to stabilize a set of "learning resources" (Hammer et al., 2005). I briefly explain this claim below.

Hammer, Elby, Scherr, and Redish (2005) viewed learners as possessing a rich repertoire of *learning resources* and responding to questions by activating a "locally coherent" set of resources (p. 5). When Hammer et al. (2005) discuss *learning resources*, resources include both conceptual and epistemological ones, and they are most of the time intertwined. *Epistemological resources*, a subset of *learning resources*, have been reviewed in the previous section. *Conceptual resources* are those relevant to the cognitive aspects of understanding. Instances of conceptual resources are intuition, common sense, and semi-formalized rules, such as p-prims (diSessa, 1988). Contrasting *conceptual resources* with unitary *(mis)conceptions*, and *epistemological resources* with unitary *epistemological beliefs*, Hammer et al. (2005) emphasize the instability of *resources* or combinations of *resources* (referring to both conceptual and epistemological, the same below if not specifying whether conceptual or epistemological). In a certain situation, what *resources* are activated, to what extent they are structured, and how they structured, is temporary and sensitive to context. When students respond to questions, they activate resources, and often shift among different resources, or among different sets of resources, in a very short period of time. Triggers for these shifts are many, such as interviewer/instructor's prompts, students' own reflection, or other aspects of the situation (Hammer et al., 2005).

However, a resource combination could be stabilized over time. Hammer and his colleagues (2005) discuss three mechanisms for stabilizing a set of resources: *contextual*, *deliberate*, and *structural*. *Contextual* mechanism is a passive mechanism of stabilization. In this mechanism, no epistemological resources are involved. A set of resources becomes stable simply because the questions these resources intend to answer are always put in the same context. The second mechanism, *deliberate* mechanism, is the one that involves the role of epistemologies. In this mechanism, the subject deliberately monitors her argument and checks the resources she has activated, trying to make global coherent explanations. Over time, a globally coherent structure emerges and stabilizes. When the structure is crystallized, the learner becomes less and less "mindful" when checking coherence (Hammer et al., 2005, p. 18). The third mechanism, *structural* mechanism, means that the same structure of a set of resources are repeatedly used and thus become stable. When a set of resources becomes stable, this set could be viewed as a unitary conception/belief (Hammer et al., 2005).

For the present study, I will be mainly focusing on examining the second mechanism Hammer et al. claim for stabilizing a resource set, *deliberate*. By presenting the participant science problems and tasks, I wanted to identify how she understands science concepts and how she approaches the problems and tasks. Furthermore, I aimed to find out whether or not her understandings of science concepts are stable, and if so, whether or not her epistemologies played a role in stabilizing them.

The Study

The goal of the interview was to investigate Klara's understandings of speed and acceleration. There have been other similar studies regarding students' understandings of these same concepts (e.g., Raven, 1972; Trowbridge & McDermott, 1980, 1981), but my methodology differs from those studies in a couple ways:

1) The subject in this study is a non-scientist adult interviewed in a non-school setting. In other studies, the subjects have been either elementary students (Raven, 1972) or college students (Trowbridge & McDermott, 1980, 1981). They all have been interviewed or tested in schools. The college student subjects were taking physics classes covering content about motion.

2) In this study, the questions presented to the interviewee were more open-ended. In other studies mentioned above, there were judgments about the correctness of the answers that subjects provided to the questions, or judgments about the appropriateness of the participants' performance on the tasks. This study does not intend to judge the participant's responses as right or wrong.

The interview was videotaped and later transcribed. Interview transcripts, notations, and drawings Klara made during the interview were analyzed. This interview was carried out in Chinese and translated by the interviewer later into English.

The setting for the interview is shown in Figure 1. Klara was seated at a desk on which an inclined track was placed. One book was placed under one end of the track to make it slightly inclined, and another book was later added to this same position, making the track incline steeper than before (see Figure 2). A cart was released from the upper end and slid down to the lower end. Note that the surfaces between the track and the cart have little friction. Klara was allowed to play with the cart and track by herself besides observing my operation of it.

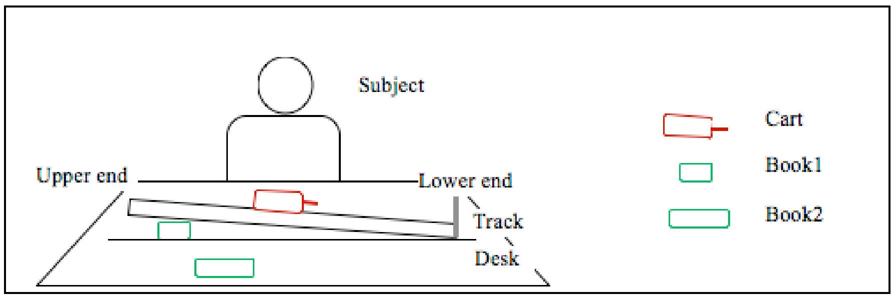

Figure 1. The setting for the interview with Klara.

During the interview, after presenting the sliding of the cart, I asked Klara questions such as: “What did you notice?”; “What do you mean by … (a particular word she had used or a particular drawing she just produced, etc.)?”; “Could you show this idea in other ways?”

As the conversation continued, I asked more specific questions. For example: 1) “When the cart slides, did you notice any difference between the beginning and the end?” (this question was intended to probe Klara’s understanding of non-uniform speed during the motion); and 2) “What’s the difference between when I put two books here [to make the track incline steeper]; and when I only put one book here [making the track less inclined]?” (see Figure 2; this question was intended to probe Klara’s understanding of the different accelerations—not necessarily using this word—in these two situations).

Figure 2. Less inclined (flatter) track and more inclined (steeper) track.

In the next section, I will present the interview and discuss relevant issues for the present study. The entire interview lasted ninety minutes, in which I tried to identify Klara's epistemologies. Additionally, I wanted to look at whether there were shifts among different epistemologies when she was answering questions in different contexts. If there were identifiable shifts, she would be characterized as activating epistemological resources, and then I wanted to investigate what triggered those shifts. If no shifts were identified, however, I would conclude that she holds epistemological beliefs. Besides identifying Klara's epistemologies, I also explore the stability of her conceptual understandings and the mechanism of stabilization. To be more specific, I will examine whether and, if so, how Klara's epistemologies help to stabilize her understandings of physics concepts.

I discuss Klara's epistemologies from two aspects: the first being the nature of science knowledge and the second concerning science related activity and her epistemological framing of the activity itself (Hammer et al., 2005). Undoubtedly these two aspects are closely related. For example, if her epistemological framing of the activity is "to make sense of the phenomena presented to her," then this probably implies that her epistemologies about the nature of science knowledge are "knowledge must help us make sense." On the other hand, if her epistemology about the structure of science knowledge is "knowledge is a coherent system," then it is possible[3] that her epistemological framing of the activity includes "coordinating different forms (words, formulas, and graphs, etc.) of knowledge and making them coherent."

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[3] I say *possible* here because as Hammer has pointed out, some students may believe that science knowledge is a coherent system, but it is not their own responsibility to make it coherent; someone else, scientists, textbook writers, or instructors, have done this job already (Hammer, 1994). For students like these, the epistemology about the nature of science as "science knowledge is a coherent system" does not relate to an epistemological framing of their activity as "coordinating various forms of expressing the knowledge."

To analyze how the participant's epistemologies affect her conceptual understanding, I show in the next section her evolving understandings of the concept of speed across the interview, which I think exhibits the most salient thinking or learning process during the interview.

The presentation of this interview is organized into several successive sections: a pre-story, three successive episodes about the participant's responses to questions about the concept of speed, and a post-story. I present the pre-story because it displays the context in which the participant first brought up the word "speed" and also her first step in framing the activity. Following the pre-story, I present three episodes with each episode focusing on the participant's understandings of a specific aspect of the concept of speed: 1) speed in general, 2) average speed, and 3) instant speed. Lastly, I present the post-story because it shows that the participant's confusion about instant speed (this confusion is especially relevant to her epistemologies, as will be shown shortly) remained until the end of the interview.

Results and Discussion

Pre-story: The Context and Klara's Introduction of the Word "Speed."

At the beginning of the interview, I released the cart from the upper end of the inclined track (see Figures 1 and 3). The cart slid down and reached a vertical slate installed at the lower end of the track, so the cart bounced back a certain distance and slid down again. It did this sliding-down-and-bouncing-back action a few times before the cart came to rest at the lower end of the track. Then I asked Klara: "What did you notice?"

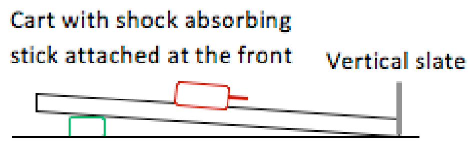

Figure 3. Vertical slate on the track and shock absorbing stick on the cart.

She responded with:

> I noticed that the cart went down and bounced back. After several bounces, it stopped. I found that when the cart started from a higher point [on the track], it bounced back a longer distance, than [the distance of bouncing back] the next time when it slid from a lower point [on the track] (see Figure 4).

Figure 4. Two successive sliding down and bouncing back movements.

After she described what she saw, I asked her to explain this phenomenon. She said there might be some "strengths" driving the cart down, and when the cart collided with the vertical slate, there was a competing "strength" from the slate towards the upward direction along the track to bounce the cart back. After listening to her for a while, I noticed that her attention at that moment was on the phenomenon of "bouncing" and a concept of "strength" (I was not clear about the exact meaning of this concept for her). Because my goal in this interview was to probe her understanding of the concepts of speed and acceleration, I did not want her to spend too much time focusing on the phenomenon of bouncing, which at that moment I thought had more to do with forces. However, I did not want to press her to abandon her current thinking either. My thought was that doing so might make her less confident about her own responses and that might bias her to try to provide what I wanted her to say during the rest of the interview rather than focus on her own thinking. I struggled on my mind for a short time and decided to make her focus on the sliding-down part while still talking about the "strengths" she had brought up on her own: "Ok, let's leave the bouncing-back stuff for later, now just think about the process of sliding down. What are the 'strengths' you referred to, exactly?"

She murmured: "what are the strengths driving it down…". Then she said: "First there is gravity." I asked her: "What is gravity?" She answered, "It is an attracting force from the center of the Earth. It drags things down and how much a thing weighs, is how much gravity it has." When she could not talk more about gravity, she brought up another word: "inertia," and said: "Besides gravity, there might also be 'inertia' to keep the cart [moving] like this" (she released the cart from the upper end and watched it sliding down when she said this). I asked her to explain what "inertia" meant and she responded,

> Inertia might refer to, when you do something, for example, when you are moving, you have a kind of "strength" because you want to keep moving. But I don't know where inertia comes from.

She continued talking about inertia:

> When you drive and you brake, you still move forward for a while before you stop. I think all moving things have inertia. But I don't know whether inertia is a kind of force.[4]

[4] In Chinese, the word for "strength" and the word for "force" share a character. They are similar in both spoken and written forms. My interpretation is that this is the reason why she was switching between saying "strength" and "force".

Then she was stuck thinking about the meaning of inertia for quite a while. I asked her to clarify her understanding of the connections between "gravity," "inertia," and the phenomenon of the movement of the cart, and she answered with:

> Gravity makes the cart move down, and the inertia makes the cart move along this direction [gesturing to draw an imaginary line along the track from the upper end to the lower end]. It will not move toward me or away from me.

She tried to provide me with another example, besides the presented track-cart equipment, of her understanding about "inertia" and said, "Imagine you are walking along a slope." She stopped and thought for a moment, and then said, "[You] still need to have a certain *speed* so that you can have inertia[5]." This was the first time that Klara brought up the word "speed."

During this part of the interview, starting with an observation of the cart-sliding phenomenon, Klara talked very broadly and brought a lot of words to the foreground: strength, gravity, inertia, force, and speed. I did not force her to abandon her ideas that were not my main focus, but showed interest in every concept she mentioned and allowed her to navigate the phenomena freely. Under this condition, she brought up the word speed on her own, a concept in which I was genuinely interested.

In retrospect, I interpret this section of the interview as the first steps of Klara's epistemological framing of the activities I was presenting her with. From the questions I asked, she was able to frame the activity as one that involved my own interest in her own thinking; and one in which I was not looking for particular answers.

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5 What Klara called "inertia" in some sense resembles the disciplinary meaning of "inertia" in physics; that is, the attribute of an object that keeps it moving (or at rest) as it was. But she also took, although not very confidently, "inertia" as a "force" or "strength." This made the "inertia" she was talking about also resemble the naïve physics concept of "impetus", an inert agent in the direction of motion that drives the moving object.

Episode 1: Klara's Ideas About Speed.

At the end of the pre-story when Klara brought up the word "speed," I asked her, "What is speed?" She responded as follows:

> Speed? ... It is running fast or slow? Meaning during the same period of time, if you run a longer path, that means fast, the speed is fast; and during the same period of time, if the distance is shorter, the speed is slow.

She appeared to be surprised when I asked her "What is speed?" Before this question, I had asked her similar questions regarding other concepts she had brought up, such as "What is gravity" and "What is inertia." She was not very surprised by these questions, however. When I asked her "What is speed?" her responses seemed to show that she thought this was a silly question, perhaps because she thought everyone knew what speed was.

After she finished the above sentences, I moved on and asked her: "When the cart slides, did you notice any difference between when it [pointing to the cart] was at the beginning and when it was at the end [of the track]?" When I asked this question, I didn't necessarily expect an answer about the difference in the cart's speed. I meant any difference she might have noticed about the cart. I wanted to see what difference she would notice, related to speed or anything else. After I asked this question, she released the cart and watched it slide twice, and then said: "I feel the speed is getting faster when the cart is going down." She watched the cart slide a third time, and added:

> I feel when it [the cart] is at the higher part [of the track]… The speed is…Mm… To cover the same distance, it spends longer time. For example, if we mark the middle point of the track [pointing at the middle], the distances for each half are roughly the same.

Look, the time passing this part [the higher half] is longer than that of passing this part [the lower half].

When she was explaining this idea to me, she released and watched the cart sliding down one more time.

She noticed the increasing of speed as the cart moved closer to the end of the track, and used the middle point of the track to divide the track's length into two halves. By watching the cart sliding down the two halves successively, and by perceiving and comparing the time intervals, she claimed the speed began slowly and then got faster.

In her first statement about speed, answering my question of "What is speed," she claimed that speed was during the same period of time, if somebody ran a longer distance, the speed was faster; and if somebody ran a shorter distance, the speed was slower. That time, she brought up her understanding of the quantitative relationship among speed, distance, and time. Clarifying this relationship, she kept the time variable constant and compared the distance variable to decide which speed was faster. This time, when she responded to my question about the difference of the cart when it was at the upper end and at the lower ends of the track, she provided further evidence of her understanding of the quantitative relationship among speed, distance, and time. She kept the distance variable constant (by marking the half point in the track) and compared the time variable: the longer time spent on the upper half of the track corresponding to slower speed, and shorter time spent on the lower half of the track corresponding to faster speed.

I would claim that when Klara brought up and elaborated her understanding of the quantitative expression of speed, in relation to distance and time, her description had little to do with her memory of formal knowledge from school or a science course she had taken. She described her understanding in the contexts of everyday experience, running, and the cart-track phenomena in front of her. She was making sense of the word "speed" rather than gathering pieces of information for it from places that she believed to come from some external authority. This is evidence showing her epistemologies of science knowledge: science concepts make sense; they come from, and also refer to, phenomena.

I then asked her to show her idea about speed on a piece of paper.[6] She started to write, and murmured that she remembered having learned this before. She wrote down two lines of words, in Chinese (see Figure 5).

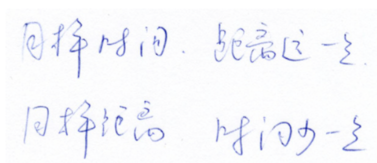

Figure 5. The verbal description of speed that Klara wrote. The first line reads "same time, longer distance", and the second line reads "same distance, shorter time."

Klara read them aloud when writing:

> I sort of remember I might have learned before that speed is, during the same period of time, if you run a longer distance, your speed is faster; or for the same distance, if you spend shorter time, your speed is faster.

I asked her if these two lines of words were expressing the same meaning. She said yes. I asked her why as well as why these two sentences about "distance" and "time" were actually talking about "speed." She pondered for a while and said: "I feel speed is the distance you run in a unit

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[6] From the first time, each time I asked Klara to show her idea on paper, I was expecting that she might possibly draw a graph. But until the very end of the interview, she never used this type of representation.

time." I asked her to explain "unit time." She answered with "a stipulated period of time and a standard to compare speed between us. It could be an hour, a minute, but has to be same for both of us." She clarified her idea with an example: "If you and I are running and comparing our speed, each of us is given one minute. If I run farther, then my speed is faster than yours." Because she had consistently brought up verbal descriptions of the quantitative relationships among distance, time, and speed, orally and in writing, I asked her to present her idea about "distance," "time," and "speed" she had expressed in Figure 5 in some other way she could think of. When presenting my request, I wrote on a paper the Chinese words "speed," "distance," and "time", next to one another (see top of Figure 6).

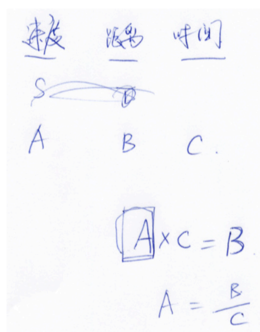

Figure 6. Formula of speed that Klara wrote.

At this moment in the interview, I just wanted her to think about any other ways—other than the verbal expression that she had already used—to express her ideas. She paused for a moment, probably because I didn't articulate my request well enough. I could identify some confusion on her face. She then added the letter S under the word speed to represent it, thought about what letter she should use to represent the word distance, and tried to write down D. I saw her struggling to find the appropriate letters for each word, but I did not care whether or not she would use the conventional letters for the three concepts, so I suggested that she arbitrarily use letters A, B, C. She immediately accepted my suggestion and added A for speed, B for distance, and C for time. She articulated the process of her thinking while she was writing down the mathematical formula of speed on paper: “Speed multiplied by time is distance.” She wrote the formula, A times C equals B (see in the middle of Figure 6). Then I asked: “How can this [formula] explain these two sentences [the verbal expressions in Figure 5]?” Klara answered while writing down the division formula at the bottom of Figure 6:

> So look, if we are going to compare speed. Speed is A [circling A in the formula]. A equals B divided by C [writing the division formula]. Then you only need to compare B and C… Oh, to compare my B and C with your B and C. So then if time is the same, time is B, oh no, time is C, if C is the same, then bigger B makes bigger A, and smaller B means smaller A. If distance... distance is B, if our Bs are same, then it is obvious that smaller C makes bigger A.

When she began to write down the word expression in Figure 5, she said she had an impression of having learned about speed. However, from the way in which she was expressing her idea, it was clear that she was not just reciting it or recalling without understanding.

So far, Klara did not have much trouble with the questions about speed. Although she occasionally struggled a little with a particular question, such as “what is a unit time,” she soon found a way to articulate it and showed confidence with her explanations.

After Klara worked out the formula for speed, we chatted about it for a while. I asked her how she felt about her verbal expression for speed (see Figure 5) and the formula for speed (see Figure 6). She said that the formula in Figure 6 was clearer and more accurate than the verbal expression in Figure 5. She also said that speed had always been a pretty visible thing to her. When I asked her about speed in the formula, it became a little abstract.

She further added that if I gave her a problem to solve, she would "promptly grab this [the formula], for the very first step." But as she said, she would not do that now because "here we are just chatting."

Klara explicitly framed the interview we were doing as "just chatting." Although she knew there are other ways to approach a physics problem, such as finding formulas and solving equations, she did not choose to do that for this interview. Instead, she started describing speed using her common sense, and formulated the mathematical expression for the magnitude of speed bearing in mind her common sense. She could not recall the conventional letters to represent the concepts, but felt comfortable with arbitrarily using A, B, and C after I suggested this.

To summarize, Episode 1 exhibits a few aspects of Klara's epistemologies about the nature of science knowledge and her epistemological framing of the activity we were doing. She understood that science knowledge could consist of explanations for phenomena using common sense; at least it was so in this particular interview situation. Her epistemological framing of the task I presented her with was to chat with me about her own understandings.

Episode 2: Klara's Understanding of "Average Speed."

I asked Klara to show the ideas of speed she had brought up so far in other possible way(s); again, she didn't understand my request. I offered a suggestion by saying "for example, you may draw." She drew the picture shown in Figure 7. She said the following as she was drawing:

Well, two same distances, and two carts are running. When they reach the ends [she drew two parallel solid lines in Figure 7, each with a cart on the left end], [let's] count their times. Like run run run... run to here [drew the dashed line and the right end cart a little above the upper solid line]. Run run run .... run to here [drew the dashed line and the right end cart a little above the lower solid line]. If this one [the upper cart—# 1] spent longer time, then it was slower. This one [the lower cart—# 2] spent less time, so it was faster.

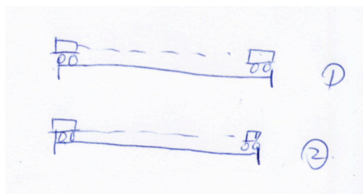

Figure 7. Klara's drawing about comparing speeds.

Not many new ideas were displayed in Figure 7. Klara kept the distance constant and described the time as varied, probably because it is easier to show the "same distance" in a picture than to show the "same time."

Then I asked Klara to observe the following phenomenon. I held the cart at the upper end of the track and released it. She watched it very carefully. Then I added a second book under the first book [see Figures 1 and 2], lifting the upper end of the track higher than it was before. I told her explicitly that I was lifting the upper end of the track. Then I released the cart from the upper end of this lifted track. Klara was watching the whole process.

I asked Klara what difference she noticed between the cart sliding down this time (on the more inclined track) and the cart sliding down the previous time (on the less inclined track). She answered immediately: "Definitely this higher [steeper] one is faster. It's obvious." I asked: "Where is it faster?" In retrospect, this was not a clear question. She did not answer my question immediately, but moved the cart back to the upper end of the track (the track stayed in the more inclined status) and released it, and she watched. Then she said: “overall I feel it is much faster.” I asked: “by ‘faster’ you mean…” She answered: “meaning it [the cart] spent shorter time from here [the upper end] to here [the lower end] than it did before [on the less inclined track].” She repeated the release of the cart and carefully watched it sliding several times [the track staying more inclined], and then she said: “Right. Overall it is faster.” She added another statement while repeatedly doing this demonstration, and she repeated this statement a few times: “The overall time is shorter.” Then she added: “And I feel the *average speed* is faster.” I asked her: “What is average speed?”

When I asked this question, she could not help laughing. I guess she realized that she had brought up another term, for which I certainly would ask for clarification. She then stated:

> Because I think… like what I just said about this [pointing to the two carts she had just drawn on Figure 7]... If this road is very long, if we only compare the time to the end point, then I can first be fast, and then slow for a while. And this one [pointing to cart #2 in Figure 7] may first be fast, even faster than that one [pointing to the cart #1 in Figure 7]. But ultimately the two... Or let’s put it this way: two things, at the same time... umm... set off, and they arrive at the end at the same time. You cannot say they have the same speed, right?
>
> Interviewer: Why not?
>
> Oh. You can only say, overall, they have the same average speed... I feel I should add average speed, that kind of description.
>
> Interviewer: The average speed you are saying is...

It is that I can only say, during a chunk of time [she gestured a segment in the air using both hands] ... Average speed... It's so hard! I can't really say it clearly... I know it [speed] is distance divided by time, but to say average speed refers to... Meaning I don't consider the details in between, that sometimes I go fast, sometimes I go slow. I only say, overall, let's compare our speeds.

Interviewer: You mean to compare the overall speed, the speed is average speed?

Right. Meaning without considering the details.

During this part of the conversation, Klara brought up and explained "average speed" because she found that when speed varies during a course of moving, she needed a word or term to describe the "overall" speed, ignoring the variation of speed during the process.

When she was explaining the concept of average speed, Klara was coordinating all the resources she had access to at that point. She tried to find coherence among the resources that had helped to express her understandings. In the interview setting, she played and observed the cart-track equipment frequently. She used her everyday experiences to support her explanation. She brought up the concept of average speed to describe the different speeds between the cart moving on the steeper track and moving on the flatter track. When she then explained it following my request, she also included the pictures she had just drawn about two running cars in Figure 7 and a hypothetical situation that we were running a race. When explaining, she linked her explanation to the quantitative relations among speed, distance, and time she had established a little earlier in Episode 1, and added more detailed description such as "a chunk of time," "unit time," "stipulated period of time," and "overall," etc. She actively navigated among the resources she had access to. She seemed to expect for all the resources she brought up in the conversation to be coherent with each other and to provide a sound explanation in response to my question. So far everything appeared to be going smoothly.

It is important to note that until this point, from Klara's tone of speaking, her face, and her gestures, I identified her confidence and level of comfort with what she had said. Also, her explanations thus far about speed and average speed align with the formal scientific explanations, which constitute a coherent knowledge system. I would then argue that her epistemologies about science knowledge displayed in Episode 2 were consistent with those displayed in Episode 1: that is, to her, knowledge should be a coherent system, and concepts and formulas must be consistent with intuitions. These epistemologies were revealed by the way she explained the concepts, by her confidence and comfort when she was able to coordinate the resources to explain average speed, and by her later confusion and frustration when she was *not* able to coordinate all the resources for another concept she brought up: instant speed.

Episode 3: Klara's Understanding of "Instant Speed."

Just after Klara said at the end of Episode 2 that average speed meant a speed "without considering the details," I pushed her on this point.

Interviewer: What about the speed that *does* consider details?

That speed I feel is talking about... I feel the time [for that speed] is cut into slimmer [slots]. No… That slimmer time can still have average speed. Mm... You are asking what the difference is between average speed and that speed. That one is called *instant speed*, right?

Interviewer: No matter what it is called...

Oh. Oh. I just feel... That is a "*real time* speed"... It is just, at a *moment*, I compare my speed with yours, at a specific *point*. I feel time is *constituted by* many, many points... No. No.... It should be... time can be *cut by* many points...

Interviewer: You may draw if you want…

(I thought she would draw a time line, but she did not. Instead, she drew the clock below.)

Ok. It's like… If we have a clock [drawing the clock in Figure 8], then we know time. We can specify... I decide just at this point [point A], what about our speeds? Wait. No. Nope.

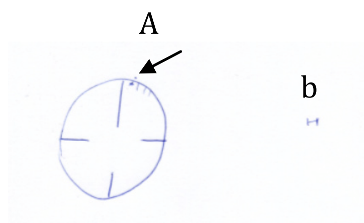

Figure 8. Klara's drawing to express a "time point."

Interviewer: What nope?

If it's just a [time] point, I don't even run, how come we compare speed? There still has to be a *span* [drawing a short segment b on the right in Figure 8], right? At a point… [thinking]... why it becomes more complicated when I think more... I feel that at a point... at a specific time point, we still can have a speed… I feel that time can be divided into infinitely slim [slots]... Because there is light speed, right? Traveling that much long [distance] just in a second. So… [thinking] Oh my! I am so confused... It is… I feel instant speed is... OK. Just put it this way, instant speed is slimmer than average speed.

Interviewer: What is slimmer?

The time to compare [speeds] is slimmer...

Interviewer: How slim is slim enough, do you feel?

How slim is enough? Mm... Uh... I am so confused. How slim is enough? Average speed… Instant speed... [murmuring]

When Klara felt she needed a concept to describe the specific speed at a specific *instant* or “time point,” she called it “instant speed,” but had a very hard time reconciling it with the algebraic formula for speed, which needs a time *interval* or a “time span.”

She had some understanding of the difference between average speed and instant speed. She said that the time span for instant speed is “slimmer” or shorter than that for average speed. But when I asked her “how slim is enough” for the time span to be for an instant speed, she could not determine whether this slimmer time span was still a span, although very short, or whether it was an exact point.

In this part of the interview, Klara felt uncomfortable with her inability to coordinate her intuitive understanding of “instant speed” and the algebraic formula for speed. She did not have access to the calculus formula for speed at the time of the interview. She could not provide an explanation for “instant speed” comprising, coherently, both her intuitions and other ways of expression (through words, orally and mathematical formula); and she was not satisfied with relying only on her intuition to understand the phenomenon of “instant speed.”

She tried hard to find coherence on her own even when she felt it was very hard to do so. I did not respond to her questions about instant speed when she was thinking aloud to herself. I just listened. She believed that there exists a concept of “instant speed”, and she also believed that everything has instant speed. She brought up the example of the speedometer as evidence for the instant speed: “There *is* instant speed. Just like driving, every single moment, the speedometer tells you the instant speed… That speed is instant speed. The speedometer always tells you how many miles [per hour] is now.” Then I asked whether the cart had instant speed, she immediately said: “Of course it has. Everything has instant speed.” She moved the cart back to the top and let go several times, showing to me: “This cart’s instant speed is the speed at every single point. At every single point how fast it runs. Just like the speedometer, it tells you instantly that you are driving 80 miles [per hour] or 100 miles [per hour].”

At this point of the interview, Klara could not coordinate her intuition of instant speed that corresponds to a time instant and the other aspects of speed that correspond to a time interval: to get a speed she needed to move, to move she needed to spend a time span, etc. Although this time she could not make all the bits of knowledge coherent, she never doubted that they *should* be coherent. Her epistemologies were robust: everything she brought up should be coherent with each other, and it is her own responsibility to coordinate all the pieces into a coherent picture if she wants to understand the phenomena thoroughly. It is just because she strongly held these epistemologies, and at the same time she was not able to demonstrate them (the coherent explanation for instant speed, for example) that made her struggle and become very confused. Her confusion lasted until the end of the interview.

Post-Story: Acceleration.

After she pondered about instant speed for a while, I felt she had exhausted her thoughts about speed and wanted to move on and probe her understandings about acceleration. Trying to elicit her ideas about acceleration but trying also to avoid saying the word “acceleration” itself, I asked the following question: “Mm. Alright. My question now is this: You just said that when I only put one book here [pointing to the position under the track where the books are placed], and when I put two books here, the carts' speeds are different. I want to ask you: are they always different from the beginning, or are they just becoming different when moving?"

First she claimed that from the beginning, the "higher cart" [on the steeper track] had been faster than the "lower cart" [on the flatter track], after releasing the cart and watching the process over and over again. Later, she also agreed that when the cart stayed at the upper end, the speed was zero, for both situations. Following her statement, I asked her why the cart started with the same speed, zero, and then came to have different speeds, when the track was differently inclined.

She struggled with this question for a long time. First she said that "because this one [steeper track] is higher." When I asked why higher matters, she brought back gravity, and claimed that gravity affected the speed. Following my questions about how the gravity in these two situations was different, she figured out that the gravity should be the same. Then she claimed that the higher track was shorter, but soon realized that it was always the same track, thus the cart had the same length or distance to travel. She thought really hard and got very confused and tired. So we took a half hour break. After coming back to the interview, I set up a motion detector (equipment to collect data of the carts' positions over time and graphing position-time and velocity-time on a computer screen), and showed her the graphs of the cart's motion in the two situations. She worked on it for a short moment and soon gave up.

In order to assist her a little bit, I asked her to compare the speeds at the middle point of the track for the two situations. From this moment, Klara little by little formulated the description of the cart moving on the less inclined track as "speeding up slower." By clarifying this idea of "speeding up slower" to me, she came up with the description of the cart moving on the steeper track: "it is getting fast faster." After a little more refinement, she explained the idea of "getting fast faster" with, in a slow, steady, and decisive voice, "during the same period of time, for the higher cart [cart on the steeper track], the value its speed reached, is bigger than the value the lower cart [cart on the flatter track] reached." Thus, she found that one difference between these two situations was "the speed of speeding up." This concept of "the speed of speeding up" is very close to the concept of acceleration.

In the above part, when Klara tried to formalize the concept of "the speed of speeding up," she emphasized "the same period of time" she used to compare the difference of speed-change in the two situations. I followed up and tried to see whether she could express this concept in a formula, like she had done for speed in Figure 6. She wrote down a formula "$(S_2-S_1)/t$," with a clear explanation of the meaning: the difference of speed two (later speed) minus speed one (earlier speed) divided by the time spent. However, when she described these speeds at different time instants, her confusion about "what a speed at an instant was" came back to her. She started again to think about the meaning of "instant speed" and because she was not able to explain "instant speed," she said she felt she did not even know what "speed" was:

> What is speed after all? How to measure instant speed? If it [speed] is distance divided by time, then I don't have a distance [for an instant speed]… And at the time point... What is the time you use to [divide] ... Instant... Does that count as time? There is no time span. There is no... Right? How to measure instant speed? Is speed really distance divided by time? I am so confused. Yes. I feel if it [instant speed] is at an instant, then at that point, you don't have time to divide. You don't have a distance, either. I am so confused. I don't

> know what instant speed is. This is torture. The more I think, the more I get confused. I don't know what speed is. If you are just talking [about speed], it's a feeling of moving fast. But to make it a thing over something [the division formula], speed, time, distance...

The post-story shows that Klara's epistemologies about the nature of science knowledge were strong and consistent throughout the interview. She was satisfied with her description of the concept of acceleration in her own language, "speed of speeding up," which did not conflict with other pieces of knowledge she had activated. But she was not satisfied with her explanation of instant speed because she perceived it was incoherent with other ideas she had presented. She started to consider the limitations of the algebraic formula of speed near the end of the interview by saying "Is speed really distance divided by time?" She considered that she "really [did] not know what speed is," a self-assessment which was very different from her reaction at the beginning of Episode 1 to my question "What is speed?" when she thought she surely knew what speed was and found my question almost silly.

Conclusion

Klara's Epistemological Beliefs/Resources

In summary, I would argue that there is not strong enough evidence to classify Klara's epistemologies in this interview either as epistemological beliefs or as epistemological resources. On the one hand, there were no shifts of epistemologies identifiable within the interview process. Yet I did not probe her epistemologies in any situation other than this single interview. Thus, I am only able to conclude that during this interview, Klara's epistemologies were stable. I can characterize these epistemologies either using the beliefs framework (Hammer, 1994) or using the resources and framing framework (Hammer et al., 2005).

If adopting Hammer's (1994) dimensions and terminology of epistemological beliefs, Klara's epistemological beliefs can be characterized as Coherence / Concept / Independent along the three dimensions of the structure of physics/the content of physics/learning of physics, respectively. To elaborate, Klara appeared to hold beliefs including "physics knowledge is a coherent system (Coherence);" "the formalized canonical expressions/explanations cannot conflict with intuitive understandings (Concept);" and "one's re-explaining of the meaning of the concept is essential (Independent)." Examples that demonstrated these beliefs can be found throughout the interview. Klara appeared to stick to these beliefs fairly strongly. She first answered the question "What is speed?" with her common sense "speed is running fast or slow…" She formalized the quantitative expression of speed in terms of distance and time while also referring to everyday examples. She repeated the cart-track experiment by herself and watched it very carefully, trying to make sure that her explanation of speed was valid not only in terms of her everyday experiences, but also in this lab-like setting. She kept on trying to coordinate her intuitive understandings with the formula for speed when more nuanced aspects related to speed (average speed, instant speed) were brought up in our conversation, even when it was challenging for her.

In the later part of the interview, no matter how hard it was for her to reconcile the inconsistency between the algebraic formula for speed and her intuition of "instant speed", and eventually, even though she did not find a satisfying explanation for this inconsistency, she never gave up the belief that "different ways of understanding phenomena should be consistent."

For these epistemologies about the nature of science, we can either say that Klara held the beliefs during the interview, or we can say that Klara activated epistemological resources and these resources were reinforced during the interview. Based on what we know from this interview, there is not much difference whether we call Klara's epistemologies unitary beliefs or resources that in this situation are stably held.

Klara's Epistemological Framing

Besides the epistemologies in relation to the nature of science knowledge described above, Klara's epistemological framing reflected her understanding of activities related to learning/doing science (Hammer et al., 2005). This is another aspect of epistemology that the literature has discussed and that I wanted to investigate.

Based on what Klara said and did in the interview, I claim that her epistemological framing includes "we are just chatting," "I can use my own language," "the interviewer is looking for my own explanation," "I need to make sound arguments," and so forth. The incentives for her to frame our activity this way were many: the interview setting, the way that the interviewer asked questions, the feedback from the interviewer to her responses, etc. She knew that there were other ways to approach a physics problem, e.g., "promptly grab formula" as she said herself, but she chose not to go that way in this situation. Compared to the use-formula-solve-problem framing, the explain-phenomena-in-everyday-language framing that Klara actually adopted in the interview is taken, by education researchers, as more productive (Hammer et al., 2005).

Stability of Klara's Understandings of Speed

In terms of how Klara's epistemologies affect her conceptual understanding of speed, I focus on whether or not her epistemologies helped to stabilize her comprehension. In this section, I briefly summarize Klara's understanding of the concept of speed and evaluate the stability of her understandings. Then in the next section, I will conclude whether or not her epistemology played a role in the process of stabilizing her understanding.

When Klara was thinking about speed in general in Episode 1, and about average speed in Episode 2, she relied on her perceptions, a mathematical expression, and measurable elements within the mathematical expression: distance and time intervals. When she was thinking about instant speed in Episode 3, she only had her own perceptions to rely on, without a mathematical expression that she considered reasonable. In the meantime, she parsed a time interval into smaller and smaller "slices" in order to explain the difference and the connection between average speed and instant speed: "The time is slimmer [for instant speed than for average speed]," but had great difficulty figuring out whether this kind of parsing could finally transform the time interval into a time instant (See Figure 9).

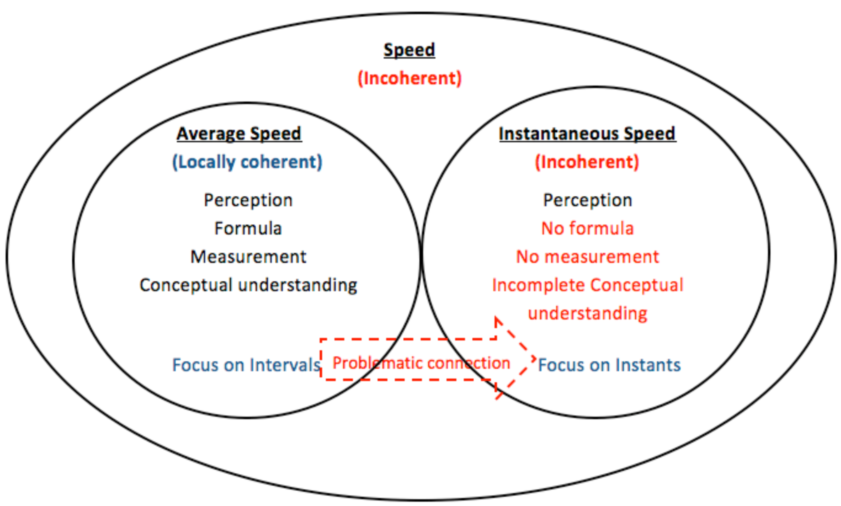

Figure 9. Klara's understandings of speed.

I believe that Klara's understanding of speed was "stabilizing," although not yet "stabilized." I argue this based on the assumption that a structural comprehension is easier to become stable than a loosely, or non-, connected collection of ideas, and Klara's understanding of speed is structural (shown in Figure 9). Every component in Klara's understanding of speed was connected to others, directly or indirectly. It is she herself who made the connections when she explained her ideas to me. She had clear understandings about the parts that were coherent to her, as well as the parts that were not coherent yet. She also understood *why* some parts were coherent or incoherent. She once asked me to tell her "What is speed after all?" I interpret her request as she had the sense of needing extra information that she lacked at the moment. Perhaps, she was ready to offer a more complete and overall coherent understanding once the missing information she felt she needed was provided. This implies that Klara, during the interview, was moving toward a stable comprehension of speed.

Stabilizing Mechanism

As for the mechanism that can explain the stabilization of Klara's understanding of speed, I argue that Klara's case fits the second mechanism proposed by Hammer, Elby, Scherr, and Redish (2005): *deliberate*. Compared to the other two mechanisms (*contextual* and *structural*), the main feature of a *deliberate* mechanism is that it is an active mechanism, with the learner's epistemologies playing a role in examining the coherence of different aspects of the concept that have been brought up.

During the interview, Klara actively coordinated all her ideas. When she was explaining new ideas, such as average speed and instant speed, she frequently looked back at what she had already argued a little earlier: the algebraic expression of speed, for example. She checked the formula she had written that worked well for average speed, and found it didn't work for instant speed. She also checked back and forth and confirmed the incoherence between the algebraic formula of speed and her intuition about instant speed, and found that the key of this incoherence lay in the relation between the concepts of "time interval" and "time instant".

From the evidence above, we can see that Klara was explicitly and frequently monitoring her reasoning when she provided explanations to the interview questions. By doing this, Klara made every piece of her understanding connected and her comprehension of speed structured as seen in Figure 9—a structure that was moving toward stabilization. Thus, Klara's case illustrates that a learner's epistemologies can help to stabilize a set of learning resources, the *deliberate* mechanism of stabilization (Hammer et al., 2005).

Implications for Education

Klara's knowledge of physics at the moment of the interview was similar to an adult novice. Thus, her case has implications for physics education at the introductory college level and perhaps also high school level. I took Klara as a learner in the interview, and as a productive learner because she was thinking thoroughly and toward a promising direction of comprehending the concepts involved.

Klara's case implies that it is important for an instructor to prompt students to activate productive epistemologies in a learning activity. In Hammer's work (2004b), he suggests that at times an instructor can provide epistemological prompts which help students transit to a productive epistemology. One example of such a prompt is presented by Hammer in his paper (2004b) when a student came to the instructor and complained that he had studied very hard and done many exercises in the textbook but still could not do well in the exam. The instructor suggested to this student that he should explain a concept to a ten year old (Hammer, 2004b). The instructor's suggestion indicated epistemologies like "learning science is making sense of the phenomena." Holding these epistemologies, students could have a better chance to understand the physics concepts and problems and find the appropriate resources to solve them, rather than just looking for formulas and plugging in numbers. In addition, the potential for a wide application of Hammer's theory of epistemology, as illustrated in Klara's case, also implies that the adaptation of such an epistemology-prompting pedagogy may be applied to a wide range of settings.

In order to prompt students to activate productive epistemologies, several pedagogical actions can be adapted from this interview. For instance, the interview setting acted as one trigger of Klara's epistemological framing. We started with a lab demonstration, not with paper-and-pencil problems. This way of beginning the interview avoided her framing of the interview as an equation-solving activity. This suggests that if we want students to think about the phenomena a problem is representing, and not to rashly search for formulas to solve the problem, we should place them in the real situation (or provide them with simulated pictures/videos at least) before presenting the word problem itself.

In addition to providing an entry point, the experimental equipment appeared to facilitate Klara's thinking throughout the process. The track-cart setting is in no ways novel (there are a lot of similar demonstrations in high school physics classes and lab experiments), but Klara was still intrigued to manipulate and observe it again and again while she was thinking about the questions. She was really focused when she repeated the seemingly simple experiment. This suggests to educators that real-stuff-observation/manipulation is always significant in learning physics.

Some ways of providing feedback that reinforce productive epistemologies can also be adapted into pedagogy. The interviewer's patience, appropriate silence, and focusing on the interviewee's thinking seemed to have helped Klara's thinking. When Klara was talking about the strength and forces at the beginning of the interview, she was not interrupted, although those concepts were not the interviewer's main interest in this interview. One other example is when Klara was asked to formalize the quantitative relationships among speed, distance, and time, which she had verbally described to a certain extent. Klara could not remember the canonical letters for speed, distance, and time and hesitated. The interviewer made a suggestion of just arbitrarily using A, B, and C, thus releasing her from recalling conventional symbolism. A similar moment is when Klara tried to describe instant speed but could not remember the conventional name (instantaneous velocity) and instead called it "instant speed," "a real-time speed." At that moment, the interviewer encouraged her to use whatever language made sense to her, by saying "no matter what it is called." These actions altogether kept Klara's productive epistemologies active throughout the interview.

Closing Thoughts

This study of a young adult non-scientist's conception of speed has provided additional evidence in support of the theories about a learner's epistemologies, especially about the perspectives of *epistemological beliefs* and *epistemological resources* (Hammer, 1994; Hammer et al., 2005). The learner's characteristics are different from those previously studied. Thus, this study extended the explanatory scale of these theories and implies that they could be more widely applied.

It is true that based merely on the single interview carried out with Klara, it is not possible to conclude how Hammer and his colleagues' theories about learner's epistemologies could be extended and/or adjusted. Nevertheless, Klara's case suggests that these theories may apply to individuals regardless of the learner's science background, language, education experience, and cultural background. More cases should be examined with learners with different academic backgrounds and from different cultures if we want to provide more compelling evidence for this claim.

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