Evidence of Intuitive and Formal Knowledge in Student Responses: Examples from the Context of Dynamics

Mel S. Sabella and Geraldine L. Cochran
Department of Chemistry and Physics, Chicago State University
msabella@csu.edu, 773-995-2172

When presented with a question, students activate a set of knowledge, or schema, that they use to respond to the question. For many instructors, one of the goals of the introductory physics course is to help students build robust schemas of formal knowledge that are activated for a given task. In this paper, we present evidence that suggests that even when schemas of formal knowledge are formed, students often struggle to activate this knowledge. We focus on the analysis of interviews with two introductory physics students concerning the topic of dynamics. We also demonstrate that the act of explaining, during the interview, has a profound impact on the students' responses.

Introduction

This preliminary study takes place in the introductory physics class at Chicago State University (CSU). Students were given seven questions from the Force Motion Concept Evaluation (FMCE), concerning a sled on a frictionless surface [1]. These questions were given as multiple-choice questions and as one-on-one interviews.

There have been a number of studies that have investigated how students respond to questions on the FMCE and specifically to how students respond to the sled questions [2]. This study differs from previous work, in that it focuses on the conflict between the sets of the knowledge, or *schemas*, that students activate in responding to these questions [3]. We present sections from two interviews and attempt to illustrate the struggle students have in activating formal physics knowledge, over intuitive knowledge.

Method and Results

The students in this study were engaged in lectures, laboratories, and tutorials [4]. Students completed two tutorials on forces before being given the FMCE questions. The tutorials focused on drawing free-body diagrams, identifying forces, and analyzing situations in which the object of interest was either at rest or in motion.

The sled questions, paraphrased in Figure 1, were administered to students in the algebra- and the calculus-based physics courses. About one quarter of the students in the calculus-based course answered the questions correctly, when the questions were given in multiple-choice format. There are a number of possible explanations for

Figure 1: Force Sled Questions from FMCE

A sled on ice moves in the ways described in questions **1-5**. **Friction can be ignored**. Choose the one force which would keep the sled moving as described in each question below.

A. The force is toward the right and is **increasing** in strength (magnitude).
B. The force is toward the right and is of **constant** strength (magnitude).
C. The force is toward the right and is **decreasing** in strength (magnitude).
D. No applied force is needed.
E. The force is toward the left and is **decreasing** in strength (magnitude).
F. The force is toward the left and is of **constant** strength (magnitude).
G. The force is toward the left and is **increasing** in strength (magnitude).

1) Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?
2) Which force would keep the sled moving toward the right at a steady (constant) velocity?
3) The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?
4) Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?
5) The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?
6) The sled is slowing down at a steady rate and has acceleration to the right. Which force would account for this motion?
7) The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)?

the poor performance on these questions. Students may not understand Newton's Laws and are therefore applying these laws incorrectly. Alternately, students may be utilizing another set of knowledge to answer these questions and are therefore not applying their knowledge of Newton's Laws. These are very different explanations of student performance. In the first case, one assumes that the students are bringing the knowledge of Newton's Laws to the task and because the student has a weak understanding of these laws, they misapply the laws. In the second analysis, the student brings up a separate schema for solving the problem, possibly a more intuitive response, or a p-prim and uses this knowledge to respond to the questions – the knowledge associated with Newton's Laws is not brought to the task at all [5].

In order to probe the type of reasoning students were using to answer the sled questions and to look at the particular schemas students are using, we conducted interviews with two students, *Friday* and *Red*, who were enrolled in the algebra-based physics class.

Discussion of Interview Responses

When the questions were given to the students in an interview setting, both students initially answered in a manner that was consistent with the idea that the magnitude of the force is proportional to the of the speed. For example, when asked which force would keep the sled moving to the right with *increasing* speed, the students said that it would require a force to the right that was *increasing* in strength. Yet, during the course of the interviews, both students changed many of their responses. We found that both students showed a fairly robust understanding of Newton's Laws that allowed them to correctly revise some of their initial answers.

The data we present in this paper indicates that *(1)* the schemas the students activate are often isolated from other schemas and *(2)* the knowledge in the individual schemas often has pieces that are inconsistent with each other.

Friday

Friday begins the interview by responding to question 1 regarding the force required to cause the sled to move to the right and speed up. She states that to keep the sled moving to the right and speed up, we would need a force to the right with increasing strength (choice A). At this point the interviewer asks Friday to explain why she gave this particular response. Initially, she provides an explanation that is consistent with the idea that she is thinking there is friction in the problem but she catches her error and revises her explanation:

> "Since it is frictionless … if the force … was taken off … it wouldn't slow down … but it wouldn't speed up either … it would be … constant."

Friday clearly has the idea that without a force the velocity would be constant. Despite this, her next statement is the following:

> "Which force [would] keep the sled moving towards the right, [at] steady constant velocity? B, which is a constant strength, is applied to the sled."

Here we see that these pieces of knowledge are largely inconsistent. When asked to explain why she chose B, Friday gives the following response:

> "I figured if the same amount of strength is applied to the sled throughout, then the velocity would be constant."

Later in the interview, through the course of explaining her answers, Friday begins to question her answers to the earlier questions. She then goes back to question 1 and provides the following statement:

> "… it's accelerating because it's frictionless. So no force is needed if it wants to go … at a steady pace. And which one will keep the sled moving-speeding up to the right? I know for sure that the increase in strength will make it increase in speed, but … it could … be B because it's at a constant acceleration on a frictionless surface, but I'm going to stick with A because I know that with increasing strength, it is increasing acceleration because it's increasing velocity.

Friday then brings up a connection that seems very inconsistent with what she has said earlier.

> "I figured that if the strength is constant then that means the change in position would be constant and the change in position over the change in time would be constant."

This piece of knowledge regarding the displacement becomes part of the schema along with the inconsistent piece brought up earlier. The interviewer then asks what kind of motion would you have, if a force that is constant in strength is applied to the right?

> "… you would have a constant displacement. And if the displacement is constant then the velocity should be constant also … I don't think on a frictionless surface that can happen unless you just push it off or you do just what D is … if you keep applying a force then that means you will have an acceleration on a frictionless surface.

Although the statement regarding displacement seems largely out of place, in relation to Friday's earlier statements about force and velocity, Friday holds on to it and incorporates this piece of knowledge with the fact that if you apply a force to an object the object will accelerate. These inconsistent pieces are now part of the schema Friday is using to answer the question. In order for her to succeed on this question, by abandoning the idea that constant force implies constant displacement, she would have to draw upon other knowledge that also conflicts, or incoheres, with this idea [6].

During the interview there is no mention of NII and little explicit mention of most of the formal rules and concepts taught in the course until the interviewer asks Friday whether she has used any physics laws to answer these questions. Surprisingly, Friday responds by saying that among other principles, she used Newton's Laws. It is at this point in the interview that Friday begins to think about these laws and how they can be applied to the situation. By the end of the interview she begins to apply the laws and is able to correctly revise some of her responses. But this comes only after a lengthy exchange with the interviewer in which she is continually asked to explain her reasoning and clarify her responses.

Red

In Red's interview, she also begins by answering all the questions consistent with the idea that force is proportional to velocity. In question seven the interviewer asks Red how she figured out the direction of the force for the case in which the sled is moving to the left and slowing down. It is at this point, late in the interview, that Red starts to question her earlier answers.

> If the sled is moving towards the left and you have a force that is applied to the sled from the right. … in rethinking this answer I would say … if the sled is moving towards the left and … the force that's moving towards the right is increasing then I would think that it would be overcoming the motion of the sled towards the left so it would slow the sled down.

Although Red is still incorrect about the magnitude of the force, and the language she uses may indicate additional difficulties, she recognizes that to slow something down the force would need to be directed opposite to the velocity. This is a piece of knowledge that was only brought up after the interviewer asked Red how she arrived at her answer. It is important to note that if this question was given in a multiple-choice format Red would most likely have given final answers consistent with the idea that force is proportional to velocity.

Here we see that the piece of knowledge indicating that force is opposite to motion when something slows down is isolated from the schema initially brought to the task. Once this piece of knowledge is brought to the task it becomes part of the knowledge Red uses to answer the earlier questions. This piece of knowledge is fairly robust – once activated she uses it often.

Like Friday, Red never explicitly refers to Newton's Laws, or any formal knowledge from the physics course until very late in the interview. She brings up Newton's Laws after the interviewer asks "what would happen if you pushed the sled … and then … stopped pushing?"

> Because you've removed the … push that caused it to move in the first place … Oh, boy. Newton's law. It's either the first or the second law …

Red seems almost excited when she thinks of using these formal concepts from the course. Although this new piece of knowledge becomes part of the schema, the next series of statements clearly show that Red's new schema for solving the problem contains inconsistent information that Red has great difficulty in resolving.

> Okay. If the sled is moving - … you take the force away from the sled that's causing it to move -Newton's law says that an object that's in motion will remain in motion. So, it's going to remain in motion and that's why it wouldn't stop right away.

The interviewer then responds "…you're saying [it] would stop eventually?"

> Yes, I did say that … I have to change that answer. Newton's law is saying that an object in motion stays in motion … so, if you're pushing the sled you're causing it to move … and you stop pushing it then the sled would continue to move, but …the motion would decrease in velocity.

The interviewer further probes: "…the motion would decrease?"

> No, let me change that answer … Okay, this is my final answer. If you're applying a force … and you stop pushing it, Newton's first law says that an object in motion stays in motion so it's just going to keep on moving.

Later on during this exchange Red states "... my brain is waking up now." Red may recognize that she has activated a productive schema. In addition, this statement indicates that Red may be placing more of a value on this section of the interview then the earlier sections.

Conclusion

The research presented in this study has implications for the teaching and learning process. During the interview, the interviewers repeatedly asked the students to explain why they chose their answers. This often helped the students activate the relevant formal knowledge for the questions. The intervention, in this situation, is quite different from the type of intervention that an instructor would typically engage students in, in that it is much less guiding. Although this type of interaction takes much more time, this lack of guidance in the interview may be more useful to the students since the students are forced to activate the relevant knowledge very much on their own. The interviews in these cases may help the students make the connections from intuitive knowledge to formal knowledge, where perhaps a more guided-inquiry approach may have left many inconsistencies unresolved.

Students at CSU typically perform below average on many of the multiple-choice diagnostics we administer. The information provided by these diagnostics is very important because, among other information, it may show that many of our students tend to activate an intuitive answer rather than a formal answer based on the course content. Although additional research is required, these interview excerpts provide some evidence to support this idea. The students in these interviews have much of the requisite knowledge and are able to activate the knowledge, but this takes time and it seems to require someone continually asking students to explain how they came to their answers.

We should also note that even when Newton's Laws were brought to the task student understanding was not as robust as we would hope. One item worth noting is that these students did not readily apply NII as a tool to solve these qualitative questions. In this study, when we asked Friday whether she took Newton's Laws into account in answering the questions she stated "I took it into account. Well, not exactly. I didn't calculate anything."

It is interesting to note that in the multiple-choice setting, the only picture of understanding we would have is the students' initial responses. These responses appear to be largely a result of the activation of intuitive knowledge. In the multiple-choice setting there is little evaluation of student understanding of Newton's Laws because the schema containing these ideas was never brought to the task. It may be more accurate to state that these students had great difficulty recognizing and activating a schema consisting of knowledge of Newton's Laws, despite the fact that this knowledge is crucial to the task.

Acknowledgements

The authors would like to thank *Red* and *Friday* for their participation and Sarah Workneh and three anonymous reviewers for their constructive comments on the paper and research.

---

1. See Sokoloff, D. & R. Thornton, "Assessing Student Learning of Newton's Laws: The Force and Motion Conceptual Evaluation of Active Learning Laboratory and Lecture Curricula", Am. J. Phys., 66 (4), 338-352, 1998. In this paper they discuss how responses from the Force-Sled questions describe student understanding of Newton's Laws.
2. We have found that the percentage correct in the calculus-based introductory physics class at CSU is approximately the same as the percentage correct at the University of Oregon after traditional instruction. For comparisons with other schools see Meltzer, D., "A Perspective on Teaching Physics Courses for Future Elementary-School Teachers," presented at the AAPT Physics Education Research Conference, 2000 at www.physics.iastate.edu/per/talks/guelphperposter.pdf and Cummings, K., J. Marx, R. Thornton & D. Kuhl, "Evaluating Innovation in Studio Physics," Phys. Educ. Res., Am. J. Phys. Suppl. 67 (7), 1999.
3. For background on schemas see Rumelhart, D., "Schemata: The building blocks of cognition," In J. Gurthrie, (Ed.), *Comprehension and Teaching: Research reviews.* International Reading Association, Inc., 1981; A description of how schemas relate to patterns of association and mental models is discussed in E.F Redish, *Teaching Physics with the Physics Suite,* John Wiley and Sons, Hoboken, 2003.
4. McDermott, L.C., P. Shaffer, and the Physics Education Group at the University of Washington, *Tutorials in Introductory Physics*, Prentice Hall, First Edition, 2002.
5. For information on p-prims see diSessa, A. A. "Knowledge in Pieces," In *Constructivism in the Computer Age,* Forman, G. and P. Pufall (Eds.), Lawrence Erlbaum, NJ, 1988.
6. For a discussion of coherence see Ranney M. & P. Schank, "Toward an integration of the social and the scientific: Observing, Modeling, and promoting the explanatory coherence of reasoning." In S. Read & L. Miller (Eds.), *Connectionist models of social reasoning and social behavior*, Lawrence Erlbaum, NJ, 1998.